EUROPEAN JOURNAL OF STEM EDUCATION

Volume 3, Issue 2
2018

Editor-in-Chief
Hanno van Keulen
Windesheim University of Applied Sciences (The Netherlands)

e-ISSN: 2468-4368

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European Journal of STEM Education,
2018, 3(2), 03
ISSN: 2468-4368

Portrait of a Second-Grade Problem Poser

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Citation: Kopparla, M. and Capraro, M. M. (2018). Portrait of a Second-Grade Problem Poser. *European Journal of STEM Education*, 3(2), 03. https://doi.org/10.20897/ejsteme/2684

Published: August 8, 2018

ABSTRACT

Although some students might struggle with problem posing, the positive effects on student learning and abilities may be far reaching for those who engage in this activity. Problem posing requires students to create their own problems rather than to solve problems posed by others. Problem posing is not regularly taught; however, reform proponent groups recognize problem posing as a strategy that should be integrated more routinely into mathematics classrooms. A single case study was conducted in conjunction with a larger quasi-experimental study in which mathematics education researchers worked with groups of 2nd-5th grade students twice a week over the course of a semester. For the single case study, two of the researchers randomly selected one second-grade student and examined the student's progress as she engaged in problem-posing activities during the semester. Based on the student's work, some possible elements of the lesson that impacted her engagement and performance were identified. Results from this case study indicate that problem posing for this student was an effective tool with which to evaluate misconceptions and to explore her informal mathematics understanding.

Keywords: case study, early childhood, mathematics, problem posing

INTRODUCTION

Problem posing is multifaceted in nature and structure. Problem posing requires that one must create problems. This is uniquely different from the traditional exercise of solving problems. In many classrooms across the United States (U.S.), problem posing is not ordinarily taught; nevertheless, the National Council of Teachers of Mathematics (2000) and the National Research Council (2005) have advocated the inclusion of problem posing in standard mathematics teaching strategies and curriculum. This support for incorporating problem posing in classrooms is centered on the documented constructive consequences of developing these skills. Findings from prior research have indicated that as students' problem-posing skills evolve, positive outcomes can be noticed in their creativity, understanding, problem solving, and critical thinking (Singer et al., 2015; Van Harpen and Presmeg, 2013). Moreover, problem posing can assist teachers in identifying mathematical misunderstandings (Koichu et al., 2013). Multiple benefits of integrating problem-posing activities in classrooms have been identified.

While problem posing is widely advocated, posing is not an end in itself but a means to attain improved mathematical understanding. Generally, when problems are presented in multiple formats, students are better able to acquire deeper understandings (Cai et al., 2013; Singer and Voica, 2012). When students can revise the problem itself, or design an analogous one, their understanding of the subtleties of the problem increases (Priest, 2009). Problem posing shifts the emphasis from attempting to uncover appropriate methods and derive correct answers in problem solving, to imaginatively posing a problem and then discovering the appropriate solution from a wide range of possibilities (Brown and Walter, 2005). An improvement in problem-solving skills is often observed as an outcome of engaging in problem-posing activities (Kar et al., 2010). Problem posing and solving can be two sides of the same coin – both pedagogies helping students develop mathematical understanding.

In addition to complementing and improving students' problem-solving skills, problem posing provides a creative space for teachers and students that is lacking or limited during the problem-solving process. While educators and teachers recognize the importance of using real-world scenarios when providing students with mathematical problems to solve, integrating authentic contexts into problems can be challenging. Problems based on real-world contexts are never true replications of real-world scenarios 'considering the infinite number of variables offered by real life problems' (Boaler, 1993, p.14). As every student understands and interprets problems they must solve differently, there is a need to integrate open-ended activities into mathematics classrooms that allow students to relate in-school and out-of-school mathematics experiences (Lowrie, 2004; Wright, 2017). Students may then realize that school mathematics and real-life mathematics are not disjoint entities. Teachers who implement problem-posing activities open a window of opportunity in which real-world scenarios and out-of-school mathematics experiences derived from their students' lives can be incorporated into the problem space.

Although bringing real-world contexts into the math classroom maybe challenging, educators have recognized that students' out-of-school mathematics, or informal mathematical knowledge, can be used as a foundation for classroom instruction. A number sense has been observed to develop among children as early as infancy, with a rapid improvement in informal mathematical understanding thereafter (Resnick, 1989). However, children's informal mathematical understanding does not develop independently, but is influenced by their everyday lived experiences (Starkey and Klein, 2008). Therefore, students may benefit if educators base their curriculum on students' existing knowledge and experiences to formalize their knowledge and guide their understanding (Fennema et al., 1993). To this end, problem posing provides students with an opportunity to demonstrate and improve their mathematical knowledge, both formal and informal, in the mathematics classroom.

Problem posing allows the students to truly experience the essence of mathematical word problems. Instead of tasks with one right solution, problems in mathematics become 'opportunities to explore mathematics and come up with reasonable methods for solution' (Hiebert et al., 1997, p.8). The Common Core State Standards for Mathematical Practice #1 require children to make sense of problems by justifying their answers while persevering in solving them (National Governors Association Center for Best Practices and Council of Chief State School Officers, 2010). Engagement with problems fosters motivation and long-term performance in mathematics (Furrer and Skinner, 2003). Thus, mathematical understanding and performance may be improved by student engagement in problem-posing activities.

Along with the numerous learning benefits for students, problem posing maybe used as an assessment tool by teachers. Research has shown that analyzing student work allowed teachers to gauge students' learning and thinking patterns (Lin and Leng, 2008). Problem-posing activities allow students to display the depth of their understanding of techniques and processes, which can provide teachers with an insightful assessment of their students' progress and current knowledge (Silver and Cai, 2005), while concurrently affording students a greater self-awareness of the extent of their mathematical understanding. Though problem posing can be used as an assessment tool, there is very limited research focusing on its efficacy as an informal assessment tool for teachers.

Using a single case study, the purpose of this study was to explore the possibility and effectiveness of adopting problem posing as an assessment tool to allow educators to understand students' mathematical strengths and weaknesses. Researchers in the present study investigated the role of problem-posing activities in understanding a second grader's mathematical understanding and reasoning.

METHODOLOGY

The structure for the larger study, approved through the Internal Research Board from the university, was a quasi-experimental design whereby the teachers of 2^{nd}-5^{th} grade classrooms each placed their students in heterogeneous groups organized by prior performance on the Texas STAAR test (high-stakes). All students participating in the study signed assent forms and their parents signed consent forms. Next, researchers who delivered the intervention were randomly appointed to a grade level in which they would administer the problem-posing intervention; the researchers had no knowledge of the students or the teachers within their assigned intervention groups beforehand. The two authors of this manuscript were assigned to a second-grade classroom and received the following preparatory information and items before the study began: 1) instruction on both content and pedagogical methods for each problem-posing activity and 2) a folder containing lesson plans and materials for each of the problem-posing activities.

Table 1. Problem posing lessons conducted in the second-grade classroom

Sessions	Topic	Description of lesson
1	Pictures	Students wrote problems based on pictures provided
2	Models	Students could choose one among manipulatives such as pattern blocks, unifix cubes and tokens.
3	Equation/number sentence	Students wrote problems based on a number sentence
4	Graphs	Wrote problems based on a given graph
5	Geometry	Sorted pattern blocks by shape
6	Graphs	Created a graph using a bag of M&Ms
7	Measurement	Traced out hand and measured length of their fingers
8	Measurement	Measured heights of characters in a picture
9	Finance	Posed problems based on a store with priced items, making change.

Participants

The current study was conducted in a rural school located in a small central Texas town with a population of 3000. The school (K-12) demographics included African American (31%); Hispanic (25%); and White (42%). Of these students, 66% were categorized as economically disadvantaged. For this single case study, Paula (pseudonym) was selected as the research subject from a self-contained second-grade classroom of 28 students. Paula was a seven-year-old White female who lived within the rural community. She had one older brother, and her family qualified for free lunch. Paula showed improvement from pre- to post-testing, was present for all of the lessons, was actively engaged in the intervention, was fairly typical of the students in the second-grade classroom and was willing to justify her answers. For these reasons, the researchers selected this particular student's experience with the intervention to explore more deeply in order to determine what factors may have influenced the improvements in Paula's problem-posing abilities.

Data Analysis

Through the research design of this single case study (Kazdin, 1982), the researchers focused on one particular second-grade student. The following requirements for single subject designs were included: a) *Continuous assessment* - The mathematical reasoning of one individual second grader was observed over the course of the intervention, which was one semester. This ensured that any treatment effects were observed long enough to understand how the intervention affected the student's mathematical problem posing. b) *Baseline assessment* - Before the intervention was implemented, the researchers measured the student's mathematical problem-posing knowledge with a pretest and measured it again at the end of the semester. c) *Variability in data* - Because the one student's mathematical problem posing was observed repeatedly, the single subject design allowed the researchers to observe how consistently the intervention influenced her mathematical reasoning, as demonstrated through the change in her problem-posing skills over time. During the intervention, the student's work and researchers' observational notes were collected repeatedly throughout her completion of the weekly problem-posing activities. The student's work was evaluated for aspects of understanding and mathematical fluency.

Classroom Milieu

The 2nd grade-level classroom contained learning centers. During the intervention period, one of the centers was led by the researchers, who facilitated student engagement in problem-posing activities that required students to create problems using real-world pictures, objects, or manipulatives. The researchers employed a variety of problem-posing strategies at this learning center during the intervention, all of which are outlined in **Table 1**. Two intervention activities were held each week for three months during the students' mathematics learning center time in the Spring 2017 Semester. Each activity lasted approximately 20 minutes. The researchers remained in the classroom for the entire mathematics period (90 minutes) and met with each group of students as they rotated through the learning centers during this time. At the other learning centers during the mathematics period, students practiced and reinforced skills that were introduced at the teacher instructional center through games, technology, and hands-on activities.

Instrumentation

A four-question quiz that included two problem-solving questions and two problem-posing questions (see **Appendix** for grade 2 level example) was administered to all participants. The pretest quiz measured problem-solving and problem-posing abilities at the beginning of the intervention (February 2017). Due to the inextricable link between problem solving and problem posing in previous literature, both types of questions were included on the quiz. An identical quiz was then administered to all participants in April, 2017 as a posttest. Each quiz was graded by two researchers to check for consistent and reliable scoring.

RESULTS & DISCUSSION

The second-grade mathematics teacher informed the researchers that she had never taught this group of second-grade students problem-posing strategies and had incorporated very few problem-posing activities into their instruction. She also reported that most of this cohort of students had great difficulty with posing their own problems. One student from this group, Paula, was the focus of the current study, and her problem-posing work was analyzed.

Over the span of the problem-posing intervention, Paula's ability to write and solve mathematics problems marginally improved as indicated by her improvement in problem-posing and problem-solving scores from pretest to posttest. For the first problem-posing question, which was based on a graph of books (see Appendix, Question 3), her pretest and posttest posed problems were as follows:

Pretest: "There was a book fair in the library on Wednesday and Saturday which one sold the books?"
Posttest: "Is there more Wednesday books sold than Friday?"

Similarly, for the second posing question (Question 4), Paula was asked to pose a problem based on a farm picture, to which she posed the following:

Pretest: "There whar [sic] 17 amnals in a barn and 3 came out because they ware [sic] too hot?"
Posttest: "Is there more chickens than hay bells [sic]?"

Unlike the pretest questions, both the posttest questions that she posed could be answered based on the accompanying graph or picture. In addition, Paula's focus shifted from providing details about the problem situation to constructing a problem statement. The change in focus may indicate an automatization of the problem scenario and problem-posing process in Paula's mind, therefore eliminating the need to re-iterate the description of the provided picture. This shift in focus, when applied to problem solving may help students streamline their thought process toward the problem statement. This change in focus may eliminate the need for rote methods such as highlighting the key words in a word problem to ascertain the mathematical operation required. An understanding of the problem structure may help Paula to better identify necessary and unnecessary information in a word problem.

Paula's ability to solve problems showed marginal improvement from pretest to posttest. On the first problem-solving question (Question 1), which required finding the difference between 25 and 17, Paula derived an incorrect answer on the pretest, but correctly solved the problem on the posttest. Her pretest setup for the problem was 17 – 25 with a final answer of 12. However, on the posttest she set the problem up and solved it correctly with a final solution of 8. On the second solving question (Question 2), Paula's performance from pretest to posttest was more nuanced than that of Question 1. Paula was asked to calculate based on a graph, how many more books were sold on Wednesday than on Thursday. Paula solved Question 2 correctly on the pretest; however, she appears to have misread the question on the posttest as she calculated the difference between books sold on Tuesday and Wednesday instead of books sold on Wednesday and Thursday. Although she could not derive the correct answer to the original problem due to her mistake, Paula nevertheless set up and correctly solved a problem of a relatively equal level of difficulty using the number of books sold on Tuesday and Wednesday.

While the pretest and posttest were used to measure both Paula's problem-posing and -solving performance, the researchers in the present study limited their primary analysis to Paula's problem-posing work over the course of the intervention. Constant comparison was used to investigate the non-linear gains found in Paula's problem-posing performance to identify the similarities and differences in Paula's problem posing in an effort to understand the variance in her problem-posing performance among 9 lessons. First, some common errors made by Paula were identified, then her performance was analyzed in relation to the structure of the posing lesson.

Like many second graders, Paula occasionally struggled with creating a complete mathematical question. Her questions could be separated into those containing mathematical or non-mathematical errors. Errors were classified as mathematical if her question clearly indicated her intended mathematical operation but was incompletely worded. Non-mathematical errors were found in questions that did not contain or suggest the use of a specific mathematical operation.

Non-mathematical Errors

When Paula made a nonmathematical error while problem posing, it was most often in posing a problem that required an opinion, rather than a mathematic calculation. For example, during Lesson 5 Paula was given a bag of pattern blocks to sort by shape, and she created a bar graph using colors to represent the number of pieces she had in each shape. She then posed two questions, the second of which read, "My favit [sic] shape is rhombus?". Given that she had the highest number of rhombi compared to other shapes, her second statement might have been an attempt to ask, "Is my favorite shape a rhombus because I have the most of this shape?". However, there is no way one could mathematically infer her favorite shape (see **Figure 1**).

