Teaching for Scientific Understanding:
A Study of the Effects of Two Methods.

Dania M. Mc Donald

University of Manitoba
Abstract

This study examined the effectiveness of a traditional, teacher-centered, didactic method (the Traditional Approach) and a social-constructivist, inquiry-based method (the New Approach) of instruction for the teaching of physical science concepts in order to improve students’ critical thinking skills. The sample consisted of 46 female, Grade Six students from two classes (23 students in each class) from one preparatory school in Jamaica. Using a repeated measures design that allowed for three testing occasions, the participants within the two classes were equally exposed to both approaches. The dependent variable was the performance on the critical thinking/higher order questions in each of the three non-cumulative term tests. Type of instruction used to teach seventeen lessons of the two units on light and sound was the independent variable. Participants were encouraged to construct concept maps, complete exit-slips, and engage in journal writing. The lessons were video taped. It was found that (1) there was no significant overall difference between the New and Traditional Approach on students’ performance when answering higher order questions on tests; (2) there were significant interaction effects present; (3) the New Approach was more effective at improving the attitudes of students towards science, than the Traditional Approach.
Teaching for Scientific Understanding:

A Study of the Effects of Two Methods.

Introduction

The Educational Policies Commission (EPC) published the *Central Purpose of American Education* in 1961. According to the EPC:

The purpose which runs through and strengthens all other educational purposes – the common thread of education – is the development of the ability to think. This is the central purpose to which the school must be oriented if it is to accomplish either its traditional tasks or those newly accentuated by recent changes in the world…Many agencies contribute to achieving educational objectives, but this particular objective will not be generally attained unless the school focuses on it. (As cited in Marek and Cavallo, 1997 p. 18).

The message of this passage is as relevant for education of children in today’s schools, as it was 42 years ago. According to Marek and Cavallo (1997), the central purpose of every school activity should lead students to develop their thinking abilities. Educators need to help children who represent the future leaders and decision makers of our societies, develop the ability to think logically and use reason in life situations.

Based on a review of 25 prior definitions by Griggs, Jackson, Marek and Christopher, (1998) Renaud, (2000) cites a summary definition of critical thinking as:

A process of evaluating evidence for certain claims, determining whether presented conclusions logically follow from the evidence, and the considering alternative explanations. Critical thinkers exhibit open-mindedness; tolerance of ambiguity; and a skeptical, questioning attitude. (p.9)
This definition illustrates how well the goals of science education, which should be to teach students to think scientifically and the elements of critical thinking coincide. All the components of sound critical thinking are included in scientific thinking (Beisenherz and Dantonio, 1996). The American Association for the Advancement of Science (1990) outlined goals for Project 2061 – goals for science education for the twenty-first century. According to the AAAS:

Scientific habits of the mind can help people in every walk of life to deal sensibly with problems that often involve evidence, quantitative considerations, logical arguments, and uncertainty; without the ability to think critically and independently, citizens are easy prey to dogmatists, flimflam artists, and purveyors of simple solutions to complex problems...The life-enhancing potential of science and technology cannot be realized unless the public in general comes to understand science and to acquire scientific habits of the mind (as cited in Marek and Cavallo, 1997 p. 17).

As discussed in Project 2061 (as cited in Marek and Cavallo, 1997), science teachers are in an ideal position to promote the development of higher-order thinking skills. In prevalent approaches to teaching school science, however, there is a lack of emphasis in developing critical thinking skills. Henri Poincare, French mathematician and physicist, offered this description of science: “Science is built up with facts as a house is built with stones, but a collection of facts is no more a science than a heap of stones a house” (Kelly, 1941, p.240). That students know the facts, concepts, principles, and laws of science does not necessarily mean that they have developed their thinking skills. The Educational Policies Commission (EPC, 1961 as cited in Marek and Cavallo, 1997 p. 20) said the following:

No particular body of knowledge will of itself develop the ability to think clearly. The development of this ability depends instead on
methods that encourage the transfer of learning from one context to another and the reorganization of things learned.

