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Incorporating Critical Thinking Into a Regular High School Biology Curriculum

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Introduction

Critical thinking has been defined as "suspension of judgement" (Mcpeck, 1981), as "the correct assessment of judgement" (Ennis, 1982) and as "reasonable reflective thinking focused on deciding what to believe or do" (Ennis, 1989). The third definition is more recent and more comprehensive and is used in this article. The development of critical thinking has been regarded since ancient times as one of the major aims of education (Resnick, 1987). Yet, studies have revealed time and again that quite often students fail in tasks which require critical thinking (Jungwirth, 1985; Jungwirth & Dreyfus, 1990). Moreover, students who had studied the new inquiry-oriented science curricula of the 1960s performed as poorly as their traditional counterparts (Shuman & Tamir, 1973). It appears that critical thinking does not develop in passing but rather explicit and deliberate efforts are needed in order to develop it. Indeed, the results of several studies indicate that learning experiences explicitly designed to develop reasoning skills achieve their goal to various degrees (Friedler & Tamir, 1986; Kaplan, 1967; Pappalis, Pohlman, & Pappalis, 1980; Reif & St. John, 1979; Wheatly, 1975).

Educators have been and are still debating on the best approach for enhancing the development of reasoning skills. Two major unresolved issues in this debate are: (a) to what extent reasoning skills are general, content-free or, rather, subject matter and concept specific abilities and (b) the extent to which and the circumstances under which transfer of critical thinking takes place. The answers to these questions have significant implications for instruction. The major dilemma is whether special courses should be designed for teaching thinking skills as implied by the general approach or, instead, infuse the development of thinking within regular disciplinary courses (Ennis, 1989; Mcpeck, 1981; Resnick, 1987).

Perkins and Salomon (1989) have reviewed the debates and disagreements along with pertinent research and concluded that the truth lies somewhere in the middle. Critical thinking, like other reasoning skills, has at the same time both general and content dependent attributes. Since the regular school curriculum is already overcrowded, they predict that "wider scale efforts to join subject matter instruction and teaching of thinking will be one of the exciting stories of the next decade of research and educational innovations" (p. 24).

Several examples of projects that were designed according to the general approach are Philosophy for Children (Lipman, 1985), Crt (De Bono, 1985), and Odyssey (Dominguez, Hernstein, Nickerson, Swets, & DeSa"anchez, 1986). Similarly, various projects have been designed according to the infusion approach. One of the disciplines in which such projects have been uttered is biology (Jungwirth, Dreyfus, & Amir, 1986; Moll & Allen, 1982; Novak & Dettloff, 1989; Stakievič & Allen, 1983); however, routine use of specially designed activities has yet to be realized.

This article describes the rationale and activities developed and trialled by a project entitled Biology Critical Thinking (BCT). The BCT project aims at developing a pool of activities which can be incorporated within the regular course of study without investing too much extra time (Meyer, 1987).

Purposes of the Study

The purposes of the study were:

1. To present the rationale of the BCT project.
2. To describe an example of a BCT activity and the responses to it in the classroom.
3. To report the results of a pilot study that examined the feasibility of implementing some BCT activities.

Design and Procedures

Guidelines

The following guidelines have been adopted by the BCT project:

1. Critical thinking activities will constitute an integral component of the regular curriculum. No attempt is made to develop a new biology curriculum.
2. In order to enhance transfer, the same skill should be applied in many occasions and in a variety of contexts.
3. The activity will include metacognitive discussions of the particular reasoning skills and how they were used.
4. The time devoted to the activity should be reasonably
short, so that other instructional goals will not be deprived.

Skills

As a first step the following 10 skills (abilities) were selected as goals of the BCT:
1. Distinguish between findings of an experiment and conclusions made on the basis of the findings.
2. Draw valid conclusions from given data.
3. Identify and evaluate controls.
4. Design adequate controls.
5. Identify explicitly and hidden assumptions.
6. Determine logical fallacies such as jumping to conclusions or overgeneralizations.
7. Tautology.
8. Isolating variables.
9. Testing hypotheses (hypothetic reasoning expressed as "if ... then . . .").

Examination of the above list shows a partial overlap with scientific inquiry skills (Schwab, 1962; Shulman & Tamir, 1975; Tamir & Lunetta, 1978). This is not surprising. One the one hand, according to the infusion approach, critical thinking in each knowledge domain is specified by the knowledge structure of the pertinent discipline. Different subjects have different types of good reasons and of evidence. What counts as a good reason in law, might not be acceptable as good reason in mathematics or in science (Mepeck, 1981). Scientific knowledge grows by the process of scientific inquiry. It follows that, in order to be able to think critically about scientific knowledge, it is necessary to understand the process by which scientific knowledge is created. No wonder that some of the critical thinking skills such as the first four in the list above will also be found in any list of scientific inquiry skills. The ability to draw valid conclusions for example (skill 2 on the list) is one of the basic skills to be found on every list of general critical thinking skills. Thus, it appears that some scientific inquiry skills are closely related to some scientific critical thinking skills. Nevertheless, the two kinds of skills are not identical and each deserves attention and treatment on its own rights.