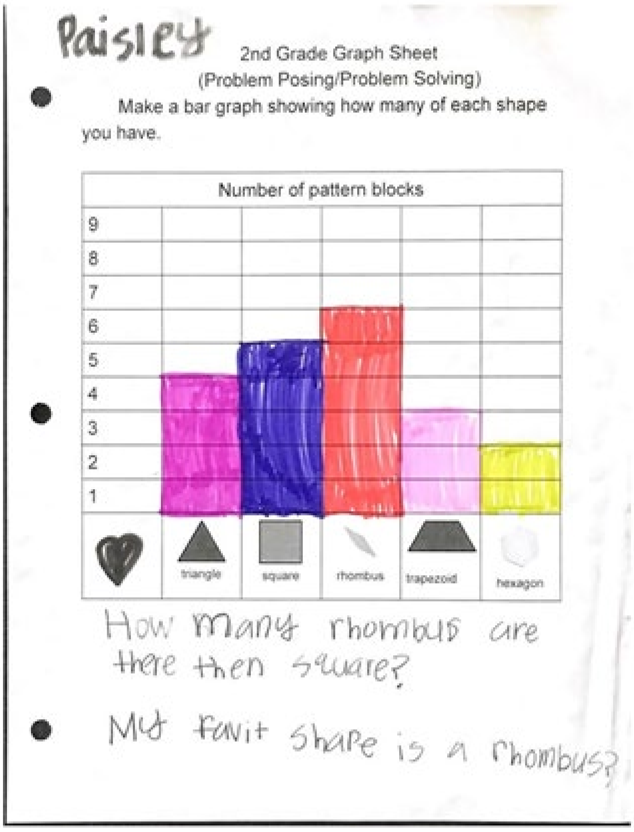

Figure 1. Paula's work for Lesson 5

Another error Paula made was providing a scenario with no question statement. When asked to write a problem based on a picture with farm animals, she wrote, "There whar [sic] 17 amnals[sic] in the barn and 3 came out because thay[sic] ware hot?". She immediately followed with setting up the solution as 17 – 3 = ?. Paula assumed subtraction was a natural choice and replaced the lack of a question sentence with a question mark.

Mathematical Errors

Some of Paula's questions conveyed a mathematical question, but had words missing. When she wrote comparison problems, she omitted the words 'more' or 'less', leaving the reader to interpret the intent of the question. For example, in Lesson 5 (see **Figure 1**), Paula's first posed question was "How many rhombus [sic] are there then square [sic]?". In another example during Lesson 6 (sorting M&Ms by color), her question read, "How many red than yellow?" instead of "How many more red M&Ms are there than yellow?". Though the intent of these questions is easily interpretable, she needed to be reminded to include words such as 'more' or 'less' in her questions to make them complete. During the posttest, she was able to write complete and solvable questions.

While Paula practiced writing addition, subtraction, or comparison problems throughout the 9 lessons, her performance varied by the amount of mathematical abstraction. Specifically, when writing equations, Paula was able to successfully set up the solution for her posed problems in the form of an equation on multiple occasions. However, she had difficulty writing a problem when she was only given an equation. For an equation 9 – 3 = _____, she wrote an unrelated problem:

"So three hundred sixty-seven jelly been whar [sic] in a jar a boy gave me 200 now how many do I have now?".

This indicated a lack of cognitive flexibility in translating equation into a word.

Paula's performance during some lessons was independent of the mathematical content of the lesson itself. In other words, her performance on lessons that contained the same mathematical topic (e.g. measurement, graphs, etc.) varied depending on extraneous elements such as the context of the lesson or materials provided. Three possible artifacts of the lessons that may have impacted Paula's engagement and performance during the lessons were identified: 1) interaction with the materials, 2) relevance of the context, and 3) visual representation.

Interactions with Materials

Paula performed well when she could interact with materials (manipulatives). Physical objects or materials were an integral part of five of the nine lessons during the intervention. Paula was allowed to create her own scenario in Lesson 2 (using models); however, Lessons 5, 6, 7, and 9 (namely, categorizing shapes, creating a bar graph with M&Ms, measuring finger length, and buying grocery items, respectively) each had a predefined context. In Lessons

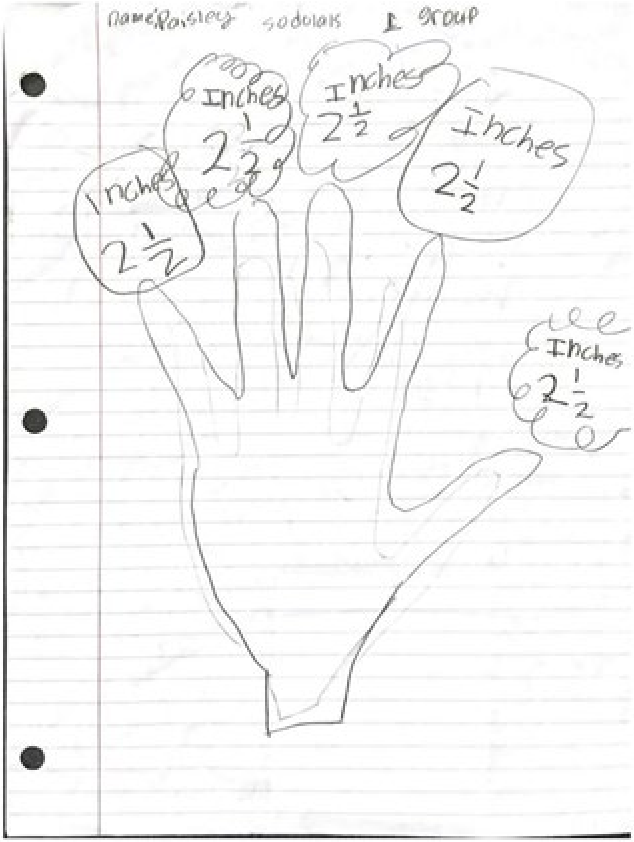

Figure 2. Paula's work for Lesson 7

5, 6 and 9, she was able to pose two to four problems during the 20-mintue activity, even after spending some of her time interacting with the materials. For Lesson 2, after posing one problem, she made an elaborate illustration of the scenario in the problem. These instances demonstrated her comfort with using the manipulatives to assist her in posing problems as a second grader.

However, not all hands-on activities seemed to be equally engaging for Paula. During Lesson 7, she was asked to trace out her palm and pose questions based on the measurements (see **Figure 2**). She wrote down the same length of 2 ½ inches for each finger. All four questions she posed were similar to "What is the length of my thum [sic] finger in inches?"; in posing the other three questions, Paula merely changed the name of the finger. Finding the answer required no mathematical calculation, unlike the other problems she had previously posed. While interaction with the materials helped Paula, the visual appeal and relevance of the materials impacted her enthusiasm.

Relevance

Paula seemed to be especially interested in topics that included animals. While she struggled with measuring her own traced palm, she performed better measuring the heights of animals in a picture of a popular children's movie, Jungle Book. She was able to measure 15 items in inches and write 4 problems each using a different operation such as counting, comparison, and addition. The difference between her performances with the hand measurement and animal measurement scenarios could indicate that the animal scenario was more interesting and relevant to her, thereby signifying that she exhibited her mathematical knowledge better when the scenario was relevant to her.

When the problem scenario contained animals, Paula was able to pose problems that contained multiplication, a concept beyond her grade level. In Lesson 1, when students were provided a pet shop picture, Paula wrote,

"So there were 12 pets in the pet store 3 people came and got two each how many are in the pet store now?".

In this problem, Paula was able to pose a problem that was solvable. Moreover, she extended her knowledge of addition to incorporate repeated addition. This posing response shows that Paula was familiar with repeated addition in an informal context and suggests that repeated addition could potentially be used as a tool to transition into teaching multiplication.

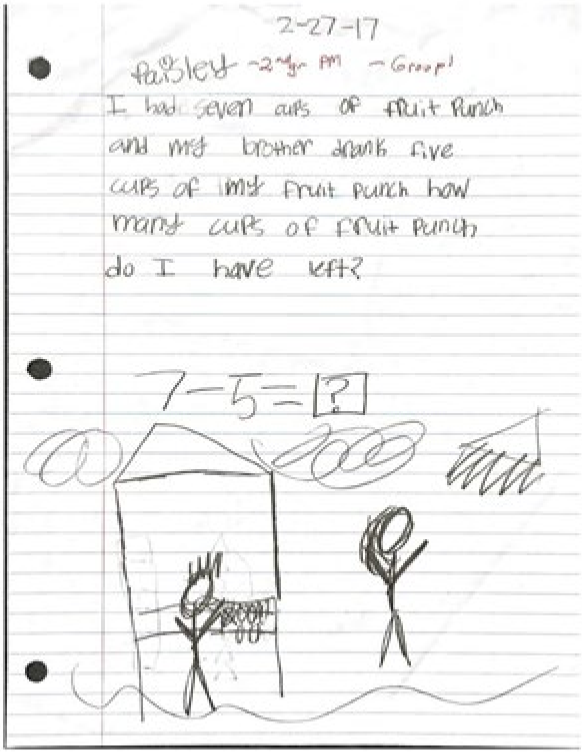

Figure 3. Paula's work for Lesson 2

Visual Representations

Paula displayed her enthusiasm and creativity while problem posing. Paula's work indicates that she appeared to have a vivid imagination that she used to create the scenarios that she included in her problems. Visual representations appeared to stimulate and aide her imagination. Paula compensated for the lack of mathematical structure, which she frequently used to guide her problem-posing process, by relying on her imagination and ability to visually represent and justify her imagination. This tactic appeared to help her better process abstract mathematic problem scenarios whose information she had to understand in order to pose her own problems. For example, in Lesson 2, she used models of her own making to help her write a real-world problem about her and her brother (see **Figure 3**).

Paula consistently seemed to enjoy visuals that accompanied the problem scenarios she was required to use when problem posing. She may have been more receptive to pictures as content in elementary grades is usually accompanied by visuals. Paula, like most second graders, was excited to pose problems using a picture of a popular cartoon character, Spongebob. After a discussion about the objects in the picture, such as patties, buns, and barrels, she wrote,

"Sponge Bob grilled 13 burgers and he burned 3 by accident, how many could he sell that were not burnt?".

Similarly, visual stimuli like graphs enabled Paula to construct a fairly complicated problem:

"There is 35 girls at the swimming pool then 35 boys came to the pool how many boys and girls are there now? There are 15 girls and 20 boys at canoeing? How many more kids are at the pool than canoeing?".

Thus these visuals clues especially related to a familiar context were helpful when Paula, as a second grader, began her problem posing journey.

CONCLUSIONS

A majority of the current teaching and evaluation methods in elementary classrooms are directed toward solving problems. While efforts are made to integrate real-world scenarios into problem solving, a disconnect between in-school and out-of-school mathematics is often evident (Boaler, 1993). This gap between real-life and school mathematics may be bridged with open-ended activities such as problem posing. While problem solving usually has a binary outcome of correct or wrong, problem posing provides students with an opportunity to explore a plethora of mathematical scenarios.

During the intervention focused on problem posing, Paula displayed marginal improvements in her problem-solving skills as was substantiated by prior researchers (Cai et al., 2013; Kar et al., 2010). More importantly, Paula's problem-posing responses were helpful in informally assessing her thought processes, understandings, and performance. As suggested in prior research (e.g., Koichu et al., 2013), through these brief informal assessments Paula's error patterns and problem areas could be identified based on her problem-posing work. Her posing responses helped identify errors directly related to the mathematical topic at hand, as well as general mathematical misconceptions. Paula was more likely to display her understanding of mathematics concepts when she was physically engaged or was given a scenario that sparked her imagination. For example, when provided the visual of the pet shop, Paula was able to formulate and justify complex multi-step problems and extend her mathematical knowledge. Paula was able to pose a "multiplication problem" even though she was never exposed to the concept multiplication in her second-grade classroom. In contrast, she had trouble with mathematical abstraction, which she sometimes compensated for by using visuals or manipulatives. Exposure to problem-posing activities provided Paula with a picture of the inverse of solving problems. Problem posing may be used not only as a means to evaluate student misconceptions, but also to explore their informal mathematics understanding. Educators should assess and utilize students' familiarity with higher level math concepts, acquired through real-life experiences, as a tool and bridge that may be used to formally introduce concepts in school.

The focus of the current study was to explore the viability of using problem posing to understand the mathematical profile of a second grader through seamless informal assessments. A single case study was the most suitable method for an in-depth analysis of posing responses. Furthermore, the current method of analysis is likely most applicable when seeking to understand the mathematical profile of individual students. However, creating a detailed portrait of every student in the classroom may be neither practical nor feasible due to factors teachers encounter that place constraints on their instructional choices, such as limited time during a class period. Therefore, the portraiture scope in many cases should be modified. Rather than aiming to derive a mathematical portrait of each student through the incorporation of problem-posing activities, teachers should strive to sketch a mathematical 'class portrait' from which they may begin identifying subgroups of students in their classes that require intervention and specialized assistance in particular mathematical areas of weakness (e.g., multiplication of whole numbers, equivalent fractions, division into equal groups). This use of problem-posing is a feasible and more flexible alternative to individual assessment, and its use may assist teachers in targeting specific deficiencies in their students' mathematics performance. In addition, continued use of problem-posing activities within the identified subgroups will help these students to initiate mathematical dialogue, which teachers can guide and evaluate to determine their students' progress and identify their misconceptions, informal understanding, thought processes, and learning patterns (Lin and Leng, 2008) in relation to their identified mathematical deficiencies. In sum, there are benefits to creating 'mathematical portraits' of individual students as well as 'collective mathematical portraits' through which educators can identify subgroups lacking or deficient in specific mathematics skill sets, and the use of both may assist educators in identifying their students' mathematical deficiencies and improving their overall mathematical understanding and performance.

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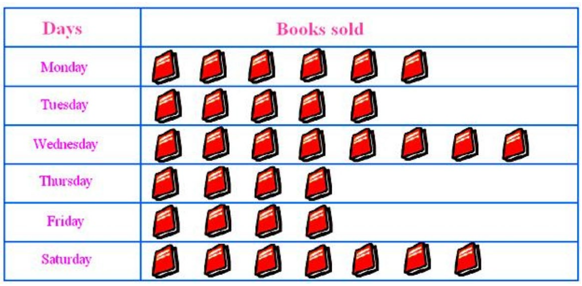
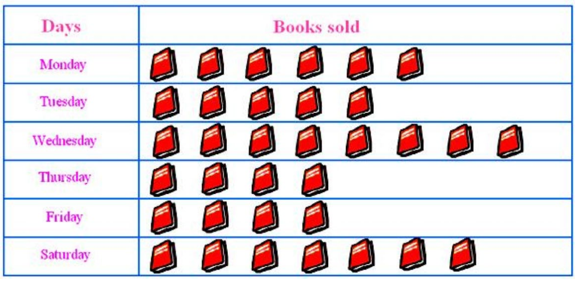
APPENDIX

Pre/Post Test (2nd Grade)

1. Wendy spent $17 on a DVD. If she gave $25 to the cashier, how much change did she get back? Be sure to show your work.



2. Using the pictograph above, how many more books were sold on Wednesday than on Thursday? Be sure to show your work.



3. Using the pictograph above, create an addition word problem for a friend to solve. Set your problem up, but you do NOT have to solve it.

Problem ____

Setup ____

4. Using the farm picture, create a word problem for a friend to solve. Set your problem up, but you do NOT have to solve it.