It is the way the content is used and not necessarily the content itself that leads to thinking skills development. Thus, students can learn facts, concepts, principles, and laws of science by directly engaging in science processes that require the use of their thinking abilities. In doing so, students will not only become proficient in the use of their thinking abilities, but will remember and make sense of the associated concept (Marek and Cavallo, 1997). Beisenherz and Dantonio (1996) contend that by practicing the methods of science, students will not only better understand the nature of science and how it works but also develop thinking skills that will increase their ability to solve problems.

Using textbooks as the sole source of science knowledge, and/or telling children about the facts of the world to memorize in order to achieve high scores on standardized tests will not help them to develop thinking skills (Marek and Cavallo, 1997). Neither will modeling science classes on language arts classes where students read the text, answer questions from the text, and then complete worksheets. The focus is clearly on low level cognitive skills (Kyle, Bonnstetter and Gadsden, 1988).

More and more educators have come to realize and recognize that the essence of teaching science is to provide students with opportunities to explore and develop understanding by constructing their own meaning, in an authentic social learning environment. Tobin, Capie and Bettencourt (1988) suggest that science education courses must de-emphasize learning in lectures and texts in favor of more active modes of learning. The teacher’s role in providing such an emphasis is to adopt
strategies to monitor student engagement and understanding. Marek and Cavallo (1997) argue that it is the teacher’s responsibility to provide the special type of learning environment and experiences that promote the development of students thinking skills. Furthermore, Marek and Cavallo (1997) maintain that teaching for rote learning is a grave underestimation of the capabilities of the human mind. Children must use their thinking abilities to construct understandings about the world for themselves. In the process of constructing knowledge, children develop their thinking skills and acquire knowledge that is meaningful to them. The learning and understandings children acquire are much greater and deeper than can occur through rote learning. If science is taught as inquiry and as a process, students will use less rote learning and more thinking processes in the construction of meaningful understandings of science concepts (Marek and Cavallo, 1997).

This study investigated and compared two teaching methods, a traditional, teacher-centered, didactic method (the Traditional Approach) and a social-constructivist, inquiry-based method (the New Approach) to determine which was more effective at improving students’ understanding – ability to think critically – of physical science concepts light and sound. The research question was:

“On comparing the two methods of teaching the concepts of light and sound, which is the most effective at promoting improved understanding of Grade six students in Jamaica?”

The research question was a product of previous teaching experiences. The teacher/researcher expressed dissatisfaction with the teaching strategies previously employed, the Traditional Approach, and sought to change her teaching practice. Major discrepancies were found, involving the actual teaching practice and the goals
of science education. Students were being taught science in a manner that encouraged rote learning, memorization, and regurgitation. The lessons were characterized by the use of lectures, demonstrations, seatwork and recitation. The students could be characterized as being passive recipients of knowledge, comparable to sponges ready to “soak up” science, primarily presented by the teacher/researcher as the compilation of facts.

Such learning directly contradicted the fundamental goals of science: a search for evidence and justification of conclusions drawn from empirical data. Students were not being challenged to ask questions, reflect, or relate their learning to personal experiences, and the ideas of others. As a result, they were able to successfully answer all the questions that required the rote recall of specific information, yet could not even attempt higher-order/critical thinking questions that required them to analyze, synthesize, and evaluate the new information taught.

The New Approach was developed by the teacher/researcher as an eclectic framework, composed of a combination of many other teaching approaches that have been found to be effective in fostering critical thinking. It included the 5E Instructional Model (an extension and elaboration of the Learning Cycle first proposed by Atkin and Karplus in the early 1960’s), Concept Mapping and the Inquiry Approach. The development, evolution, and merit of these teaching approaches has been thoroughly documented by several educators and researchers (Lawson, Abraham and Renner, 1989; Novak and Gowin, 1984; Brooks and Brooks, 1993; Beisenherz and Dantonio, 1996; Trowbridge, L.W., Byisee, E.W. and Powell, J.C., 2000).
This study was significant. Four reasons were considered: The Jamaican context, the school context, the use of an eclectic framework for the New Approach, and the combining of qualitative and quantitative methods.