Topics

The second step following the selection of skills was to identify topics included in the regular biology curriculum which lend themselves to BCT activities (e.g., digestion). The final product of these two steps was a matrix of specific content areas matched with the ten skills.

Activities

The third step involved the development of the activities indicated by the matrix. The time needed to complete those activities ranged between three minutes and two and a half periods.

Sample

The pilot study involved 77 ninth-grade students comprising four study groups. Two groups studied the regular biology program taught by an experienced teacher of high reputation. The remaining two groups were taught by the researcher. Only the last two groups performed the BCT activities. Both groups used the same textbook. No extra time was allocated to the BCT groups. The BCT activities lasted five months.

Instruments

Three tests were used:
1. Cornell Critical Thinking Test, Form Z (Ennis, 1961). This test was divided into two matched halves. One half was used as a pretest and the other half was used as a posttest. The hypothesis was that on the posttest, there would be no significant difference between the two treatments because: (a) the skills assessed by Cornell Critical Thinking Test are partially different from those taught by the BCT project and (b) as yet it has not been shown that critical thinking skills transfer from one content domain to another. Cornell Critical Thinking Test, Form Z, was used because of its established validity and reliability as a measure of general critical thinking ability. It was important to ascertain that the experimental and comparison groups did not differ from each other in their entry reasoning ability. Another reason for using this test was to see whether some transfer might have taken place from the content specific BCT activities to the more general critical thinking performance.
2. The second test was developed specifically for the study and was designated the Critical Thinking Application Test (CAT). The CAT evaluates performance in the 10 reasoning skills listed above. The tasks in this test are similar in structure to the BCT activities but deal with different and unfamiliar content. It was used as a posttest only to avoid any effect of the pretest on the performance on the posttest.
3. The third test considered of eight multiple choice knowledge items that were incorporated into the regular biology midterm examinations covering the topics represented in BCT.

Results and Discussion

The results are reported in two sections. First, a typical activity is described, and second, the results of a pilot evaluation study are reported.

The Vitamins Activity

While studying about vitamins, the students were introduced to an activity called "The importance of vitamin B." This activity was based on a description of an experiment, which
investigated the influence of vitamin B on the heartbeat rate of mice. When one group of mice was given food with no vitamin B, their heartbeat decreased as a function of time. The conclusion presented was that vitamin B is necessary for maintaining the normal heartbeat rate. Obviously, this conclusion is not valid since the experiment lacks an adequate control. Part two of this activity was designed to let the students become aware of the problems that might arise from the lack of control. The students had not been familiar with the concept prior to this activity. The text for this activity is:

When the scientist told his friends about his conclusion, one of the friends argued that this conclusion was not necessarily valid because the experiment had been conducted in January; hence, it was possible that the heartbeat rate decreased as a result of the cold and not because of the lack of vitamin B. Another friend argued that since 10 days after the onset of the experiment, the laboratory was sprayed with a strong poison against insects, the poison might have caused the decrease in the heartbeat rate of the mice.

1. What do you think? Which of the scientists is right? Explain.
2. Following are a number of suggestions for additional experiments. Please mark the experiment that the scientist has to perform in order to defend his conclusion against the claims of his friends. Explain your choice.
   a. Repeat the experiment in a warmer month (e.g., July).
   b. Repeat the experiment but make sure that the laboratory will not be sprayed during the experiment.
   c. Repeat the experiment with two groups of mice. Group A will get regular nutrition, and Group B will get nutrition with no vitamin B.
   d. Restore vitamin B to the diet of the mice and examine whether their heartbeat will return to normal.

To perform the task the students worked in small groups. The students got involved in hot debates, and a variety of answers were offered. After about 20 minutes, the teacher switched to a whole class discussion. Only towards the end of the lesson was the concept of control introduced and defined.

About four weeks later, during which the concept of control had not been mentioned, the class learned about digestion and discussed the role of an enzyme found in the saliva. The students performed the following experiment:

Each group received two plates with agar that contained starch. Wet bean seeds were cut into halves and placed on the starch-agar in plate 1 for about 20 minutes, after which the seeds were removed. Now Lugol was poured in both plates (see Figure 1).

Figure 1. Results of starch digestion enzyme experiment.
After iodine was poured on the starch agar, the agar (which was initially white), turned purple.

Plate 1. There are white spots where the bean seeds had been.

Plate 2. The whole plate turned purple.

Having examined plate 1 and describing what they saw, the students were asked to explain the results. Some of the students explained that the enzyme in the seeds digested the starch in the places where the seeds touched the agar, and this resulted in white spots following the treatment with Lugol. One of the students then raised her hand and asked, "How do we know that this is indeed what happened? Perhaps whenever Lugol is added to starch-agar plate some white spots appear?" The teacher redirected the question to the rest of the class. Most of the students raised their hands to reply. Responses included:

Lisa: This is exactly the same as with group 2 in the experiment with the vitamins and the mice.

Yifat: But the reason we had plate 2 as a comparison was to answer such questions.