Problem ____

Setup ____

EUROPEAN JOURNAL OF STEM EDUCATION

European Journal of STEM Education,
2018, 3(2), 04
ISSN: 2468-4368

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Effectiveness of Collaboration on Low and High Achieving School Students' Comprehension of Electrochemistry in South Africa

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Citation: Amponsah, K. D., Kotoka, J. K., Beccles, C. and Dlamini, S. N. (2018). Effectiveness of Collaboration on Low and High Achieving School Students' Comprehension of Electrochemistry in South Africa. *European Journal of STEM Education*, 3(2), 04. https://doi.org/10.20897/ejsteme/2685

Published: August 8, 2018

ABSTRACT

This paper is part of a larger study that investigated the 'Effectiveness of collaboration on low and high achieving school students' comprehension of electrochemistry in South Africa'. The study occurred in the Ximhungwe circuit of the Bohlabela district in the Mpumalanga province of South Africa. The theoretical framework for this study was based on Vygotsky's social constructivism theory, which he defines as 'a sociological theory of knowledge that applies the general philosophy of constructivism into social settings'. A sample of 47 12th grade physical sciences students from two public schools (one of the schools is high achieving and the other is low achieving) in the circuit was purposively selected to participate in the study. Students were given electrochemistry concept test (ECT) as pre-test and post-test. Results from mean and standard deviation, and one-way between group analysis of covariance (ANCOVA) showed that high achieving school (HAS) students taught with the conceptual change teaching strategy (CCTS), specifically collaboration had significantly better acquisition of scientific conceptions related to electrochemistry than low achieving school (LAS) students, also taught with CCTS. Analysis from a scatterplot of post-test against pre-test grouped on type of school showed a linear correlation between pre-test and post-test scores for each intervention type, which indicated that there was no interaction effect. The study has shown that collaboration contribute to meaningful learning, which inadvertently improves students' comprehension and consequent achievement in electrochemistry concepts but more positive for students from high achieving schools.

Keywords: collaboration, electrochemistry, high and low achieving schools, social constructivism

INTRODUCTION

A couple of the forefront principles of Vygotsky's theories on cognitive development: the More Knowledgeable Other (MKO) and the Zone of Proximal Development (ZPD) have been used in classroom settings to enhance student achievement. According to McLeod (2014), the MKO is indicative of someone who is equipped with a comparatively superior understanding or otherwise a superior range of abilities with respect to the particular task, process or concept. McLeod argued that MKO can refer to teacher or an older adult, or the peer group of students, or subsequently an adult who has acquired pertinently more knowledge and also experience. McLeod went further to indicate that MKO need not be indicative towards an existent individual. E-Tutors may be used in the education set-up in order to expedite and also direct the students through the requisite learning procedure. In summary, a common denominator is indicative of the proposition that MKOs should wield more knowledge than the learners with regard to the particular topic being taught to them. Furthermore, the idea of MKO is inextricably linked to the Zone of Proximal Development. ZPD relates to the pertinent contrast between the extent to what can be achieved by a student in an individual context as opposed to what are the horizons of an individual's achievement endowed with the necessary counsel as well as fortification garnered in association with a skilled partner (McLeod, 2014). Research in chemistry has indicated that consensus building during discourse results in what they term as the concept of *knowledge creation*, which can be construed as '*the production of knowledge that adds value to the community*' (Bereiter and Scardamalia, 2010; Scardamalia and Bereiter, 2006). "This model of knowledge building postulates that knowledge advancement is the collective work of a community, analogous to scientific communities, and that knowledge is improvable through discourse" (Chan et al., 2012, p. 201-202). Even though it is believed that comprehensive classroom discourse can improve students' achievement, some researchers have indicated that some students still perform poorly as a result of their inability to connect various concepts of solving science problems (Ahmad and Che Lah, 2012).

Numerous researches have been undertaken on Alternative Conceptions related to the sub-discipline of Electrochemistry (Garnett and Treagust, 1992a, 1992b; Ogude and Bradley, 1994; Sanger and Greenbowe, 1997a, 1997b). Ogude and Bradley (1994) observed that students were capable of solving Chemistry examination questions as a result of their quantitative nature. Ogude and Bradley however contended that majority of the students could not answer qualitative questions, as they lacked thorough conceptual knowledge required to tackle such questions. Two studies on electrochemistry that were previously conducted by Garnett and Treagust (1992a, 1992b) were replicated and extended by Sanger and Greenbowe (1997a) to thoroughly research further on Alternative Conceptions in Electrochemistry. The research was conducted on Electrochemistry, specifically concentration cells, electrolytic cells, and galvanic cells and at the end of the study, 28 Alternative Conceptions were found. According to Sanger and Greenbowe sixteen undergraduate students offering introductory college chemistry courses volunteered to participate in the study.

Further research in chemistry education has shown that students often have problems in comprehending conceptual knowledge in chemistry due to its abstractness. This has propelled many researchers to investigate issues related to student learning in order to identify the challenges faced by them and to proffer solutions to those challenges (Greenbowe, 1997a and 1997b; Niaz and Chacon, 2003; Ozmen, 2004; Ozkaya et al., 2006). Similarly, several studies have reported Alternative Conceptions about Electrochemistry and indicated that Electrochemistry can be construed as one of the most demanding, nuanced as well as arduous sub-disciplines encompassed within the ambit of Chemistry since it has a plethora of vague and unreal terms with reported discrepancies and illogical representation (Ahmad and Che Lah, 2012; Al-Balushi et al., 2012; Karsli and Ayas, 2013; Karslı and Çalık 2012). According to these studies, chemical equilibrium is a prerequisite knowledge in comprehension of concepts in Electrochemistry. These studies indicate that most students lack conceptual knowledge because assessment carried out within the sub-discipline of electrochemistry are essentially based on the domain of algorithmic problems, and as such, learners are prone not to focus on the pertinent concepts of electrochemistry. Most of the time teachers teach students through lecturing thereby ignoring the fact that students can also contribute meaningfully to classroom discourse. This is the situation prevailing in the South African science class as teachers have overloaded curriculum to contend with and therefore do not have the luxury and time for classroom discourse. Practical investigation with hands-on experiences is virtually non-existent in most rural schools. Students have to be taught the same topic over and over again with the same teacher or different teachers who are presumed to be experts in some of the challenging areas in the Physical Sciences and Electrochemistry is no exception. In spite of this majority of learners perform poorly to the extent that it becomes so difficult to get 30% and above in the National Senior Certificate (NSC) examinations.

THEORETICAL FRAMEWORK

Vygotsky (1962, 1978) defined social constructivism as a sociological theory of knowledge that applies the general philosophy of constructivism into social settings. He indicated that social constructivism has three components: (a) knowledge and knowing originate in social interaction; (b) learning proceeds from the inter-psychological plane (between individuals) to the intra-psychological (within an individual) plane with the assistance of knowledgeable members of the culture; and (c) language mediates experience, transforming mental processes. Additionally, Mercer (2002) emphasized that science teachers should understand the importance of constructivism especially in terms of the discourse that happens. Treagust and Duit (2008) maintain that conceptual change recognizes the importance of dialogue. However, Scott (1998) has posited that teachers' talk focused on everyday concepts and scientific perspectives is critical to helping students learn science concepts. Discursive teaching is supported by Vygotsky's (1978) view of socially mediated learning. Vygotsky has indicated that social contexts facilitate meaning and learning. When students first hear outward descriptions, they then turn these words inward, thus leading to modifications or transformations of their knowledge base. Accordingly, Gutherie and Wigfield (2000) indicated that cognitive engagement is enhanced when students are actively involved in social spaces where they discuss, debate, or critique each other's idea. Similarly, Wells (2000) has stated that an individual learns by interacting with a competent person. This means that lecturing can play a critical role in students' meaning making and conceptual development (Scott, 1998). A teacher's encouragement for exploration of scientific ideas through discourse can help students understand concepts. Extended and elaborate teacher discourse helps students shift their conceptual understanding. From a social-constructivist position, classroom discourse provides opportunities for students to test the validity of their ideas and develop meaning of higher complexity (Aufschnaiter and Aufschnaiter, 2007). Discourse within a group provides potential for a clash of ideas. Student-to-student and student-to-teacher discourse is important in a science classroom as it provides students with the tools and culture of the scientific community (Vosniadou, 2008). This suggests that discourse provides a platform for students to be socially engaged in a meaningful learning process.

In tandem with the perspective of Vygotskian model of social constructivism, schooling is responsible for the creation of a social context of learning insofar as the individuals turn out to be immensely proficient with the deployment of the cultural tools (Smagorinsky and O'Donnell-Allen, 2000). Thus, the idea of collaboration can be understood as the interactions that take place whereby the participants in a symbiotic manner tend to discover pertinent solutions as well as generate knowledge in association with each other (Smagorinsky, and O'Donnell Allen, 2000). Furthermore, the idea of collaboration involves learning experiences, which facilitate a social context in association with which the learners understand one another by jointly working together. In the course of the process of collaboration, the students jointly operate together in order to solve a problem. Accordingly, Vygotsky, 1978 and Wertsch, 1991 have indicated that the role of social interaction in the development of cognition is the very basis of Vygotsky's theories and cannot be overemphasized. Thus, it is expedient for learners to work together to solve a given problem during collaborative discourse. It is believed that students have the opportunity to discuss concepts, practice what they do as they negotiate for more plausible outcomes and teach each other in order to deepen their comprehension of the subject matter. According to Galloway (2001), two of the main principles of Vygotsky's work linked to collaboration are the More Knowledgeable Other (MKO) and the Zone of Proximal Development (ZPD). The MKO refers to an individual with superior comprehension or someone with greater level of competence of the subject matter (such as a particular task, process, or concept) than the learner. The MKO and the ZPD form the basis of the comprehension component of the cognitive guidance model of instruction. ZPD is defined as "*the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem-solving under adult guidance or in collaboration with more capable peers*" (Vygotsky (1978, p. 86). Vygotsky was of the conviction that when appropriate assistance is given to a student who is at the ZPD to perform a particular task, the student will be motivated enough to achieve the task. In actuality, this is the goal of collaboration, which allows students to work together on the same task, rather than in parallel on separate portions of the task. Collaborative Teaching Strategy helps students to develop their competence in some 21st-century skills, such as communication, critical thinking, metacognition, and motivation (Heyman, 2008; Thayer-Bacon, 2000). Students who participate in collaborative activities tend to improve their communicative and critical thinking skills which increases their self-confidence.

The US-based Partnership for 21st Century Skills (hereinafter P21), a coalition of business leaders and educators, proposed a Framework for 21st Century Learning, which identified essential competencies and skills vital for success in twenty-first-century work and life (P21, 2007a, 2011). These included 'The 4Cs' – communication, collaboration, critical thinking and creativity, which are to be taught within the context of core subject areas and twenty-first-century themes, which should be implemented in the 21st-century classroom. It has been observed however that during collaboration, students have the opportunity to discuss, practice by doing and teach each other, which ultimately enhance their creative, critical and innovative skills. This makes collaboration an essential tool to promote the inculcation of 21st-century skills into students that will help them function and compete with their peers all over the world in the 21st century. Incidentally, educators in a variety of educational settings have over the years used collaborative approaches to teaching and assessing students. Similarly, it has been observed that educators and policy formulators have identified the ability to collaborate as an important outcome in its own right rather than merely a means to an end. This is the reason why the Partnership for 21st Century Skills has identified collaboration as one of several learning and innovation skills that are important for post-secondary education and workforce success. Accordingly, collaborative learning is broadly defined as "a situation in which two or more people learn or attempt to learn something together," and more specifically as joint problem solving (Dillenbourg, 1999, p. 1). Collaborative learning is broadly defined as "a situation in which two or more people learn or attempt to learn something together," and more specifically as joint problem solving (Dillenbourg, 1999, p. 1). Roschelle and Teasley define collaboration more specifically as "mutual engagement of participants in a coordinated effort to solve a problem together," (as cited in Dillenbourg et al., 1996, p. 2). Dillenbourg and other experts have indicated that it is incredibly difficult to accept a single definition for collaborative learning as a result of the processes involved during collaborative learning. However, collaborative learning strategy occurs within small groups for effective discourse between group members. In collaborative discourse, members of each unique group work on the same task and pool their results together through negotiation and concerted effort from each other.

Small group discussion can be seen as one of the pertinent strategies deployed in the constructivist approach to teaching and learning. Normally, through the implementation of group study, an educator can recognise the cognitive processes (relevant to education) of the students, as they work in conjunction with one another in order to foster a pertinent understanding of scientific phenomena. It can be argued that the interaction that is centric from student to student per se encompasses the exchange of ideas as well as motivating each other by functioning in conjunction with one another with respect to accepted learning assignments. Piaget (1970), states that other people perform a significant role within the domain of the cognitive development of others. In the course of group work it can be argued that the occurrence of a cognitive conflict is most likely to be witnessed by an individual, which through the requisite negotiations, spurs further to sophisticated structures of cognition. In addition, it can be empirically stated that according to Vygotsky's school of thought, the comparatively superior mental cognition skills are formulated as a result of the classroom social interaction that takes place between the students, which further facilitates the construction of knowledge. Further, Vygotsky delineates two sources of knowledge, namely; everyday knowledge, one that is derived from the interaction undertaken in tandem with the environment, and second, in terms of the formal instruction that is derived from the classrooms. It can be stated that the previous form of knowledge is based on the basis of peer interactions, language as well as experience, as peers play an important role in the construction of knowledge as well as the formulation of the new concepts. Learners use both form of knowledge to construct meaning. Researchers have indicated that students' peer to peer interaction is more effective than student to adult interaction as they have similar developmental levels, and it is believed contributes effectively to learner achievement.

PROBLEM OF THE STUDY

The woes of South African educational system originates from a well-developed education bureaucracy that was designed by the apartheid government to provide inferior education to fail black South African learners and prepare them only for menial work (Smut, 2014). Apartheid-era educational disparities still suppress even the current crop of Black South African learners in post-apartheid South Africa. Majority of South African students, especially Blacks have a gargantuan fear for Mathematics and Science and see these subjects as anathema. In fact, current trends in South African students performance in internationally accredited tests, such as TIMSS (Trends in International Mathematics and Science Study) leaves much to be desired. A test on TIMSS (a 20-year-old international metric), was administered in 2011 to all participating countries including South Africa. The results indicated that a third of South African school children performed worse than if they had guessed the multiple choice answers to questions in mathematics and science (Smut, 2014; Martin et al., 2012). This antecedent historical challenge continues to affect most South African students desiring to pursue science and mathematics in high school and beyond. It is in the light of this that the research was conducted as high school students in South Africa continue to perform poorly in Physical Sciences in general and in topics in Electrochemistry in particular since 2009, when the National Senior Certificate (NSC) examinations were introduced (Department of Basic Education Mpumalanga Province [DBEMP] 2015; Ochonogor, 2011). Ahmad and Che-Lah (2012) observed that students experience conceptual difficulties as a result of the way they are taught in the classroom, which is predominantly the lecture (traditional) method as well as problem-solving difficulties they experience. Because of this, the majority of learners perform poorly and find it extremely difficult to attain a pass mark of 30% on the chemistry section of the NSC (National Senior Certificate) examinations. Although some stakeholders in education such as DBEMP (Department of Basic Education Mpumalanga Province) continue to support Physical Sciences learners through various interventions, results in Physical Sciences, Chemistry, and specifically Electrochemistry have been declining since 2010 (DBEMP, 2018) except for 2012. Some of the programmes organized by the DBEMP to improve the performance of Grade 12 students in particular in Physical Sciences include winter schools, spring schools, as well as special weekend camps, where expert teachers are brought together to teach students. **Table 1** shows the pass percentage of students from 2010-2015 in Mpumalanga Province (DBEMP, 2018, 2017, 2016, 2015, 2014, 2013, 2012, 2011).