**Research Design and Methodology**

*Participants and Settings.*

A total of forty six, Grade six students from two classes (25 students in each class) took part in this study. The setting of the study was an all girls, private Catholic Preparatory School situated in Kingston, Jamaica. The students ranged in age from ten to twelve years and came from upper-class and upper-middle class family backgrounds. The students were placed randomly in their respective classes on enrolment at kindergarten (age 4 to 5) and remained in these classes till they completed preparatory school.

The two classes were almost identical (age, family background, financial status, academic achievement, and capabilities of the students) since the school reserved the right to screen students before admittance was granted. There were no special characteristics of these students that required extra measures.

*Methods.*

Quantitative and qualitative methods were employed by this study. The qualitative methods included journal writing, exit-slip completion, concept mapping exercises, and video tapping. The quantitative method involved a split-plot design with the two classes, facilitating three testing occasions.

*Quantitative methods.*

To analyze the results a 2 x 2 x 3 split-plot analysis of variance was performed
There was one between-subjects factor namely the number of classes with two levels, and two within-subjects factors being the types of instruction (i.e. The Traditional Approach vs. The New Approach), with two levels and the testing occasions with three levels. The independent variable was the type of instruction (i.e. The Traditional Approach and The New Approach) used to teach seventeen lessons of the two units on light and sound. Each class stream (class 6C and class 6R) was equally exposed to the two teaching approaches (by alternating the teaching approach that would be used to teach each lesson). Table 1, is a visual illustration of the split-plot design.

At the end of each unit, a uniform test was given, covering all the topics within that unit. Each test consisted of a set number of higher-order and lower order questions, pertaining to each individual topic within the unit (at least one higher-order question per topic). The higher-order questions were worth between five and 11 marks. Therefore, scores ranged from a low of 0 to a perfect score of 26 on test 1, 36 on test 2, and 32 on test 3. The higher-order questions were intended to be more vigorous than lower-order questions. There were a total of three term tests: the first on the Sound unit, the second test on the Light unit, and the third test on a combination of the two units. Both class streams were given the same test at the same time. The dependent variable was the performance on the critical thinking/higher order questions in each of the three non-cumulative term test. Each critical thinking question was in the form of a short answer essay. Each term test contained at least six critical thinking questions with each focusing on a topic covered within the unit. In terms of grading, the critical thinking questions accounted for approximately half of
A Study of the Effects

the marks on each test, with the first two tests worth 25% of the final grade and the third test worth 50% of the final grade.

*Qualitative methods.*

The Qualitative methods used in this study as mentioned previously included: Journal writing, video tapping, the completion of exit slips and concept mapping. The journal writing and concept mapping were both components of the New Teaching Approach. The combination of the two activities gave students multiple opportunities to develop conceptual understanding by integrating practical, hand-on work with peer group discussion, writing and reading (Hand and Keys, 1996).

The concept maps, unscored, were analyzed to determine how well students understood the concept being taught. The journal entries served as an indicator of the level of students' understanding (critical thinking).

The exit-slips were simply sheets handed out at the end of each lesson, with questions designed to encourage the students to document their emotions and personal opinions about what they were being taught.

The video tapping served two purposes: To facilitate the cross-validating of data, and to collect data in the form of students’ social interaction and dialogue within the classroom (i.e. questions asked, peer discussions).

*Enacted Procedure.*

During the first lesson each class stream (class 6C and class 6R) was introduced to concept mapping using the activities and strategies for introducing concept mapping in Grades three to seven, as suggested by Novak and Gowin (1984).

