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INTRODUCTION

One of the common themes that is heard frequently in circles which deal with educational issues is that of a focus on all students. This is especially true in the case of science education, where the theme is usually referred to as ‘Science for All’ (American Association for the Advancement of Science, 1989; Ministry of Education and Training, 1995, 1998, 1999; Hodson and Reid, 1988). Hodson and Reid (1988) state that this phrase is to be interpreted as providing the same science curriculum for all children regardless of difference of race, gender, social origins or intellectual attainment. This would imply that at the same time as offering universal scientific literacy for everyone and raising the minimum level of scientific attainment for all, the scientifically gifted should be presented with high expectations which will lead to a high standard of attainment. De Boer (2000) calls for a broad and open-ended approach to scientific literacy that would free teachers and students to develop a wide variety of innovative responses. Elsewhere, Hodson (1998) states that the type of scientific literacy he would like to see pursued in the schools would have the “central goal ... to equip students with the capacity and commitment to take appropriate, responsible and effective action on matters of social, economic, environmental and moral-ethical concern.” Hodson continues by listing three major elements of the ‘critical scientific literacy’ defined above. These elements would include:

- learning science
- learning about science
- doing science

While all three elements of ‘critical scientific literacy’ remain as important issues involved in this central goal of science education, due to limitations in space, the remainder of this paper will focus on the middle element - learning about science - as a rationale for the promotion of more authentic professional science and the final element - doing science - using correlational studies as a means of providing students with additional scientific procedures as they expand their scientific repertoire.

Nature of Science (NOS)

Typically, nature of science (NOS) refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge. These characterizations nevertheless remain fairly general, and philosophers of science, historians of science, sociologists of science, and science educators are quick to disagree on a specific definition for NOS. Such disagreement, however, should not be surprising given the multifaceted and complex nature of the human endeavour we call science. These conceptions have changed throughout the development of science and systematic thinking about its nature and workings (Abd-El-Khalick & Lederman, 2000). For example, McComas, Clough & Almazroa (1998) defines NOS as a phrase describing the scientific enterprise for science education and includes areas such as history of science, philosophy of science and research from cognitive sciences, including psychology. According to McComas, NOS addresses two areas of major concern - understanding the institution of science and understanding the practice of science. A consensus view of NOS objectives, as identified in eight international studies, include:

- Scientific knowledge has a tentative character
- Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments and skepticism
- There is no one way to do science
- Science is an attempt to explain natural phenomenon
- Laws and theories serve different roles in science, therefore students should note that theories do not become laws even with additional evidence
- People from all cultures contribute to science
- New knowledge must be reported clearly and openly
- Science requires accurate record keeping, peer review, and replicability
- Observations are theory-laden
- Scientists are creative
- The history of science reveals both an evolutionary and revolutionary character
- Science is part of social and cultural traditions
- Science and technology impact each other
- Scientific ideas are impacted by their social and historical milieu

The goal of helping students develop adequate conceptions of NOS has been agreed upon by most scientists, science educators, and science education organizations during the past 85 years. At present, despite their varying pedagogical or curricular emphases, agreement among the major reform efforts in science education (American Association for the Advancement of Science, 1989, 1993; National Research Council, 1996) centres on the importance of enhancing K-12 students' conceptions of NOS. However, the achievement of this long-espoused goal has been met with little success. Research has consistently shown that students' NOS views are not consistent with contemporary conceptions of the scientific endeavour (Akerson, Abd-El-Khalick & Lederman, 2000).

Not all practitioners and academics have jumped on the bandwagon for NOS inclusion. Matthews (1998) states that the unrestricted use of NOS in science and technology courses would amount to the indoctrination of students since teachers like people to believe what they believe (as do most people). Abd-El-Khalick & Lederman (2000) sound a similar warning note that explicit teaching of NOS may impose certain views of the scientific enterprise. Matthews (1998) suggests that efforts must be made to offer a variety of alternative positions and Roberts (1988) concurs in that "different curriculum emphases are possible and that a particular view of what counts as science education (must be) selected from an array of alternatives."

A wide variety of methods of enhancing and deepening student understanding of NOS issues are suggested in the literature. Open-ended practical work of all kinds garnered much support. One set of authors, Duveen, Scot & Solomon (1993) indicate that explicitly teaching NOS in science courses for students can be accomplished using interviews, questionnaire responses and action research. Other authors contend that open-ended, problem-based, practical, hands-on activities supported by teachers with procedural knowledge (within context) specifically targeted would be best to teach NOS (Watson, 2000; Hodson, 1982; White & Gunstone, 1992; Gott & Duggan, 1996; Lock, 1990; Woolnough, 2001).