The pass percentage at 30% shows a continuous improvement from 2010 to 2013 and then a decline in 2014 across the districts and the province, with the Bohlabela district scoring lower percentages. In 2015 there was an improvement in the district performance, which culminated in an improvement in the provincial performance as well. Similarly, the pass percentage at 30% shows a continuous improvement from 2010 to 2012 and then a decline in 2013 and 2014 in Electrochemistry and consequently Chemistry, but the Electrochemistry average is generally

Table 1. Pass % achieved by students (30% and above)

Year	Bohlabela	Province	Chemistry	Electrochemistry		
				Galvanic	Electrolytic	Total
2010	27.6	41.5	41.4	-	-	27.0
2011	41.0	52.2	49.3	-	-	27.0
2012	52.1	63.2	53.3	-	-	35.0
2013	53.8	65.5	34.4	34.1	18.5	26.3
2014	49.0	58.7	32.5	29.3	22.3	25.8
2015	55.4	62.5	33.1	34.4	20.4	27.4

lower than the overall average for Chemistry so it is contributing to pull the Chemistry average down. However, in 2015 there was an improvement in the Electrochemistry performance, which led to an improvement in the learners' performance in chemistry. There was a decline in performance in galvanic cells in 2014 and then an improvement in 2015. Even though learners' achievement in electrolytic cells increased from 2013-2015, the pass percentage was less than that of galvanic cells. This suggests that students' achievement in galvanic cell, electrolytic cell and ultimately Electrochemistry indirectly affects achievement in Chemistry, which is a cause for concern as it contributes 17.4% towards the Chemistry paper (DBE, 2011).

Purpose

The study used collaboration as a teaching strategy to compare its effect on the comprehension of electrochemistry by students from both low and high achieving schools. It was also to further investigate students' achievement when they have the opportunity to collaborate on problems related galvanic cells, electrolytic cells and electrode potential separately. The study focused on the outcome of students' negotiation during collaborative learning. This study analyzed the outcome of collaborative learning in HAS and LAS classrooms in Ximhungwe Circuit of rural South Africa in order to observe its effects on conceptual comprehension of electrochemistry by students from HAS and LAS.

Significance

First this study will show the sources of students' Alternative conception, miscomprehension and difficulties of electrochemistry. It will promote comprehensive discussion in the problem areas among students, which appears to generate positive cognitive conflicts that will probably enhance conceptual comprehension, conceptual change and problem-solving capabilities. Secondly, the study will discover and record practices and situations in the experimental group, which might give some insight into the factors that might account for the difference in performance of HAS and LAS students in electrochemistry. This study will also provide useful information as to the processes that students go through in solving a particular problem through collaboration to finally come up with a correct pooled solution. Finally, this study will have significance for future policymakers in South Africa on the use of collaboration to enhance students' comprehension and achievement in challenging high school chemistry topics such as electrochemistry. Camps organized for students in the various municipalities can also make use of collaborative learning strategies as a 21st-century skill to help address students' difficulties in electrochemistry.

Research question

One research question was framed for this study:

1. What is the effect of collaboration on as a teaching strategy on low and high achieving physical sciences students' comprehension of electrochemistry concepts?

Hypotheses

The following hypotheses were framed for this study:

1. **Ho_1**: There is no statistically significant interaction effect between type of school and conceptual change teaching strategy with respect to students' comprehension of electrochemistry concepts.
2. **Ho_2**: There is no statistically significant mean difference between post-test mean scores of HAS and LAS students with respect to their comprehension of electrochemistry concepts.

METHODOLOGY

Research Design

The researcher found that a quasi-experimental design was suitable for the research as it was impossible to casually allocate students to a specific class division; hence the researcher employed the convenience sampling technique (Gliner et al., 2011). For instance, in the research schools, the researcher did not casually allocate students as individuals to investigative groups and control groups as the school timetable could not be altered for the purposes of the current research. For example, all students in a specific classroom were casually allocated as an intact group to act as the Experimental Group (EG) or Control Group (CG). The main research employed four pre-established or intact groups (classes), made up of two low achieving schools and two high achieving schools. However, this article focuses on only the experimental group, which is made up of one low achieving school and one high achieving school. The experimental group teacher employed collaborative discourse combined with conceptual change texts (theoretical modification texts) with the role of a facilitator being enacted by the teacher.

Sample and Sampling Technique

The sample of the study consisted of forty-seven grade 12 physical sciences students from two high schools in the Ximhungwe circuit, which were randomly selected using the table of random numbers from six high achieving and four low achieving schools respectively. These two schools formed the experimental group and consisted of 28 students from HAS and 19 students from low achieving schools, which were taught using collaboration. In addition, the schools were selected based on their performance in the NSC examinations. This is to ensure that the findings from this study were solely based on the differences in the type of school used.

Instrumentation

The data collected in this study was mainly focused on the responses in the post-diagnostic test. The instrument used is Electrochemistry Concept Test (ECT), and a semi-structured interview protocol based on ECT. Some of the instruments were developed by the researcher and some adapted by comparing with various literature and validated by some experienced physical teachers and Physical Sciences subject advisors. In this paper, only the data on ECT in the pre and post-diagnostic pencil and paper tests are presented. A ten-question two-tiered test was constructed based on the format developed by Treagust (1988). The first tier of each pair of questions was based on procedural knowledge and the second tier was based on conceptual knowledge, with the student choosing a reason for their choice in the first tier. This type of questioning has the potential to distinguish between procedural knowledge and conceptual knowledge when examining student work (Treagust, 1988). The researchers created this test to assess the students' comprehension of electrochemistry concepts. Alternative conceptions reported by Sanger and Greenbowe (1997a), Garnett and Treagust (1992b), Ogudey and Bradley (1994), and O'grady-Morris (2008) were examined and the Alternative conceptions were selected based on the topics and used in this study to develop ECT. There were four alternatives for each question. Distractors that represented the Alternative conceptions were also part of the four options provided for every question. A score of one is given to a student who gets the first-tier and second-tier questions correctly. A student scores zero if the first-tier questions are answered correctly but second-tier question is answered wrongly. The reason is that knowing the concept helps one to easily answer a procedural question otherwise it is mostly guesswork. A student scores one-half of the marks if the concept is correct but the procedure is wrong. Most electrochemistry questions in the grade 12 National Senior Certificate (NSC) examinations have sub-questions in this format and in most cases, students score the first tier but not the second. The interview guide had questions relating to complete circuits and movement of charged particles, electrode characteristics, everyday meanings for scientific vocabulary and redox reactions and the redox table. An internal consistency coefficient was determined to measure the Cronbach alpha in order to identify the reliability of the test. It was discovered that the reliability of the test stood at 0.82.

Method of Data Collection

Two schools out of the ten schools from the Ximhungwe circuit served as the experimental group (made up of one low-achieving school and one-high-achieving school), which were taught using collaboration. A physical science teacher was trained by the researchers and used for the study to teach the two groups of students. He was chosen because the NSC results of his students have been improving consistently over the years. The lessons were observed by the researchers in turns weekly to ensure that there was no bias in terms of the strict implementation of the teaching strategy. When the research began, a pre-test on ECT was administered to all the grade-12 students in the two schools that had signed either the consent form or informed consent form and agreed to participate in the research. When the intervention ended, a post-test using the same instrument was conducted but the questions were scrambled randomly to ensure that students do not benefit unduly. The ECT was administered as a pre-test before instruction began as treatment for four weeks after which the post-test was administered. The researchers were present to observe when and how both the pre-test and post-test were administered to ensure that the same classroom climate prevailed in all the research schools. The physical sciences educators for the research schools were advised not to be in the classrooms when the pre-test and post-test were administered to the learners in order not to possibly influence their answers. Both the pre-test and post-test were marked by two of the researchers and cross-checked by the other two to ensure that there was consistency in the marking of the scripts. The ECT

Table 2. Mean and Standard Deviation for type of school

Teaching Method	Mean	Standard deviation	N
High achieving school	49.90	8.396	28
Low achieving school	42.82	7.236	19
Total	46.83	8.626	47

Table 3. Pairwise comparison between HAS and LAS

School Type		Mean Difference	Std. Error	Sig.
high achieving	low achieving	6.201*	1.741	.001
low achieving	high achieving	-6.201*	1.741	.001

*** The mean difference is significant at the .05 level.**

involved a pencil and paper test on electrochemistry concepts for the post-test. The teacher used three hours per week, one and half hours per class period for the four weeks of treatment.

RESULTS AND DISCUSSION

Analysis of the data indicated no significance skewness or kurtosis and no outliers. Levene's test was significant (p < 05) indicating that the homogeneity of variance assumption had not been violated. Students' post-diagnostic scores were analysed and a higher score indicated the eradication of alternative conceptions as against a lower score. The researchers used mean and standard deviation to find out whether collaboration used in the study has effect on the performance of learners from both low achieving schools and high achieving schools. The two school types formed the experimental group of a major study and collaborative discourse were used to ascertain its effectiveness on students achievement from the schools. The interaction term was not included in the ANCOVA output in **Table 4** as the presumption of homogeneity of regression slopes has already been validated in the scatter plot.

Research Question

What is the effect of collaboration as a teaching strategy on low and high achieving physical sciences students' comprehension of electrochemistry concepts? To answer this question, mean and standard deviation for low and high achieving students were found. **Table 2** presents the post-test means and standard deviations of the LAS and HAS, taught using collaboration.

The results from **Table 2** indicate that mean post-test ECT score (49.90 ± 8.40) for the HAS was higher than mean post-test ECT score (42.82 ± 7.24) for the LAS. This suggests that CCTS improved electrochemistry concept achievement in HAS compared to LAS.

A Bonferroni adjustment was executed to conduct a Post hoc evaluation as shown in **Table 3** to find out whether the mean differences are actually statistically significant.

From **Table 3**, HAS had the highest post-test scores, which was statistically significantly greater than the post-test scores of the LAS ($p < .001$), with a mean difference of 6.201. The pairwise comparison showed that there was a significant variation amongst the post-test mean scores of HAS and LAS with respect to comprehension of electrochemistry concepts.

Hypotheses

Ho_1: There is no significant interaction effect between type of school and conceptual change teaching strategy with respect to students' comprehension of electrochemistry concepts. In order to test for interaction effect between type of school and conceptual change teaching strategy, it was presumed that the pre-test shared a linear correlation with the post-test, for all groups of the independent variable, type of school. A scatterplot of post-test against pre-test grouped on type of school was plotted. The result is as shown in **Figure 1**, which indicates a linear correlation between pre-test and post-test scores for each intervention type for type of school, as evaluated by visually examining the scatterplot.

Furthermore, the interaction effect was statistically tested by determining whether there is a statistically significant interaction term, type of school*pre-test. In order to do this, a general linear model univariate analysis was conducted. The result showed that the interaction term was not statistically significant indicating that there was homogeneity of regression slopes, $F(1,44) = .003$, $p = .960$. When the Explore procedure was run, the results generated indicated that post-test scores were normally distributed for HAS (p=.067) but not for LAS (p=.031), as evaluated by the Shapiro-Wilk's test ($p < .05$). However, an assessment by visual inspection of Normal Q-Q plots and histograms indicated that students' post-test scores were normally distributed. An evaluation by Levene's test of homogeneity of variances indicated that there was also homogeneity of variances, ($p = .408$).

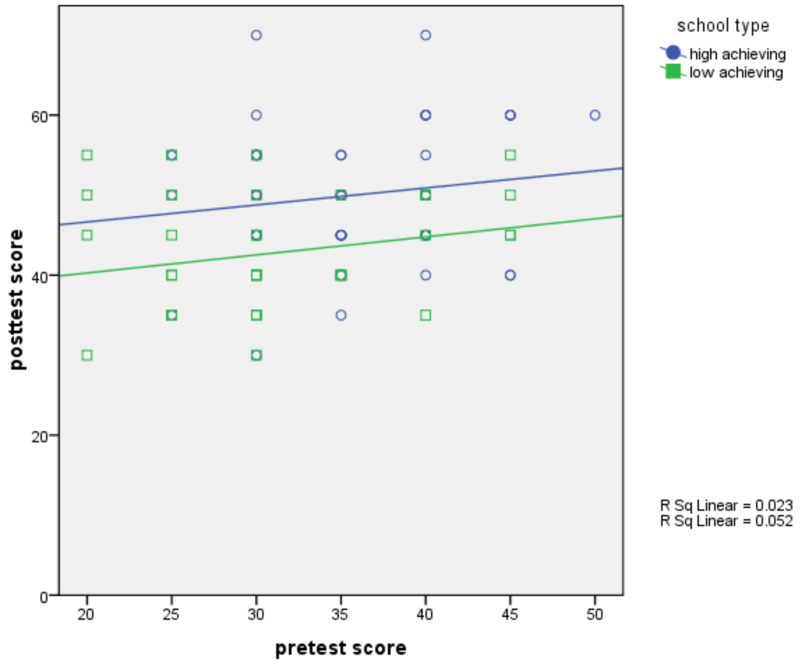

Figure 1. Scatterplot of post-test against pre-test grouped on type of school

Table 4. ANCOVA Summary on Comprehension for HAS and LAS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1291.610a	2	645.805	10.540	.000	.195
Intercept	5043.678	1	5043.678	82.313	.000	.486
pre	183.363	1	183.363	2.992	.087	.033
Schtyp	777.138	1	777.138	12.683	.001	.127
Error	5330.890	44	61.275			
Total	204025.000	47				
Corrected Total	6622.500	46				

R Squared = .195 (Adjusted R Squared = .177)

H_{02}: There is no significant mean difference between post-test mean scores of HAS and LAS students with respect to their comprehension of electrochemistry concepts. In running the ANCOVA, the dependent variable represented the students' comprehension of electrochemistry concepts (post-test scores), whereas the covariate depicted the students' pre-test scores. The independent variable showed the school type, HAS or LAS. The results are presented in **Table 4**.

After modifications for pre-test scores, there was a statistically significant difference in post-test scores between the interventions, $F(1,44) = 12.683$, $p = .001$, partial $\eta 2 = .127$.