It was explained that the concept maps would be used alternately with the journal
writing at the beginning and ending of some lessons using the New Approach. The students were aware that the teacher/researcher would indicate to them when the concepts maps would be constructed. In the lessons taught using the Traditional Approach journal writing was done once a topic had been completed. Concept mapping was not utilized. Students were also made aware of the three tests that were to be given over the duration of the term. The first pertained to the unit on sound, the second to the unit on light, and the third to a combination of both units.

Both class streams were exposed equally to the two approaches – a total of 17 lessons for the duration of the fall term (September – December 2002). The same content knowledge was taught to each class, on the same day, by the researcher. After completion of every topic, the students were encouraged to make an entry in their journals for homework, documenting what they had learned from that lesson, how well they thought they understood the concept, and how they felt about the way in which the lesson was taught. After each lesson, exit slips were completed by the students and collected by the teacher/researcher for analysis. When the New Approach was employed, the students alternated between writing journal entries and constructing concept maps. Grading of the tests and reviewing the journals and concept maps were the responsibility of the researcher. Reading assignments and homework worksheets were given after every lesson and were graded, but the grades were not be used as data in this study.

Results

Quantitative results.

Within this study, the most relevant main effect was the within-subjects effect
of the type of instruction. Because this factor consisted of two levels, the assumption of circularity was not applicable. Across both classes and all three testing occasions, the mean percentage of critical thinking test questions answered correctly that corresponds to the Traditional Teaching Approach (M = 54.8) was not significantly different from that corresponding to the New Teaching Approach (M = 51.3). Figure 1 shows the mean percentage of correct responses of higher order/critical thinking questions, comparing the Traditional and New Approaches on each testing occasion for both classes. The mean percentages corresponding to the two approaches did not differ significantly on any testing occasion.

Although there was no significant overall difference between the Traditional and New Approaches, significant interaction effects indicate that these approaches differ depending on the class (class x approach, F(1, 44) = 11.6, p < .01) and depending on the combination of class and testing occasion (class x testing occasion x approach, F(2, 88) = 10.5, p < .001).

Figures 2 and 3 show the mean critical thinking test scores of each approach and testing occasion for class 6C and 6R respectively. In class 6C (Figure 2), there was no significant difference between the Traditional Approach (M = 65.2, SD = 32.6) and the New Approach (M = 65.7, SD = 29.4) on test 1, or on test 3 between the Traditional Approach (M = 65.5, SD = 25.3) and the New approach (M = 55.1, SD = 29.3). However, on test 2 the mean percentage score for Traditional Approach (M = 48.3, SD = 18.8) was significantly greater when compared to that of the New Teaching Approach (M = 20.0, SD = 21.7), t(22) = 4.5, p < .001.

In class 6R (Figure 3), there was no significant difference between the
A Study of the Effects

Traditional Approach ($M = 64.8$, $SD = 25.4$) and the New Approach ($M = 56.8$, $SD = 31.5$) on test 1, or on test 2 between the Traditional Approach ($M = 34.8$, $SD = 28.7$) and the New Approach ($M = 43.1$, $SD = 17.0$). However on test 3, the mean percentage score for the New Approach ($M = 67.7$, $SD = 23.8$) was significantly greater compared to that of the Traditional Approach ($M = 50.2$, $SD = 28.5$), $t(22) = 3.2$, $p < .01$.

Qualitative results.

The journal entries indicate that the New Approach had a positive affect on the student’s attitudes, interest, and motivation in science. The following excerpts provide evidence for this claim.

1. Keisha, Class 6C

   a) September 9th, 2002: Sound Unit – Traditional Approach

   Lesson: “What is Sound?”

   Responding to the questions “How do you feel about science?” and “How would you like to be taught science?”

   I think science is the most boring subject and all its about is energy. Hearing that word energy everyday in science class is annoying and most teachers just give notes and chat, chat, chat, like a big blabbermouth, so it gets even more boring and sort of stupid. I HATE science... I would like the teachers to teach science doing experiments and fun activities and to do things that will make us remember the work because when I do fun things I don’t forget it.

   b) October 3rd, 2002: Sound Unit – New Approach

   Lesson: “How do animals hear?”