Since educators are calling for a more authentic portrayal of professional science in classrooms, the authors of this paper feel that this can be accomplished using open-ended investigations; that is, those in which conclusions are not planned and determined by the teacher. While most students have been exposed to 'experimental' procedures, as illustrated in most elementary and secondary science textbooks, these procedures are usually the sole scientific methodologies portrayed. It is proposed that additional scientific methodologies, such as studies and inventions, should be taught to students. The remainder of this paper suggests how an additional scientific procedure could be introduced into the school science repertoire.

Correlational Studies

Students often conduct experiments to gain evidence for laws and theories but, unlike practicing scientists, seldom conduct studies (Ross & Cousins, 1993). A "study" involves observations of variables as they change naturally, while an experiment involves forced changes in a variable. *Correlational* studies, meanwhile, monitor and compare changes in possible causes and results. Scientists could compare incidence of AIDS symptoms with natural levels of HIV virus, for example. This would be more *ethical* than purposefully injecting people with possible pathogens. There are also many practical reasons for studies. Other examples of situations where studies are a viable alternative to experiments could be: studying the various effects of aging using people of various ages than to force aging or determining the effects of diet on the incidence of heart disease.

Schools' preference for experiments seems to be based, in part, on their tendency to cast professional science in its best possible light so students choose careers in science and technology (Apple & Jungck, 1992). Since the teacher furnishes the questions, hypotheses, methods, and conclusions, there is little that is experimental about these "experiments". In effect, they are designed to guide students down an expedient pathway to scientific enlightenment without the nuisance of unanticipated detours that scientists took while conducting research (Abrams & Wandersee, 1995). This indoctrinating function of school science may be easier with experiments than with studies due to difficulties relating cause and effect (Bencze, 1996). If professional science is to be more fully represented, classroom procedures must include correlational studies.

R&D METHODS

In action research aimed at developing a more authentic science curriculum for secondary schools (Bencze, 1995), we collaborated over two years to determine the feasibility of student-directed, open-ended correlational studies in secondary schools (in and around Toronto, Canada). A number of teachers and a researcher/facilitator planned and carried out a variety of classroom interventions intended to encourage students to use alternative scientific procedures. Conclusions were based on records of discussions (involving teachers, mostly ninth grade students, and a researcher), samples of their work, records of their journal entries, and teachers' repertory grids. Steps were taken to ensure trustworthiness of conclusions (Guba & Lincoln, 1988).

PROCEDURAL LESSONS

We used a constructivist approach involving: i) Reflecting: We encouraged students to become more aware of their own attitudes, skills, and knowledge (ASK); ii) Learning: We challenged students to compare their ASK with those of professionals (e.g. scientists) and peers; iii) Evaluating: We encourage students to construct (develop) new ASK based on open-ended tests of their design.

Reflecting

After students have developed ASK regarding experimentation, teachers may ask them to analyze news articles reporting studies. They may focus on such design features as control, replication, and - especially - reason(s) for changes in independent variables. Alternatively (or additionally), the teacher could ask students how they would test cause-effect relationships involving ethical or practical issues. For example, how would they test effects of cigarette smoking on athletic performance? Given students' answers justifiably will vary, evaluation of these activities should only involve assessment of *effort*.

Learning

Before showing students how scientists conduct studies, they should be encouraged to share with peers their ASK in this regard. While again evaluating students efforts, teachers should emphasize legitimacy of their varied ASK with respect to studies.

To help students gain more expertise with studies, teachers may organize a series of sample studies in which direction of methods is gradually transferred from teacher (TD) to students (SD). These studies should be *open-ended* (OE) to simulate authentic science, and deal with *familiar* topics so students can focus on procedures. Topics should also *differ* from those of the course unit so that students eventual tests of conflicting ideas in the unit are not affected. For example, in a unit relating to the particle theory of matter a TD&SD/OE study could be negotiated involving affects on tooth decay of amounts of soft drink consumed. Or, students' resting heart rate may be compared to age, gender, sleep time, weight-height ratio, etc. Students could also be given databases of pre-measured variables (e.g. about planets) and asked to hypothesize possible correlations between variable pairs.

To facilitate this work, and to allow students to focus on study methods, computerized databases and graphing programs should be used. Students should be able to perform the tasks with and without these aids, however. It is especially important they gain comfort in drawing lines of best fit for the data and judging correlations on the graphs that are produced.

With more practice, students should be held more responsible for specific aspects of study design and evaluation of results. We have used the checklist in Figure 1 for these purposes. A more detailed discussion of these design features will be included in a future article.