The strength of the relationship between type of school and comprehension of electrochemistry concepts as shown on **Table 3** was mildly strong. From **Table 4** it is observed that school type accounted for 12.7% of the variance of the dependent variable when the pre-test is controlled as covariate. The result from this study, which indicated that high-achieving students performed better than low-achieving students is inconsistent with studies conducted by Kenneth and Young (1999), and Hampton and Grudnitski (1996). Hampton and Grudnitski (1996) reported low achieving undergraduate business students benefited the most from cooperative learning. Additionally, Kenneth and Young (1999) specifically investigated the effect of cooperative learning groups on the academic achievement of high-achieving pre-service teachers and noted that cooperative learning did not enhance their academic performance. In spite of the overwhelming evidence of high-achieving schools performing better than low-achieving schools, critical analysis of individual scores showed that some low achievers performed better than some high achievers. It is likely that low achievers received more scaffolding and help from more capable peers as opposed to high achievers who could have been at a higher level of comprehension at the time the pre-test was taken. This is in line with Vygotsky's social interaction theory with reference to the concept "the zone of proximal development (ZPD) i.e. the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers (Galloway, 2001). Consequently, low achievers attain more than high achievers based on this concept. However, Tudge (1993) found that the degree of confidence students brought to a task was an important factor in the interaction, which accounted for high performance.

Comparatively, the confidence level of high achievers was very high and that might have accounted for their high achievement in the post-diagnostic test in this study.

CONCLUSION

This study looked at the use of collaboration to teach the topic of electrochemistry in the grade-12 CAPS Physical Sciences curriculum. The study has indicated that students have several Alternative Conceptions related to Electrochemistry, otherwise called *electrochemical reactions* in the CAPS document for high schools in South Africa, and these Alternative Conceptions affect students' comprehension of chemistry viewpoints. Thus, it is crucial to seek techniques to rectify these alternative conceptions so as to fulfill meaningful learning. The inferences of the current research showed that collaboration assisted students in remediation of their Alternative conceptions and improved their comprehension of electrochemistry concepts.

However, students from high achieving schools performed better than those from low achieving schools on their post-test scores when taught using conceptual teaching strategy. Students from High achieving schools showed greater understanding of electrochemistry concepts compared to students from low achieving schools using conceptual change teaching strategy for both, when they were examined after the instruction. The data presented from the mean, standard deviation, Post Hoc analysis and ANCOVA were able to show the differences between the HAS and LAS students' performance on ECT. The results indicated that there were differences in the conceptual understanding of LAS and HAS students, especially when the students provided descriptive explanations that require further elaboration in the guided interview.

From the findings obtained on the analysis of the results, the evidence shows that HAS students developed a better conceptual understanding (even though they were all taught using collaboration), in comparison with LAS students, suggesting that HAS students benefitted more from CCTS compared with LAS students. Thus, there must be some aspects of the collaboration that contributed to these differences in the achievement of the groups. Drawing from this, the effectiveness of the collaboration can be determined according to whether or not students in the HAS had developed a better conceptual understanding after teaching in comparison to LAS.

LIMITATIONS

The most crucial limitation of the research was the sampling technique, as intact groups were employed in the present research; thus, it was likely to have limited generalizability. A research that uses random sampling and a large sample size would provide more precise inferences and offer superior generalizability. The sample could also symbolise a larger population.

IMPLICATIONS

This study has several implications for teachers and policy formulators. Just by assigning students to groups and asking them to work together will not necessarily promote collaborative learning or achievement. In the experimental condition, students often require prompting from the teacher to ensure they adequately discuss, negotiate and come out with plausible explanations with their partners. Consequently, training students in interactive skills such as facilitating collaborative discourse, communication and being sensitive to each other's needs, may be a prerequisite of successful peer collaboration.

RECOMMENDATIONS

Collaboration as a 21st-century skill, used in this study can be used as a tool in the South African classroom to help improve students' conceptual comprehension of electrochemistry as shown in this research. Physical Sciences teachers are encouraged to determine important concepts in the chemistry syllabus and apply relevant instructional strategies that will help increase learner achievement.

ACKNOWLEDGEMENTS OR NOTES

The University of South Africa is hereby acknowledged for granting the primary researcher a bursary and ethical clearance that enabled this work to be carried out. The Mpumalanga Department of Education is also acknowledged for granting the researcher permission to conduct the study in the Province.

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APPENDIX

ECT Diagnostic Instrument for Post-test

Please answer the following questions to the best of your ability. You will not be marked on your answers; it is for informational purposes only. This is a **closed-book** test, consisting of 20 questions. There are 10 pairs of questions that were designed to be answered together. The second question is based on the reason why you chose your answer to the first question in the pair. Include all of your work in the booklet. No scrap paper is provided. Please transfer your answers to the answer sheet provided. Do not write on the question paper. An electrochemistry Formula Sheet has been provided for your reference.

1-1. The half-reaction to which all other half-cell reduction potentials are compared is ____________.

A. $Na^{+}_{(aq)} + e \rightarrow Na_{(s)}$
B. $Cl_{2(g)} + 2e \rightarrow Cl^{-}_{(aq)}$
C. $2H^{+}_{(aq)} + 2e \rightarrow H_{2(s)}$
D. $Al^{3+}_{(aq)} + 3e \rightarrow Al_{(s)}$

1-2. Select a statement that explains why a standard half-cell is used.

A. There is arbitrary designation of 0 V for the standard half-cell.
B. The only reduction half-reaction that produces 0 V is the hydrogen half-cell.
C. All half reactions that are listed above hydrogen on a table of reduction half reactions will be spontaneous.
D. The chemistry of the components in the half-cell accounts for the designation of the standard half-cell.

Use the information provided to respond to the questions 2-1 and 2-2.

$FeO_2^+{}_{(aq)} + 2H^+{}_{(aq)} + e$	$\rightarrow$	$FeO^{2+}{}_{(aq)} + H_2O_{(l)}$	$E^o = +0.999$ V
$FeO^{2+}{}_{(aq)} + 2H^+{}_{(aq)} + e$	$\rightarrow$	$Fe^{3+}{}_{(aq)} + H_2O_{(l)}$	$E^o = +0.340$ V
$FeO_2^+{}_{(aq)} + 4H^+{}_{(aq)} + 5e$	$\rightarrow$	$Fe_{(s)} + H_2O_{(l)}$	$E^o = -0.250$ V
$Fe^{3+}{}_{(aq)} + e$	$\rightarrow$	$Fe^{2+}{}_{(aq)}$	$E^o = -0.255$ V

2-1. Which of the following substances is the strongest reducing agent?
A. Fe^{2+}
B. Fe^{3+}
C. FeO_2^+
D. FeO^{2+}

2-2. Which of the following statements applies to the standard electrode potential table above?
A. A half-reaction with a negative reduction potential will be non-spontaneous
B. Reduction potentials from the standard electrode potential table are added to obtain cell potentials.
C. In a standard reduction potential table, reducing agents are listed in order of decreasing reactivity from the top of the table to the bottom of the table.
D. In a standard reduction potential table, species are listed in order of decreasing the tendency to attract electrons from the top of the table to the bottom of the table.

Use the information provided to respond to the questions 3-1 and 3-2.

$Ga^{3+}{}_{(aq)} + Al_{(s)}$	$\rightarrow$	$La^{3+}{}_{(aq)} + Ga_{(s)}$
$B^{3+}{}_{(aq)} + Ga_{(s)}$	$\rightarrow$	no reaction
$B^{3+}{}_{(aq)} + Al_{(s)}$	$\rightarrow$	$Al^{3+}{}_{(aq)} + B_{(s)}$

3-1. Which of the following statements applies to the equations above?
A. The oxidizing agent loses electrons.
B. The reducing agent undergoes reduction.
C. The oxidation number increases in the species undergoing reduction.
D. Electrons are transmitted from the reductant to the oxidant.

3-2. The oxidizing agent above, listed from strongest to weakest, are ____________.
A. $Ga_{(s)}$, $B_{(s)}$, $Al_{(s)}$
B. $Ga^{3+}{}_{(aq)}$, $B^{3+}{}_{(aq)}$, $Al^{3+}{}_{(aq)}$
C. $Ga^{3+}{}_{(aq)}$, $Al^{3+}{}_{(aq)}$, $B^{3+}{}_{(aq)}$,
D. $B^{3+}{}_{(aq)}$, $Ga^{3+}{}_{(aq)}$, $Al^{3+}{}_{(aq)}$,

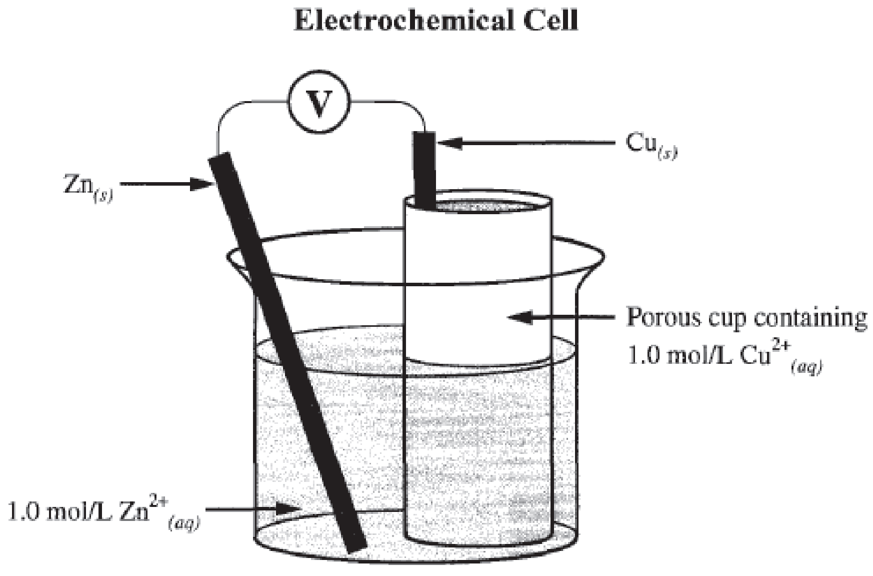
Use the information provided to respond to the questions 4-1 and 4-2.

1.	$H_{2(g)} + Cl_{2(g)}$	$\rightarrow$	$2HCl_{(g)}$
2.	$SO_{3(g)} + H_2O_{(l)}$	$\rightarrow$	$H_2SO_{4(aq)}$
3.	$NH_{3(g)} + H_2O_{(aq)}$	$\rightarrow$	$NH_4^+{}_{(aq)} + OH^-{}_{(g)}$
4.	$2NH_{3(g)} + \frac{1}{2}O_{2(g)}$	$\rightarrow$	$2NO_{2(g)} + 3H_2O_{(g)}$

4-1. Which of the following statements about the oxidation state of an atom is correct?
A. The oxidation number of oxygen in $O_{2(g)}$ is O
B. The oxidation number of chlorine in $C1_{2(g)}$ is -1
C. The oxidation number of nitrogen in $NH_4^+{}_{(aq)}$ is -2
D. The oxidation number of sulphur in $H_2SO_{4(aq)}$ is -2

4-2. Which of the equations above represents redox reaction?
A. 3 only
B. 4 only
C. 1 and 4
D. 2, 3 and 4

Use the information provided to respond to the questions 5-1 and 5-2.



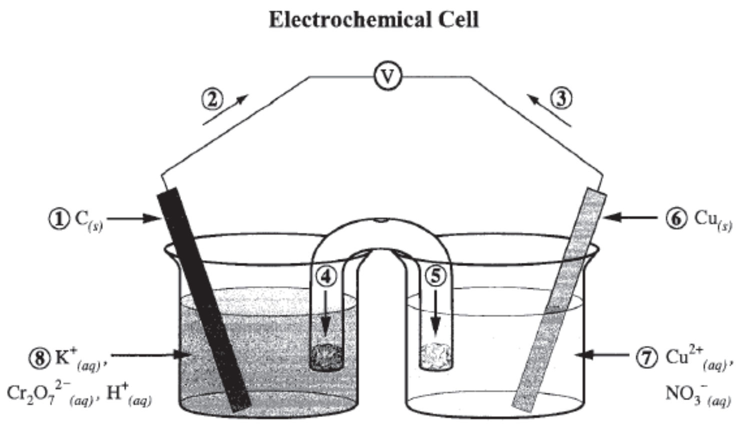
5-1. The cell potential for the electrochemical cell in the diagram above is ____________.

A. +1.10V
B. +0.42V
C. -0.42V
D. -1.10V

5-2. In the electrochemical cell above electrons move through the ____________.

A. electrolyte because the positive ions attract the electrons in the solution
B. electrolyte in one direction and protons move through the electrolyte in the opposite direction.
C. wire from the electrode with the lower reduction potential to the electrode with the higher reduction potential
D. wire from the electrode with high concentration of electrons to the electrode with the low concentration of electrons

Use the information provided to respond to the questions 6-1 and 6-2.



6-1. Which of the following statements applies to the electrochemical cell above?

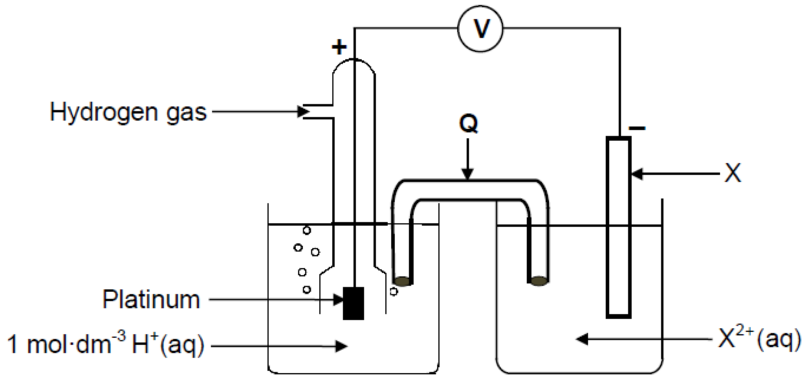
A. The anode is labelled 1.
B. Electron flow is labelled 2.
C. Cation movement is labelled 4.
D. The strongest reducing agent is $Cr_2O_7^{2-}{}_{(aq)}$ and $H^+{}_{(aq)}$

6-2. Which of the following statements applies to the electrochemical cell above?

A. The negatively charged anode attracts positively charged protons.
B. The positively charged cathode attracts negatively charged electrons.
C. Cations move towards the cathode so that the cell remains electrically neutral.
D. Cations are attracted to anions in the electrolyte which limits their movement toward the cathode.

Use the information provided to respond to the questions 7-1 and 7-2.

The electrochemical cell represented below consists of a hydrogen half-cell and an unknown half-cell at standard conditions.



The reading on the voltmeter is 2.36 V.

7-1. If the reading on the voltmeter is +2.36 V under standard conditions, then $X_{(s)}$ is most likely _____________.

A. $Ag_{(s)}$
B. $Al_{(s)}$
C. $Mg_{(s)}$
D. $O_{2(g)}+H_2O_{(l)}$

7-2. Select the statement that best describes the circuit in the electrochemical cell above.