   Responding to the questions “Did you enjoy today’s class and if so why?” and “Do you prefer being taught science this way [referring to the New Approach] or the old way [referring to the Traditional Teaching Approach]?

   I enjoyed class because we actually saw the ears [referring to the ears of live animals that were brought into the class for observation] and got to pet them. I like it better [being taught] this way because we
don’t have to write notes and we do more experiments. I didn’t like the old way because we had too much notes and we did less experiments.

c) December 3rd, 2002: End of the term
Responding to the question: “What did you like about how you were taught science this term? Tell why.”

Out of all this term, I like the experiments more than anything else because I do not like to write notes or when I have to listen to what the teacher says when she is explaining. It is much better when I see how it happens for myself, with my own eyes, like when we touched the real cow’s eye [referring to an experiment where the students dissected a cow’s eye.]

The exit slips indicate that the students preferred being taught science by the New Approach as opposed to the Traditional Approach. The following excerpts help to substantiate the claim.

1. Tracey: 6C
   September 16th, 2002: Sound Unit – Traditional Approach
   Lesson: “The bouncing or reflecting of sound waves”

   I did not like today’s lesson because it was boring. The lesson was made easier for me to understand…what I mean is I think it could have been more exciting and there should have been more experiments.

2. Roxanna 6R:
   September 16th, 2002: Sound Unit – New Approach
   Lesson: “The bouncing or reflecting of sound waves”

   I feel great about the way the lesson was taught and it [referring to the New Approach] made it much easier to understand, because Ms. McDonald [the researcher] teaches it in such a fun way. I learn science through fun. I love it!

Discussion
The goal of this study was to determine which approach would improve
higher order/critical thinking skills. As suggested by the reviewed literature, the New Approach should have caused a significant improvement in the critical thinking skills of the students. There are many plausible reasons why the New Approach did not have the predicted effects. Four will be considered here: The students’ formal reasoning abilities, the design of the study, the assessment tool used, and critical thinking within the enacted curriculum.

*Formal reasoning ability.*

A probable explanation for the results obtained could have been the failure to test the students’ formal reasoning abilities before commencing the study. Given that the overall performance on the higher order questions appeared to decline from the first to the second test, it is possible that the majority of the students participating in the study did not possess the level of formal reasoning necessary to answer the higher order questions on the tests, whatever the teaching approach experienced. It is interesting to note that the majority of students performed well on the lower order questions and most passed those sections on all three tests.

*The design of the study.*

The very design of the study must be scrutinized with respect to explaining the results obtained. The split-plot model allowed each class to experience both teaching approaches equally. One can argue, that the students simply “caught on” to the patterns established in the classroom and on the first test. Without being told, they understood that there would be a section higher order questions on each successive test. Regardless of the approach used to teach a particular lesson, the students may
have altered their studying patterns to ensure that they would perform well during lessons and assessments.

There is, as well, the likelihood that students in 6C shared their experiences with the students in 6R, and vice versa. The close proximity of the classrooms and an opening in the partition separating the two rooms near the ceiling (to facilitate ventilation), allowed the students in one class to hear clearly what was being taught to the other students in the adjacent classroom. The students of 6C could also see through windows and horizontal openings in the walls of the classroom, the outdoor activities in which the students of 6R were engaged while experiencing the New Approach. They often asked why they weren’t having the same experiences when taught by the Traditional Approach. Similarly, the students in 6R would question the unique outdoor activities experienced by 6C. Such observations, as well as interclass conversations and interactions, would tend to obscure the foci that the split-plot design required be kept discreet.

*The assessment tool.*

The type of assessment tool chosen to measure higher order/critical thinking may be a third reason why no significant difference was observed. Critical thinking is not only a skill; it is a skeptical, questioning attitude as well. When the tests were created, the assumption was made that students taught specific topics using the New Approach would be better equipped to correctly answer higher order/critical thinking questions based on those topics, when compared to students taught the same topic using the Traditional Approach. However, the section C test questions were the only measure of critical thinking skills. It could be that students unable to answer correctly
in writing, may have done so in post-instruction interviews. In addition, there was no assessment of affective aspects of critical thinking – particularly students’ attitude to science.