David: Because plate 2 was identical in all conditions to plate 1 except the examined factor which is the
Critical Thinking

It is worth noting that most students remembered the one experience they had had with control four weeks earlier and were able to transfer their knowledge from one biological context (the experiment with the mice and vitamin B) to a different biological context (the experiment with the starch-digesting enzyme). Analysis of the responses of individual students revealed that each student remembered things differently depending on his or her prior knowledge and cognitive level of development.

Yifat, an average student, was able to generalize and identify the aspect of comparison which is the essential element underlining the concept of control.

David, one of the brightest students in the class, identified control with all its characteristics even though the term control was not mentioned.

Interestingly, although most of the students showed varying degrees of understanding of the concept control none mentioned the word. Having realized that, the teacher asked, "How would you call the role of plate 2 in the described experiment?" None of the students remembered. Only when they were asked to open their notebooks and look at the summaries they had written four weeks earlier, did they remember and began to use the word control in their replies.

This case illustrates the gap that might exist between knowing the name of a concept and understanding the meaning of that concept. It also relates to the debate whether the names of the reasoning skills should be taught? Is it important, for example, to teach the terms tautology, isolation of variables, logical fallacies, or overgeneralization? The case described in this study indicates that insisting on teaching such terms may not be necessary since a reasoning pattern might be operational even though the formal term representing it is not known. Introducing the formal terms may be useful but, at the same time, can impose a burden on the working memory. Further research is need to provide guidance in this matter.

The Comparative Evaluation

Table 1 presents the results of the different tests. The experimental and comparison groups showed similar results in the pretest (mean scores of 53.6 and 53.1, respectively), indicating that the two groups were equal before the treatment in their general critical thinking abilities. Further support to the equality was provided by the practically identical results obtained in the second half of the Cornell Critical Thinking Test used as the posttest (mean scores 49.5 and 49.8, respectively). These posttest results also indicate that the treatment had no effect on general critical thinking performances.

On the other hand, the mean score in the CAT posttest was 59.9 and 31.4 on the experimental and the comparison groups, respectively. This difference was found to be statistically significant (t = 5.9, p < 0.001). The scores of the experimental group were higher than those of the control group in each of the test's 14 items. Large differences between the two groups were found in items concerning designing control in experiments, isolation of variables, tautology, and hypothetical reasoning.

| Table 1 |
| Mean Scores of the Experimental and the Comparison Groups in the Four Tests |
| | Experimental (n=39) | Control (n=38) |
| | Mean | SD | Mean | SD |
| Cornell pretest | 53.6 | 11.4 | 53.1 | 14.5 |
| Cornell posttest | 49.5 | 13.7 | 49.8 | 16.1 |
| CAT | 59.9 | 20.5 | 31.4 | 18.1 |
| Knowledge | 89.1 | 6.9 | 74.8 | 28.1 |

It may be concluded that it is possible to complete both the regular curriculum and the BCT activities in the allocated time. No significant differences were found between the mean scores of the two groups in the knowledge test (89.1 and 74.8 in the experimental and comparison groups, respectively). This result indicates that the time devoted to the BCT activities in the experimental group was not at the expense of acquiring knowledge. The data show a trend towards a higher knowledge gain in the BCT group in spite of the allocation of time to the BCT activities.

Based on the results of this small scale pilot study, it may be concluded that infusion of BCT activities into the regular biology curriculum is feasible, does not require additional time, does not decrease knowledge gain, and at the same time, substantially enhances performance on subject matter specific critical thinking tasks. It is possible that if BCT activities will be used over a larger period of time and in a variety of contexts, some transfer may occur to reasoning beyond the domain of biology.

Although the groups differed on the posttest it could be argued that this was due to pre-existing ability rather than the BCT. Whereas this claim cannot be definitely rejected since no CAT pretest had been administered, the general similarity between groups in general reasoning as well as the careful random assignment of groups to treatment make this alternative interpretation very unlikely.

Conclusions and Implications

The present study may be regarded as a small step in the direction of developing reasoning skills through activities
which can be readily incorporated into the regular school curriculum by the majority of classroom teachers.

The results indicate that BCT is a feasible approach which yields positive outcomes. The advantages of this approach include the following: (a) it does not distract the teacher from other educational goals, (b) it does not require the investment of more time in a particular topic, and (c) it does not demand special teaching skills on the part of the teacher. What is required is a conviction that it is important to enhance the development of reasoning skills, a repertoire of BCT activities matched to different topics, and the inclusion of some tasks which involve critical thinking in the regular class tests. Further studies, on a larger scale, involving more BCT activities, more teachers, more students, and larger periods of time, are needed before more detailed guidelines can be worked out and before more accurate expectations can be formulated.

References


Footnote

1BCT activities are available to interested readers in Hebrew at the Israel Science Teaching Center, Hebrew University Jerusalem. The only activity available in English is the Vitamin Activity included in this article. During the year 1991, a number of teaching workshops were conducted to guide teachers in the use of the activities. At the same time other activities, in several topics, have been developed. The authors will have the activities translated into English and made available to anyone who may wish to use them.

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