A. Electrons are provided by the salt bridge in order to complete the circuit.
B. An operating circuit requires the movement of anions, cations and electrons.
C. Electrons exit the electrolyte at the anode after entering and moving through the electrolyte at the cathode.
D. The salt bridge allows the flow of electrons through it as positive ions in the bridge attract electrons from one half-cell to the other half cell.

Use the information provided to respond to the questions 8-1 and 8-2.

Molten aluminium is produced from molten aluminium oxide by using an electrolytic cell, as represented by the simplified equation below. $2\ Al_2O_3(l) \quad \rightarrow \quad 4\ Al\ (l) + 3O_2(g)$

8-1. Which of the following equations represents the reduction half-reaction when molten aluminium oxide undergoes electrolysis?

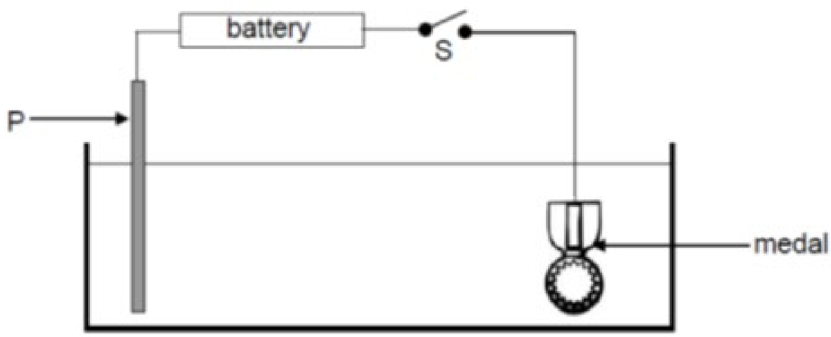
A. $2\ O^{2-}_{(l)} + 4\ é \rightarrow O_{2(g)}$
B. $2\ O^{2-}_{(l)} \rightarrow O_{2(g)} + 4\ é$
C. $Al^{3+}_{(l)} \rightarrow Al_{(l)} + 3\ é$
D. $Al^{3+}_{(l)} + 3\ é \rightarrow Al_{(l)}$

8-2. The *Emf* connected to the electrolytic cell is 240 V. The maximum electrical work that can be done by the source is 2.16 x 10 ^{11}J. Calculate the cell capacity of the source.

A. 9 x 10^8 A.h
B. 9 x 10^8 C
C. 2.5 x 10^{5}A.h
D. 2.5 x 10^{5}C

Use the information provided to respond to the questions 9-1 and 9-2.

A thin layer of silver was used in electroplating a tin jewellery to improve its appearance as shown in the electrochemical cell below.



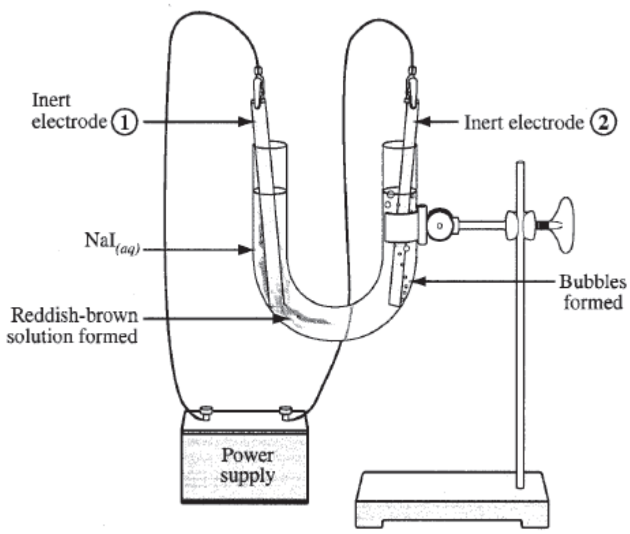
9-1. When the key is closed the plating of the medal will take place at the *i* where *ii* occurs.
Completed the statement above with the information in any of the rows below

Row	***i***	***ii***
A.	Anode	Oxidation
B.	Anode	Reduction
C.	Cathode	Oxidation
D.	Cathode	Reduction

9-2. The anode in the electrochemical cell above is ____________.

A. identified by its location in the cell
B. the species with the lowest oxidation potential
C. the metal with the least ability to attract electrons
D. the electrode with the highest concentration of electrons

Use the information provided to respond to the questions 10-1 and 10-2.
A learner set up the following electrochemical cell and allowed it to operate for a few minutes.



10-1. The gas formed near electrode 2 is most likely ____________.

A. $I_{2(g)}$
B. $Na_{(g)}$
C. $O_{2(g)}$
D. $H_{2(g)}$

10-2. Which of the following statement applies to the electrochemical cell in the diagram above?

A. The same reaction occurs at each of the inert electrodes.
B. The inert electrodes are oxidized and reduced in this cell.
C. In the electrolysis of aqueous solutions, water is unreactive.
D. The chemical reactions occur on the surface of the inert electrodes

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EUROPEAN JOURNAL OF STEM EDUCATION

European Journal of STEM Education,
2018, 3(2), 05
ISSN: 2468-4368

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A Primary Teacher Learning to Use Scaffolding Strategies to Support Pupils' Scientific Language Development

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Citation: van Driel, S., Slot, E. and Bakker, A. (2018). A Primary Teacher Learning to Use Scaffolding Strategies to Support Pupils' Scientific Language Development. *European Journal of STEM Education*, 3(2), 05. https://doi.org/10.20897/ejsteme/3115

Published: August 8, 2018

ABSTRACT

Although learning scientific language is crucial for learning science, many primary school teachers lack the knowledge and skills to support this. The present case study reports on a primary school teacher who learned to use a repertoire of scaffolding strategies for stimulating pupils' scientific language development in inquiry-based science lessons (14 pupils; grade 4). Teacher support included an instructional sequence, participation in interviews and writing reflective reports. The aim of this study is to identify how the teacher used the scaffolding strategies in a classroom with native speakers and which challenges she experienced during the process. Analysis of lesson transcripts showed that the teacher applied all scaffolding strategies suggested to her. Analysis of interview transcripts gave insight into five categories of challenges the teacher experienced while using scaffolding strategies, including her expectations regarding pupils' scientific language level and dealing with differentiation in the classroom. The findings show that a teacher can learn to apply multiple scaffolding strategies for stimulating scientific language development. Patterns in the use of scaffolding strategies arose related to the aim of the strategy, the situation (i.e., phase of the empirical cycle and teaching approach) and the required pedagogical content knowledge (and skill) of the teacher.

Keywords: scientific language, science and technology education, inquiry-based learning, scaffolding strategies, primary education

INTRODUCTION

Many primary school teachers struggle with the question of how they can effectively support science learning (Appleton, 2003; Fitzgerald and Smith, 2016). By 2020, all primary schools in the Netherlands will be required to include science and technology education in their everyday school practice (National Technology Pact 2020, 2012). This challenge is reinforced by the national trend to take an inquiry-based approach in which pupils are stimulated to actively investigate a scientific problem or phenomenon while working according to the steps of the empirical cycle (e.g., exploring, experimenting, presenting) (Furtak, 2006; Minner et al., 2010; Van Graft and Kemmers, 2007). Hence, there is a need to explore how primary school teachers can be supported to teach these inquiry-based science lessons.

Although no agreement exists on how science learning and language are exactly related, most scholars agree that learning the language of science is crucial for science learning (Anstrom et al., 2010; Valdés, 2004). As most pupils have to learn this scientific language at school and many primary school teachers have limited knowledge and skills to facilitate this (Silva et al., 2012), we explore in this study how a teacher can learn to scaffold her students' scientific language.

The source of inspiration is the literature on promoting general academic and subject-specific academic language (e.g., Osborne, 2010; Schleppegrell, 2004, 2007, 2012; Snow and Uccelli, 2009). Much of this literature is based on work with bilingual students, but the approaches developed in this domain turn out to be beneficial for speakers of their first language too (Gibbons, 2002; Silva et al., 2012). Previous research reported on scaffolding strategies that teachers successfully used to support second language learners in inquiry-based science lessons (Silva et al., 2012) and mathematics lessons (Smit and Van Eerde, 2013). What is unknown, yet relevant to know, is to what extent the usage of these scaffolding strategies can be transported to other settings, such as, in our case, science learning with native Dutch speakers. The aim of the current case study is to identify how a primary school teacher uses a repertoire of scaffolding strategies for supporting scientific language development in a classroom with native speakers and which challenges she experienced during the process.

THEORETICAL BACKGROUND

There is widespread agreement among researchers that pupils have to learn the language of science in order to learn science (e.g., Lemke, 1990; Snow, 2010; Wellington and Osborne, 2001). This does not only apply to second language learners, but for all learners in science classrooms (Gibbons, 2002; Silva et al., 2012). However, discussions exist about what this language, often referred to as "academic language", exactly entails (Valdés, 2014). This discussion mainly refers to the wide variety of categorical distinctions that exist regarding the concept of academic language in literature, which are the result of the complexity of the concept itself and the multiple viewpoints from which it has been investigated and defined (Anstrom et al., 2010). The existence of these categorical distinctions has been criticized by multiple researchers (e.g., Forman, 1996). Instead, a continuum has been suggested on which daily language is positioned on one end and formal or academic language on the other (Gibbons, 2002; Snow 2010). In line with this, the goal of the present study was to learn a teacher to support pupils' toward the use of scientific language. Inspired on the literature on promoting general academic and subject-specific academic language (e.g., Osborne, 2010; Schleppegrell, 2007; Snow, 2010), the scientific language we refer to in this study includes scientific vocabulary (e.g., hypothesis, data, friction, gravity) and scientific formulations (e.g., formulating hypotheses and research questions). Although we acknowledge the relevance of the discussion about the complexity of academic language, it is of minor importance for this study because of our broad focus on the language of science and the language to learn about science.

Scaffolding, according to Gibbons (2002), can be used as a teaching method to stimulate language learning during content lessons. Scaffolding can be defined as "the process that enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts" (Wood et al., 1976, p. 90). During scaffolding, a more knowledgeable other, such as a teacher or parent, provides temporal support to help a pupil to establish a learning task that he or she cannot yet establish alone. Over the course of the learning task the support gradually decreases in line with the development of the pupil until the task can be carried out independently (Gibbons, 2002). The method draws on the principles of the sociocultural theory that stresses the importance of social interaction for learning. According to Vygotsky, children's construction of knowledge is the result of the internalisation of external dialogue that they use when performing a learning task that is guided by a more knowledgeable adult. This guidance is necessary to help a child to proceed in the zone of proximal development (ZPD), defined as the difference between the developmental level that a child can accomplish individually and with support of an adult (Vygotsky, 1978).

Because of the adaptive nature of the scaffolding process, it is suggested to come close to "good teaching" (Bakker et al., 2015), which is defined as "the active and sensitive involvement of a teacher in students' learning" (Mercerand Littleton, 2007, p. 18). Teachers originally used scaffolding as a method to support individual pupils in their development (Smit and Van Eerde, 2013; Van de Pol et al., 2011). However, due to its benefits, recent studies also explored the possibilities of using scaffolding in small-group and whole-class settings (e.g., Abdu et al., 2015; Makar et al., 2015; Smit and Van Eerde, 2013). In particular, Smit et al. (2013) investigated how scaffolding can be used to support language development in whole-class settings and proposed three characteristics of whole-class scaffolding: (1) diagnosis (2) responsiveness (3) handover to independence. A teacher can implement scaffolding in the classroom by using scaffolding strategies: after implicit diagnosis (i.e., judgement of what pupils need) the teacher chooses a strategy that seems to be appropriate at that moment, in this way responding contingently, with the overall goal to make pupils more independent.

The inquiry-based approach of Van Graft and Kemmers (2007) appears to serve the aforementioned criteria of scaffolding. The lessons include whole-class conversations and collaborative work in which discussing, experimenting, writing exercises and reasoning have a central role (Anderson, 2002; Quintana et al., 2004). These

Table 1. Scaffolding strategies that are suggested to the teacher

1.	Reformulate pupils' utterances (spoken or written) into more scientific wording
2.	Ask pupils to be more precise in their spoken language or to improve their language
3.	Use gestures or tools to support verbal reasoning
4.	Repeat correct pupil utterances (written or spoken)
5.	Remind pupils to use a designed scaffold as a supporting material
6.	Ask pupils how a written text can be produced or improved into more scientific wording
7.	Discuss with the pupils the definition of scientific concepts and their connection to everyday language
8.	Introduce concepts that are necessary for pupils' scientific understanding

Note. Scaffolding strategies 1-6 are adopted from the study of Smit and Van Eerde (2013) and strategies 7-8 are based on the study of Silva et al. (2012).

activities stimulate pupils to use scientific language in spoken or written form, providing opportunities for the teacher to diagnose their current level. Subsequently, the teacher can enrich pupils' scientific language use by implementing a scaffolding strategy that seems suitable for the pupil(s) in the specific context. By providing support adjusted to the needs of the pupil(s), the teacher can contingently support them in their scientific language development. An important goal of inquiry-based learning is that teachers help pupils to transition toward independence of the teacher (Linn, 2000). This is in line with the third criterion of scaffolding, handover to independence. In this context, the learning goal is that pupils will be able to use the scientific language without the support of the teacher.

In this case study we assisted a teacher in using scaffolding strategies to support scientific language development during inquiry-based science and technology lessons in a classroom with native Dutch speakers. We developed an instructional sequence in which science and scientific language learning were integrated and we stimulated the teacher to use a repertoire of scaffolding strategies by participating in interviews (e.g., stimulated recall) and by writing reflective reports (see Bakkenes et al., 2010). We adopted the scaffolding strategies from the studies of Smit and Van Eerde (2013) and Silva et al. (2012). These studies were, to our knowledge, the only ones that reported on strategies that have been empirically tested in similar contexts of primary classrooms. We based our repertoire on that of Smit and Van Eerde (2013) because their strategies were developed for Dutch education, complemented with strategies developed by Silva et al. (2012). This resulted in the eight scaffolding strategies presented in **Table 1**.

We address the following research questions: (a) To what extent does the teacher use scaffolding strategies for supporting pupils' scientific language development during inquiry-based science and technology lessons? (b) What challenges does the teacher experience when using scaffolding strategies during these lessons? The findings of this study will provide a sense of understanding of what can be expected of a teacher learning to use scaffolding strategies in inquiry-based science & technology lessons.