*Critical thinking and the enacted curriculum.*

Although there were differences between the New Approach and the Traditional Approach, the New Approach as experienced by the students in 6C and 6R was not the constructivist/collaborative model discussed in the reviewed literature. It was clearly understood before the study began, that the Learning Cycle model was a framework for teaching and not a recipe. The researcher/teacher was aware that it could be applied differently; that the application depended on a number of factors including the beliefs and values of a teacher, the needs of students, and available time and resources. Consequently, there were instances when features of the New Approach, as enacted, departed from the core elements of the 5 E Learning Cycle model as described by Trowbridge, Byisee and Powell (2000). Such departures could possibly explain why students after being taught a lesson using the New Approach, were unable to correctly answer many of the higher order/critical thinking questions in section C of the tests.

Although there was no significant overall difference between the Traditional and New Approaches, significant interaction effects indicate that these approaches differed with respect to the class (6R or 6C), and with respect to the class and testing occasion. A plausible explanation for these interaction effects could be the different cognitive styles of the students. No testing to determine the cognitive styles of the students was done before the study commenced. The effect of the
A Study of the Effects

different cognitive styles was not considered as a factor in the design of the study and no allowances were made. The decline in performance of all students on the higher order/critical thinking questions given in the second test on the light unit of the syllabus suggests that the content material itself may have been developmentally inappropriate.

That the New Approach improved students’ attitudes toward science were of no surprise, as numerous researchers have reported similar findings. Kyle, Bonnestetter and Gadsden (1988) reported overwhelming data supporting the greatly enhanced attitudes toward science by students in inquiry-oriented, process-approach science classes, when compared with students in traditional classes. The data from their study indicated that students preferred a process-approach science that more closely matches real science versus the traditional textbook-oriented science that more closely resembles the Language Arts (Kyle et al., 1988).

Conclusions and Implications

Conclusions from this study suggest that even though there was no significant overall difference between the New and Traditional Approach on students’ performance when answering higher order questions on tests, significant interaction effects found. The approaches differed significantly when an approach by class (6C and 6R) test was performed. The approaches were also found to differ in the three way interaction: test by approach by class. Some limitations of these data need to be pointed out. The students’ formal reasoning ability and cognitive styles were not measured or identified before the study commenced. It would seem that with regard to certain learning outcomes in science, students’ response to a given type of
A Study of the Effects

instructional approach could be significantly influenced by their intellectual
development (Mulpo and Fowler, 1987). Knowledge of the learners’ cognitive levels
and styles might therefore be useful to researchers seeking to establish the merits of
the traditional and inquiry-based, active learning methods.

It is also suggested that replication studies be undertaken over a longer period
of time than was available for the present study. It might be possible for students to
adjust to a new instructional approach when given sufficient time. Similar studies
should be conducted with better control of extraneous variables. Observations, as well
as interclass conversations between the students of 6C and 6R, for instance, could
have been minimized by choosing an alternative research design to expose both
classes equally to the two approaches.

The New Approach was found to be more effective at improving the attitudes
of students towards science, than the Traditional Approach. Some limitations of these
data however, include the fact that the affective learning (attitude improvement) was
mostly self-report data. No instrument was used to measure the attitudes of the
students’ before the study commenced or after it was completed so that quantitative
data could be obtained to further substantiate the claims of improvement. The
findings, therefore, may be positively biased.

Based on the experience and data from this study, it is suggested that
traditional institutions need to implement more supervised teaching experiences using
structured inquiry before allowing a teacher to begin implementing inquiry-based,
active learning approaches in classrooms. The inexperience of the teacher/research
affected the enacted curriculum and possibly the findings obtained.
References