Figure 1: Design Features for Studies and Experiments

Test Design Factors for Studies & Experiments

- ❑ make sure you have many different values (amounts for the possible cause variable
- ❑ control the tests; ensure other possible cause variables do not alter results
- ❑ make sure you have several copies of each value (amount) being tested
- ❑ use measurements of all variables, wherever possible
- ❑ repeat each measurement and report the average of the two
- ❑ measure at least one more comparable possible result variable
- ❑ make qualitative descriptions of possible cause and result variables

Evaluating

Ultimately, students should perform SD/OE studies testing conflicting ideas (where ideas exposed in the reflecting portion conflict with those in the learning portion) in each course unit. At the same time, they should evaluate the study methods they chose, with assistance from peers as they debate each others' conclusions. The presentation of conclusions can be done in a number of ways, however in our experience it helps to split the students into small groups (especially if the members represent studies using similar variables) and each member is expected to present their findings to the others. Small groups of five or six students tends to encourage more discussion.

OUTCOMES

Despite having little formal experience with studies in the past, teachers felt most ninth grade students learned to conduct OE studies on topics familiar to them (refer to Figure 2).

Figure 2: Typical Study Topics

Cause Variable (Effects of ...)	Result Variable (... on amounts of ...)
type of food	body weight
acne removers	acne
melatonin (cortical steroids)	handedness
apple type	alcohol content
gender	lung capacity
amount of exercise	blood pressure
mass/height	blood pressure
concentration of automobiles	acid content of rain

Students expertise in attending to factors in Figure 1 generally increased throughout a course and as they practiced these methods in successive school grades. An outline of one study representative of the majority of ninth graders is given in Figure 3.

Figure 3: Typical Ninth Grade Students' Study

Title: **The effect of scented Perfumes and Strong Aromas**

Causal Question: What is the effect of scented perfumes and strong aromas on the severity of headaches?

Cause Variable: different types of scented perfumes

Result Variable: severity of headaches

Hypothesis: When a large amount of a strong chemical scient is inhaled, directly or indirectly, the subject will get a different degree of headache because the chemicals affect the nasal passage which then brings about the headaches.

Survey Form:
Subject Number: ______________

Age: _______ Gender: Male/Female

1. Do you use any kind of perfumes? Yes/No
2. What brands of perfumes do you use frequently? _____________________________________
3. Where do you put the perfumes on your body? _____________________________________
4. Do you come in contact with any other strong aromas? Yes/No
5. If yes for #5, state the name of the aroma: __________________
6. Do you get headaches due to strong smells or perfumes? Yes/No
7. Are the headaches severe? Yes/No

Data Chart:

Subject #	Age	Gender	Q1	Q2	Q3	Q4	Q5	Q6	Q7

In discussing studies with students, they appeared to have a reasonably good grasp of the mechanics, and pitfalls of this test type (refer to Figure 4). As well, as indicated in Figure 5, conducting them seemed to bring considerable motivation and satisfaction.

Figure 4: Students' Stated Understandings of Studies

> "Correlational studies show many things in terms of scientific ideas. They show how natural situations affect a controlled situation. They show how difficult it is to gather random data and have an accurate conclusion. Finally, they prove or disprove theories in a valid, scientific manner."
>
> "You do correlational studies because you are interested in finding out how one thing affects another. By using this data, you can discover trends and also apply your findings to reality."
>
> In using correlational studies "you have to be able to control as many things that may affect your variables."

Figure 5: Students' Stated Attitudes towards Studies

> "I feel correlational studies are very useful. For example, you could use them if you were going to market a product. You could use them as evidence in another type of report or project. You could use them to become more aware of your environment. Since correlational studies are generally easy to conduct, many people are able to use them, and understand them."
>
> "A correlational study means to me that I can do a scientific study without having to harm another human or creature. It won't cost a lot of money, and it is easy to do."

On the other hand, this success was limited by a number of factors (Bencze, 1995). Due to the extra time inherent in reflective, SD/OE investigative work of this type, teachers real and perceived freedom to sacrifice some course "content" was a major limiting factor. It took a special sort of teacher; one who was comfortable allowing students to try different methods, make mistakes, and arrive at conclusions not necessarily congruent with scientific ones. Even then, it was crucial - especially for teachers unfamiliar with studies - to collaborate in curriculum development and in assisting students project work. Action research with a heterogeneous group of educators challenging and supporting each other seemed to help.

Conclusions

In the promotion of 'critical scientific literacy', the inclusion of NOS issues allows students to develop a more authentic understanding of professional science practices and limitations. Since professional science uses a variety of methodologies students should be given the opportunities to learn different methodologies and apply them to their learning. Helping students to develop ASK with respect to correlational studies and then conduct OE studies of their design on topics of interest to them appear to be potentially feasible and rewarding components of secondary school science. Students can develop significant procedural expertise in this regard and learn much about the nature of scientific practice in general. Topics amenable to study (vs experimentation), and the relative ease and low cost of procedures, appear to be motivating for students. The use of computers in collecting and graphing the data seemed to add to the appeal of this method. We recommend more teachers consider incorporating studies into their programs.

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