METHODS

Context of the Case Study

The case study teacher Emma (pseudonym) worked at an elementary school in a suburban area in the Netherlands. At the time of this project, she had seven years of experience in primary education. Emma was selected for participating in this study because of her specialization in science and technology education and lack of experience with supporting scientific language development by using scaffolding strategies. To identify how a teacher can learn to use scaffolding strategies in science lessons, we selected a teacher who was able to teach the content of the lessons without additional support, was motivated to teach science and technology education, and eager to learn the didactics of inquiry-based learning of Van Graft and Kemmers (2007). Moreover, Emma worked at a school with above average attention for science and technology education. She conducted the lessons in a separate science and technology classroom within the school that provided a suitable environment with the necessary space and attributes for conducting the inquiry-based lessons. Emma gave the lessons to a grade 4 class consisting of 14 pupils in the age of 9 to 11 (7 boys, 7 girls). All pupils had the Dutch nationality and spoke Dutch as their first language. According to Emma, language proficiency was considered weak for two pupils, average for four pupils and above average for eight pupils. Three of the 14 pupils were familiar with the aforementioned approach of inquiry-based learning, since they had participated in an honours class.

For the present study, the researchers developed – in collaboration with a team of didactical and theoretical experts in the field of education, language, and science – an instructional sequence of science and technology suitable for supporting scientific language development. It consisted of four one-hour lessons according to the inquiry-based approach of Van Graft and Kemmers (2007) (see **Table 2**), with *friction* as the overarching subject. By covering all phases of the empirical cycle (i.e., exploring, designing an experiment, experimenting, drawing conclusions, presenting), the pupils investigated what factors influence the sliding speed of objects, such as material

Table 2. Content of each lesson and pupil activities

	Lesson content	Pupil activity
Lesson 1	Introduction and exploring	Being introduced to the subject of sliding and exploration of the subject
Lesson 2	Preparing and conducting research	Composing of research question, hypothesis and research method, conducting research and writing results
Lesson 3	Drawing conclusions and presenting research	Drawing conclusions and preparing presentations, presenting, giving feedback on presentations
Lesson 4	Presenting research and discussing	Preparing presentations, presenting, giving feedback on presentations

Note. The content of the lessons is based on the phases of the empirical cycle from Van Graft and Kemmers (2007).

characteristics and the slope of the slide. Each lesson included both science and language goals to support Emma towards integrating language development in her science lessons.

An example of a science goal is "pupils understand that sliding can be influenced by the slope of the slide and material characteristics" and an example of a language goal is "pupils use the thematic words to write a research plan (e.g., flat and steep)". Lessons were characterized by both whole-class discussions and collaborative work. The focus on scientific language was further established by inclusion of language instructions, examples of scientific formulations and activities that created opportunities for Emma to include scientific language in the lessons (e.g., the use of an scientific word list). Additionally, examples of scientific vocabulary were provided for each lesson, such as *angle, steep*, *hypothesizing* and *concluding*. Emma was encouraged to include other scientific concepts herself and to pay attention to the vocabulary that the pupils used or needed during the lessons. The lessons took place on a weekly basis with the exception of a three week gap between the first and second lesson.

Teacher Support

In addition to the instructional sequence, other components of teacher support included an instructional meeting, pre- and post-lesson interviews and reflective reports.

Instructional meeting. The project started with a one-hour instructional meeting during which the researchers introduced the pedagogy of inquiry-based learning based on the method of Van Graft and Kemmers (2007); the role of scientific language during inquiry-based science lessons; the concept of scaffolding and the scaffolding strategies that were selected for the present study.

Pre-lesson interviews. From the second lesson onwards, we conducted stimulated recall interviews before each lesson in which selected video fragments of the previous lesson were discussed with Emma. The duration of the interviews was 20 minutes and aimed at stimulating her to reflect on her use of scaffolding strategies. To enhance Emma's confidence in supporting scientific language development, we watched video fragments in which she correctly used scaffolding strategies and we encouraged this by positive reinforcement (Margolis and McCabe, 2003). Additionally, we provided her with feedback and suggestions to make some changes in her teaching in the subsequent lessons. For instance, before the second lesson, we encouraged Emma to have pupils speak independently by using the strategies "ask pupils to be more precise in their spoken and written language or to improve their language" and "remind pupils to use a designed scaffold as a supporting material". During these interviews we also discussed Emma's planning for the upcoming lesson and questions that she had concerning the lesson content or structure.

Post-lesson interviews. A post-lesson interview of 15 minutes was conducted after each lesson. During these interviews we covered general topics including the experiences of Emma regarding the content and structure of the lesson, the scientific language that was of interest, the use of scaffolding strategies and encountered challenges.

Reflective reports. To stimulate Emma to reflect on her use of the scaffolding strategies, she sent a weekly reflective report by email including a table with the various scaffolding strategies. She was instructed to formulate for each strategy whether she had used it during the lesson and to give some examples of when it was used. Emma mentioned multiple times that she had to postpone the completion of the reports to the end of the day and therefore experienced difficulties in memorizing what and how she used the strategies during the lesson. For validity purposes we decided to exclude these reports from the data analyses.

Analysis

The audio recordings of the interviews and the video recordings that were made of each lesson, including Emma's gestures that were relevant for supporting scientific language, but excluding off-topic talk, were transcribed verbatim. To answer the first research question, we identified the scaffolding strategies that Emma used during each lesson. As we were interested in how Emma applied the repertoire of scaffolding strategies we had suggested to her, we used the strategies presented in **Table 1** as initial framework for coding the lesson transcripts, using the software ATLAS.ti (www.atlasti.com). During the analyses we were aware that Emma might have applied additional scaffolding strategies outside this repertoire. However, we did not find any in the lesson transcripts. Text fragments in which Emma used or responded to pupil utterances that included scientific

Table 3. Coding scheme of the scaffolding strategies

Code	Definition
RepCor	Repeat correct pupil utterances (written or spoken)
UseGes	Use gestures or tools to support verbal reasoning
AskSpo	Ask pupils to be more precise in their spoken and written language or to improve their language
DisDef	Discuss with the pupils the definition of scientific concepts and their connection to everyday language
RemSup	Remind pupils to use a designed scaffold as a supporting material
RefUtt	Reformulate pupils' utterances (spoken or written) into more scientific wording

Note. The scaffolding strategies RefUtt to RemSup were adopted from Smit and Van Eerde (2013), and the strategy DisDef is adapted from Silva et al. (2012).

vocabulary or formulations were used as unit of analysis. Based on the work of Smit and Van Eerde (2013), we developed a coding manual with coding instructions for each strategy. All attempts by Emma to use one of the scaffolding strategies for supporting scientific language development were coded, regardless the obtained effect. During the coding process, there were problems with assigning several codes to text fragments. Therefore, it was decided to combine two codes into one broader category and to exclude one code from the data analysis. The code "ask pupils how a written text can be produced or improved into more scientific wording" and the code "ask pupils to be more precise in their spoken language or to improve their language" were combined into the category "ask pupils to be more precise in their spoken and written language or to improve their language". Additionally, the code "introduce concepts that are necessary for pupils' scientific understanding" was excluded from the data analysis. We decided this because the introduction of scientific concepts was often accompanied with asking for their definition. These fragments were coded as "discuss with the pupils the definition of scientific concepts and their connection to everyday language". This resulted in the coding scheme as presented in Table 3.

The frequencies of the remaining six scaffolding strategies were determined for each lesson, as were the total numbers and percentages. To ensure the reliability of the coding process, text fragments were coded by two raters. To familiarize herself with the data and coding manual, the second rater first coded a subset of 25 text fragments and discussed these with the first coder. Then, a second set of text fragments was randomly selected and coded by the second rater to determine the interrater reliability with use of the rule of Cicchetti (1976). This rule states that the number of fragments that should be coded to have a reliable analysis can be defined by the formula $2n^2$, where n is the number of codes. In the analysis $n = 6$, which implied that 72 fragments had to be coded. This resulted in 67 agreements in coding (93.1%; Cohen's kappa = .90), implying that the six categories could be distinguished reliably.

To answer the second research question, the transcripts of the pre- and post-lesson interviews were qualitatively analysed according to Boeije's (2005) guidelines. The analysis focussed on text fragments that included utterances concerning challenges that Emma experienced referring to the use of scaffolding strategies or to the concept of scientific language. In addition, several text fragments were included that indirectly referred to experienced challenges. After collecting all relevant text fragments, five categories of challenges were identified: (1) dealing with differentiation regarding pupils' varying levels of scientific language; (2) patience to stimulate pupils' scientific language; (3) uncertainties towards expectations of pupils' scientific language use; (4) necessity of practice to internalize the use of scaffolding strategies; (5) pupils' motivation to focus on scientific language development. A description of each category can be found in the results section.

RESULTS

Extent of Scaffolding Strategies Being Used

Table 4 shows the frequencies and percentages of the scaffolding strategies Emma used during the lessons. In total 221 instances were defined in which scaffolding strategies were used: in each of the first three lessons about 60 instances and 35 instances in the fourth lesson. The low amount of scaffolding strategies in the fourth lesson can be explained by the fact that this lesson mainly included pupils' presentations. Consequently, Emma had fewer opportunities to implement the scaffolding strategies. The following section provides examples of each strategy and a discussion of how Emma used them to support pupils in their scientific language development. The original quotations have been translated from Dutch to English.

Repeating correct pupil utterances. Emma used this strategy by literally repeating written or spoken language of pupils including scientific vocabulary or correct scientific formulations, or by responding with positive reinforcement. Emma used this strategy about equally in the different lessons during both whole-class conversations (see Examples 1 and 3) and small-group support (see Example 2).

Example 1
Emma: What is important for sliding?

Figure 1. The figure shows an example of how Emma used gestures to support verbal reasoning. Here she makes a diagonal arm gesture when using the concept *slope*.

Pupil: That the slide is not too steep, but also not too flat.
Emma: Steep. Very good words, well said, Lisa. Steep and flat.

Example 2
Emma: I'm really curious, guys. Let me see what you have done already. Research question, hypothesis, (…) method. Well, that is really extensive.
Pupil: Findings uhm… When the slope is small…
Emma: You're using the concepts wonderful Tim.

Emma also used this strategy by including both positive affirmation and elaboration in response to pupil utterances that included scientific language. Here her elaboration was always accompanied with explicit positive reinforcement (see Example 3). When she elaborated pupil utterances with a scientific concept or improved a scientific formulation without positive affirmation, it was coded as "reformulate pupil utterances into more scientific wording" (see Example 12).

Example 3
Emma: What does presenting mean?
Pupil: Telling something in real life and stuff.
Emma: Very good. Actually, you tell the rest of the group what you did.

Use gestures or tools to support verbal reasoning. Emma performed this strategy mainly by using gestures or additional tools, such as the scientific word list, as visual support during the explanation or use of scientific vocabulary in whole-class setting (see Example 4 and 5).

Example 4
Emma makes a diagonal arm gesture when using the concept *slope* (see **Figure 1**).

Example 5
Emma writes the concept *friction* on the scientific word list (see **Figure 2**).

The majority of instances of this strategy was found in the first lesson and the number decreased in the subsequent lessons (see **Table 4**). Emma used this strategy mainly to provide visual support during the introduction and explanation of new scientific concepts such as slope or angle, in whole-class conversations. The decrease of instances is in line with the declining number of newly introduced concepts during the course of the lessons.

Ask pupils to be more precise in spoken and written language or to improve their language. Emma used this strategy by explicitly or implicitly asking or hinting at the pupils to improve or elaborate their written or spoken language into more precise formulations or into more scientific wording. She used this strategy both during whole-class conversations (see Example 6) and when providing small-group support (see Example 7).

Example 6
Emma: Slope. Who can tell me that [what that means]?
Emma: Sara, slope.
Pupil: That it goes like this [makes an arm gesture].

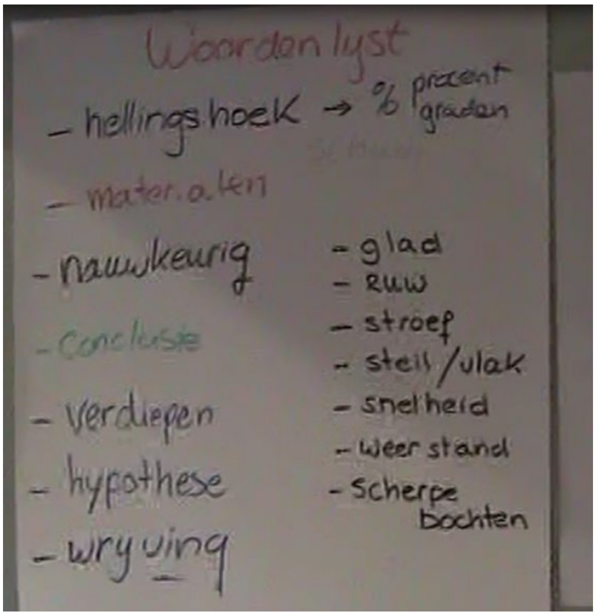

Figure 2. The figure shows the academic word list Emma used as a tool to support verbal reasoning. She frequently added scientific concepts (e.g., friction) to the word list.

Emma: No, now you tell it [by making an arm gesture].
Pupil: Well that it goes upwards.
Emma: A slope is… [implicitly]
Pupil: A slope is that something goes obliquely… that something slopes upwards or downwards [makes an arm gesture].

Example 7
Emma: The conclusion is… the shape of… [implicitly]
Pupil: Clay.
Emma: Makes… Well actually you have to… You have to give an answer on your research question now. That is the conclusion. How can you make a nice sentence to give an answer on [your research question] [explicitly]. We already started. The shape of... [implicitly]
Pupil: Clay makes a difference when you want to let it slide.

Compared to the first lesson (6 instances), the number of instances of this strategy was noticeably higher in the second (22 instances) and third lesson (12 instances). These increased numbers are in line with the intention we formulated in the interview preceding the second lesson and aimed at stimulating Emma to focus on this strategy. During the second and third lesson, she used this strategy mainly during small-group support to ask pupils for more precise scientific formulations such as research questions, hypotheses, research methods and conclusions (see Example 7).

Discuss with the pupils the definition of scientific concepts and their connection to everyday language. Emma used this strategy by asking pupils to give an explanation of the meaning of a scientific concept. In example 8 Emma used the strategy during a whole-class conversation.

Example 8
Emma: Who knows what a hypothesis is?
Pupil: Well, what you think is going to happen.

The numbers of instances of this strategy were highest during the first (7 instances) and the third lesson (9 instances). Emma used this strategy mainly when introducing and repeating the meaning of scientific vocabulary in whole-class conversations. The large amount of instances during the first lesson can be explained by the fact that a lot of new concepts were introduced and discussed compared to the other lessons. The high number of instances during the third lesson was due to pupils' confusion concerning the concept *data*. Here, the teacher used the strategy mainly to explain this concept while providing small-group support (see Example 9).

Example 9
Emma: Well what does your data tell you? What does data mean?
Pupil 1: A date.
Emma: No.

Table 4. Frequencies and percentages of used scaffolding strategies during the lessons

Scaffolding strategy	Lessons & main content: 1 introduction, exploring	2 preparing and conducting research	3 concluding, presenting	4 presenting, discussing	Total	%
RepCor: repeat correct pupil utterances	20	20	29	15	84	38.0
UseGes: use of visual tools or gestures to support verbal reasoning	30	10	5	1	46	20.8
AskSpo: ask pupils to be more precise in their language or to improve their language	6	22	12	4	44	19.9
DisDef: discuss with the pupils the definition of concepts and their connection to everyday language	7	3	9	3	22	10.0
RemSup: remind pupils to use a designed scaffold as a supporting material	1	2	7	10	20	9.0
RefUtt: reformulate pupils' utterances into more scientific wording	2	1	0	2	5	2.3
Total	66	58	62	35	221	100.0

Pupil 1: That is also a data right?
Emma: What does data mean?
Pupil 2: Data means, well actually I think information.

Remind pupils to use a designed scaffold as a supporting material. Emma used this strategy by explicitly or implicitly reminding pupils to make use of the scientific word list. In example 10 Emma used this strategy explicitly during small-group support.

Example 10
Emma: Try to use the correct words in whatever you are doing [gestures towards the scientific word list]. With that, I am referring to the scientific language that is written over here. On the scientific word list. Slope, material, accurate, later on conclusion.

Emma used this strategy implicitly by gesturing towards the scientific word list when pupils were struggling in their use of scientific words or formulations. In example 11 Emma used this strategy during a whole-class conversation.

Example 11
Pupil: Well, when the… [held his arm diagonally] is steeper.
Emma: When the… [points to the word angle on the word list].
Pupil: Angle.

The number of instances of this strategy increased slightly during the course of the lessons. This is in line with the increasing number of scientific words that were added on the word list during each lesson, resulting in more opportunities for Emma to use the word list.

We coded the use of the word list as the strategy "using gestures or tools to support verbal reasoning", when Emma used it as visual support when explaining scientific concepts herself (e.g., pointing towards the word "angle" when explaining its definition in contrast with helping pupils who struggle with their formulations as in the example 11).

Reformulate pupils' utterances (spoken or written) into more scientific wording. Emma used this strategy by reformulating or elaborating pupils' written and spoken language into more scientific vocabulary or formulations when providing small-group support (see Example 12).

Example 12
Emma: Actually, you should write "I think that a wet towel slides better than a dry one". You only have "when it is dry".

Reformulating pupils utterances was performed least of all scaffolding strategies and seems to ask for a deeper understanding and knowledge of the desired level of scientific language that suits the abilities of the pupils.

Teacher Challenges Related to the Use of Scaffolding Strategies

During the interviews Emma reported challenges that she experienced while using scaffolding strategies to support scientific language development in her lessons. All five categories in which these challenges were divided are discussed below along with quotations derived from the interviews.

Dealing with differentiation regarding pupils' varying levels of scientific language. Emma mentioned several times that she found it challenging to adjust her support to the varying levels of scientific language that pupils have in one class. She stressed that she has different expectations concerning the abilities of individual children and that it is difficult to respond to this correctly. This was especially the case during whole-class conversations, rather than when providing support to small groups. The following quotation reflects her thoughts about this:

> "I think it is difficult to deal with the different levels. You can deal with it when they are working in smaller groups. Then you can decide, I think this [language] is good enough or you can repeat it slightly different, such as it is supposed to be. Well, it is something that I have to continue searching for. How do you preserve what you want to explain, without doing harm to the child?" [post 2]

Patience to stimulate pupils' scientific language. In the interview preceding the second lesson, Emma reported that she found it challenging to let pupils speak independently in whole-class conversations. She was tempted to use the direct instruction approach for explaining new scientific content, instead of stimulating pupils to think out loud. Since the latter provides opportunities to focus on pupils' scientific language development, we asked her why she did not take more time to let the pupils speak themselves. She explained herself as follows:

> "I do notice that the children think that focussing on language is difficult. The search towards… and that I am tempted to say it myself. Because otherwise it will take too much time and they get insecure, because they don't understand what I want." [pre 2]

Emma frequently expressed her concerns about the time investment and that pupils become insecure when she focusses on language in her lessons. She stressed that the focus on language is new for these pupils and that repetition might be necessary to increase their understanding of what she is aiming for. However, during the discussion of a video fragment of the third lesson, she showed a change in her thoughts concerning independent speech of pupils. The following quotation was in response to a video fragment in which three pupils were discussing different material characteristics:

> "Yes, nice to see that the children are coming up with that [scientific vocabulary] themselves. But I saw I had to restrain myself from interrupting. Nice to see that though." [pre 4]

This quotation shows a progression in Emma's insights concerning the abilities of the children to use scientific language to discuss the lesson content with each other, instead of requiring her continuous support.

Uncertainties towards expected level of pupils' scientific language use. During the interviews Emma expressed uncertainties concerning the expectations of the level of scientific language that the pupils should reach. These uncertainties were shown by asking us evaluative questions, such as:

> "How did you think that it went with these words, because I have to search for it, because when am I satisfied with the way that they are formulating a sentence? When is it good enough?" [pre 2]

Or

> "But [about the concepts] slope and material, briefly for you, did the children formulate their descriptions well in your opinion? Do you think they understand it?" [post 3]

These utterances show that Emma lacks the knowledge to determine what scientific language, including scientific formulations and vocabulary, she can value as appropriate for the current level of the pupils. This might explain why Emma implemented the strategy "ask pupils to be more precise in their scientific language or to improve their scientific language" quite often and the strategy "reformulate pupils' utterances into more scientific wording" least. By asking pupils to specify their language use Emma can diagnose pupils' current level and abilities. In contrast, reformulation of pupils' utterances requires more knowledge about their scientific language level to allow Emma to adapt her support to the needs of the pupil(s). The language goals included in the lesson descriptions appear to not sufficiently support Emma in determining the language level she should aim at during the lessons.

Necessity of practice to internalize the use of scaffolding strategies. Emma mentioned several times that she has to consciously think about focussing on pupils' scientific language, otherwise she is inclined to forget this:

> "You are tempted to say and show things yourself. And those formulations, that is something that you have to make your own, I notice. That you pay attention to it and that you ask the children to use the right formulation. I think that is something where I have to be consciously thinking about. And otherwise you forget it." [pre 2]

She attributed this challenge to either yet lacking internalization of scientific formulations and to the fact that she had to process different tasks at the same time during the lessons (e.g. scaffolding, method of inquiry-based learning and the content of the instructional sequence):

> "I have to make this my own. And you notice during the internalization of things that you have to carefully think about everything, like how do I present it (to the kids)." [pre 3]

Pupils' motivation to focus on scientific language development. In the interview that preceded the second lesson, Emma showed concerns about the importance that the focus on scientific language has for the pupils:

> "I think that it [focus on scientific language] can be important. But to also let the children see that it is important, that is difficult. I was reading lesson 2 yesterday and it made me worry that a lot of children will think 'why are we doing this?'" [pre 2]

From the second lesson onwards she explained more explicitly why it is important to focus on scientific language and what she expected from the pupils during the lessons. For example:

> "What I also want you to do this lesson, is that you learn how to say clearly what something means. And therefore you can use school language, or scientific language. So, try to explain everything clearly, that everyone can understand what you mean. So try to use the words *this* or *that* as little as possible." [Lesson 2]

DISCUSSION

The aim of this case study was twofold. First, we explored how our case study teacher Emma used the repertoire of scaffolding strategies we handed to her for supporting scientific language development during inquiry-based science and technology lessons in a classroom with native speakers. Second, we examined which challenges she experienced during these lessons. We designed an instructional sequence for science and scientific language learning and through the use of interviews and reflective reports, we stimulated Emma to use the scaffolding strategies. Below we discuss our most important findings and the limitations of the study, and we provide suggestions for future research.

The Extent to Which Scaffolding Strategies Were Used

In answer to the first research question we can conclude that Emma implemented all scaffolding strategies that we had suggested to her in her lessons. Patterns developed concerning the use of specific strategies related to the phase of the empirical cycle that was considered and the teaching approach (e.g., whole-class or small-group support). The distribution of scaffolding strategies was about equal during the first three lessons. When considering the third criterion of scaffolding, handover to independence, it might be expected that the number of strategies declines over time, contingently with the development of pupils (Smit and Van Eerde, 2013). However, as the majority of pupils was unfamiliar with the inquiry approach, each lesson included new activities accompanied with new scientific language in which pupils had to be supported. The amount of scaffolding strategies used did decrease noticeable in the fourth lesson. Although Emma had less opportunities to implement the strategies due to pupil presentations that dominated the lesson, the "presenting phase" of the inquiry-based approach (Van Graft and Kemmers, 2007) can also be seen as an end-goal of the scaffolding process in which the responsibility of the learning task, in this case scientific language learning, should be transferred to the pupils.

Although Emma managed to apply multiple scaffolding strategies during each lesson, the low amount in which she used the strategy "reformulating pupils' utterances" was noticeable. This strategy forced Emma to actively improve pupils' scientific utterances, while being responsive to their level(s) and aware of the lesson goals. Implementation of this strategy might therefore require more developed pedagogical content knowledge (PCK) compared to the other strategies. Drawing on the definition of Berry, Friedrichsen and Loughran, (2015, Chapter 3), PCK of teachers in this context includes knowledge on the scientific language related to the topic and the inquiry-based approach that is suitable for the level of the pupils, as well as knowledge on how to use the scaffolding strategies to reach the science and language goals as formulated in the lesson plan. To empower Emma in implementing strategies that appear more complex, additional support in enriching her PCK in this context might be desirable.

Moreover, the application of a repertoire of scaffolding strategies during teaching goes beyond the teachers' PCK and asks for skills to implement this knowledge and planned instructions during teaching and to adjust it to specific circumstances. In this context the teacher's pedagogical content knowledge and skill (PCK&S) are of major interest (Berry et al., 2015, pp. 36-38). Teachers need to be able to determine by reflection-in-action what strategy should be used in a specific situation with a specific student to support language development to best reach the goals formulated for the lesson. These skills appear especially important in this context, since the inquiry-approach is mainly student directed learning (Furtak, 2006), asking for responsiveness of the teacher on scientific language that children need and use themselves during the lessons.

Teacher Challenges Referring to the Use of Scaffolding Strategies

In answer to the second research question five challenges became visible regarding the use of scaffolding strategies of which we discuss the most important ones here. Emma expressed that she found it challenging to adapt support to individual needs of pupils when focussing on scientific language during whole-class conversations. The approach Emma used in whole-class setting seems in line with the original use of scaffolding where a teacher helps one learner to proceed in his or her ZPD, instead of adapting support to a whole class of children with multiple ZPDs (Van de Pol, Volman and Beishuizen, 2011). Since the latter is challenging, Smit and Van Eerde (2013) recommended orienting on a group ZPD during whole-class scaffolding, which they proposed "to exist alongside individual learners' ZPDs." In order for Emma to focus on language in a whole-class setting, she would have to learn to become aware of this group ZPD and learn how to be responsive to this ZPD during whole-class scaffolding.

Another challenge Emma expressed was to remain patient to support scientific language development during science learning, mainly due to a sense of uncertainty she felt among the pupils towards her expectations. Confusion of pupils often appears to be the case when teachers focus on language in science classrooms, because many teachers do not explicitly explain how language is used in science and what they expect of the pupils in this respect (Mercer, 1995; Mercer et al., 2004). This issue also applies to Emma, who was uncertain herself regarding the expectations of the level of scientific language she should aim for. During teaching she searched for appropriate vocabulary and formulations instead of planning this beforehand according to the language aims and instructions included in the instructional sequence. As a consequence, her attempts of focussing on language lacked explicit aims and were therefore often not clear for her pupils. This finding contributes to the aforementioned suggestions that development of Emma's PCK and PCK&S in this context is needed.

Emma also experienced motivational issues of pupils regarding the significance of focussing on scientific language during science learning, which she found challenging to deal with. Mercer et al. (2009) argue, although in the context of dialogical teaching, that an important task of the teacher is to increase the awareness of children regarding the role of speech in enhancing their scientific understanding. As dialogic teaching and scaffolding are assumed to be related (Bakker et al., 2015; Gibbons, 2006, p. 175), this notion seems to apply to the use of speech, and in particular the scientific language used during this speech, in the context of scaffolding as well. However, during the interviews Emma never expressed that learning scientific language is important for pupils' scientific understanding and reasoning and therefore a first step seems to establish a basis of awareness at the side of the teacher. According to Smit and Van Eerde (2011) the latter appears also necessary in order for teachers to implement scientific language learning during teaching on a more structural basis.

Limitations and Future Research

The findings of our study should be interpreted in the light of some limitations. An obvious limitation is that the results of our case study can only be generalized analytically, not statistically (Yin, 1994). Yet as a case study it gives insight into what can be expected regarding the application of scaffolding strategies and teacher challenges and what may become feasible when such an approach is disseminated to a larger number of teachers.

Another limitation is that we primarily focused on the process of the teacher and not on the possible effects the approach had on pupils' learning. A logical next step would be to investigate to what extent the pupils were supported toward increased use of scientific language. During the presentations of their experiments, most groups of pupils included some scientific vocabulary, such as *research question*, *hypothesis*, *materials, conclusion*, *slope*, *light*, *heavy* and *shape*. In addition, they made attempts to include scientific formulations, such as hypothesis and research questions. We would encourage future research to empirically investigate how handover to independence takes place with respect to scientific language learning in the context of inquiry-based science and technology education.

Although we gained in-depth information about how Emma used scaffolding strategies while participating in the research project, we did not include a follow-up measurement to investigate whether Emma kept focusing on scientific language afterwards. In addition, it might be interesting as well to investigate what would happen regarding the number and distribution of implemented scaffolding strategies when Emma participated again in a similar project. Subsequently, it can be questioned whether Emma would experience the same challenges during a second experiment.

An important finding of this study appeared the role of PCK&S in applying scaffolding strategies during inquiry-based science teaching. To support teachers in implementing a repertoire of scaffolding strategies during teaching, it would be helpful if future research can search for patterns in the use of scaffolding strategies concerning the appropriateness of specific strategies related to the phase of the empirical cycle, teaching approach or to support low versus high achieving pupils. Such knowledge can enhance teachers' PCK(&S) which they can use to make more deliberate choices in implementing specific strategies during teaching.

CONCLUSIONS

This study provided empirical evidence that a teacher can learn to apply a repertoire of scaffolding strategies for supporting pupils' scientific language development in an inquiry-based science classroom with native Dutch speakers. Patterns in the use of the various scaffolding strategies arose related to the aim and complexity of a specific strategy and to the specific situation during the lesson (i.e., phase of the empirical cycle and teaching approach). Moreover, our study indicated that scaffolding pupils' scientific language development is a complicated process requiring comprehensive knowledge and skills of the teacher. In addition to teachers' PCK, the teacher's skills to apply this PCK in various situations with various pupils (PCK&S) appeared to be of importance. The teacher's PCK&S seemed especially relevant in the inquiry-based context central to the lessons. These lessons are characterized by student directed learning and require in-action responsiveness of the teacher to support pupils to learn the scientific language they need and introduce themselves. The findings of this study provide insight into what can be expected when using this approach in similar conditions at larger scales.

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