Result or conclusion? Students' differentiation between experimental results and conclusions

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1 author:

Anat Zohar
Hebrew University of Jerusalem

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RESULT OR CONCLUSION? STUDENTS' DIFFERENTIATION BETWEEN EXPERIMENTAL RESULTS AND CONCLUSIONS

Can students differentiate between experimental results and conclusions while learning biology? This study analyzes students' difficulties and discusses possible explanations regarding the source of this problem

Abstract

Science curricula often require students to collect, record, and describe experimental observations and results, as well as to draw conclusions. The first purpose of this study is to document and analyze students' performance regarding the differentiation between results and conclusions, while they are engaged in scientific investigations within biology classrooms. The second purpose is to describe and analyze teachers' thinking regarding this issue. The findings show that while learning biology in school, students often have difficulties in differentiating between experimental results and conclusions. Although teachers were highly aware of their students' difficulties, and held a rich set of ideas about the sources of those difficulties, the instructional means they used were insufficient. Two hypotheses are suggested as the source of students' difficulties. Further research is needed to investigate those hypotheses and to formulate recommendations for improved instructional means.

Key words: Students' reasoning, Inquiry skills, Results and conclusions.

Introduction

An underlying assumption in teaching science through inquiry is that children should acquire scientific knowledge through procedures similar to those employed by scientists. This is achieved by performing experiments which provide evidence to support or reject hypotheses regarding particular theories. Stages of experimentation include formulations of objectives and hypotheses, designing experiments, collecting and recording data, and drawing conclusions. The role of data is to serve as evidence at the stage of making inferences regarding theories. Such inferences are usually formulated as conclusions from experiments.

Recording experimental results and drawing conclusions are thus two distinct components of scientific investigation. Skills which relate to those components appear in numerous taxonomies of scientific process and inquiry skills (e.g. Burmester, 1952; Tamir, Nussinovitz, and Friedler, 1982; TIMSS, 1992). Many curricula require students to collect, record, and describe experimental observations and results, as well as to draw conclusions. However, students often become confused between those two stages of scientific experimentation.

Such a confusion undermines students' ability to construct coherent scientific explanations.

Solomon, Duveen, and Hall (1994) noted a difficulty that many students had in distinguishing between 'describing an event', and looking for the causal mechanisms which would enable them to 'explain' it; e.g. leaves fall off trees 'because they turn red and brown'. This phenomenon was quite general appearing in physics and chemistry as well as biology. However, when students were asked to describe a school experiment which helped them to understand a scientific theory, only very few students (7 per cent) chose to describe a biological experiment. This finding, as well as several writers' arguments regarding differences between biology and other sciences, led Solomon el al. to ask whether theory and its causal relation to evidence are different in biology than in other sciences. The experimental work of Solomon and her colleagues provided some evidence for a difference between models in physics and chemistry, which are manipulated to provide causal explanations, and the systems-in-context kind of description which is more common and valuable in biology. The authors argue that biological investigations may need to encourage 'observations interpreted through biological knowledge', and conclude by writing that more research on this topic is urgently needed.

The issue of differentiation between theory and evidence was addressed in several studies. Kuhn, Amsel, and O'loughlin, and Kuhn (1988,1989) view the coordination of theories and evidence as the heart of scientific thinking:

'A central premise underlying science is that scientific theories stand in relation to actual or potential bodies of evidence against which they can be evaluated ... Some fundamental competencies of the scientist are clearly assumed, competencies that center on the coordination of theories and evidence ... The scientist (a) is able to consciously articulate a theory that he or she accepts, (b) knows what evidence does and could support it and what evidence would contradict it, and (c) is able to justify why the coordination of available theories and evidence had led him or her to accept that theory and reject others ... Although they do not encompass all aspects of scientific thinking, these skills in coordination theories and evidence arguably are the most central, essential and general skills that define scientific thinking.'

Kuhn's findings suggest that while professional scientists fully differentiate and co-ordinate between theories and evidence, children (and many lay adults) do not differentiate between them. Instead, they meld the two into a single representation of 'the way things are'. When the two are discrepant, children exhibit strategies for maintaining their alignments -- either adjusting the theory, or 'adjusting' the evidence by ignoring it or attending to it in a selective, distorting manner.

The findings of other researchers contradict those of Kuhn. Klahr and Dunbar, and Klar and Fay (1988,1993) view scientific discovery as a type of problem solving which requires search in two distinct problem spaces: a space of experiments and a space of hypotheses. Their model of Scientific Discovery as Dual Search (SDDS) includes three processes:

a) searching the hypothesis space to generate new hypotheses; b) searching the experiment space to evaluate hypotheses through experimentation; and c) evaluating evidence to compare the predictors derived from an hypothesis with the results obtained from the experiment.

Klahr et al. (1988,1993) found that most sixth graders and some third graders understood that their task was to produce evidence to be used in support of an argument about an hypothesis, and were able to distinguish between theory (hypotheses) and evidence. Similar findings were reported by Sodian, Zaitchik, and Carey (1991) who found that first- and secondgrade children were able to differentiate between hypothetical beliefs and evidence.

One way to resolve the contradictory findings among the studies described above is to attribute them to the different contexts in which they took place. Since reasoning skills are content and context dependent (e.g. Perkins and Salomon, 1989), it can be expected that studies which differ from each other in their tasks' contents and contexts will produce divergent findings. Both contradictory views regarding children's abilities to differentiate between theory and evidence are based on cognitive psychological research that took place outside of children's classroom science learning.

In school science learning children are required to differentiate between theory and evidence when they conduct experiments or observations, followed by a requirement to describe results and to draw conclusions. The dependency of reasoning skills upon specific contexts makes it impossible to predict how children will be able to perform on such occasions. This question is important from both theoretical and practical educational perspectives. The purpose of the present study is to investigate the issue of students' differentiation between experimental results and conclusions, while they study biology in school.

Aims

This study has three aims:

1. to document and analyze students' common inability to differentiate between results and conclusions, while they

are engaged in scientific investigations within biology classrooms;
2. to describe and analyze teachers' thinking regarding this issue; and
3. discuss possible sources of students' difficulties.

Methods

The present study was conducted within the setting of a project called 'Thinking in Science Classrooms' (TSC). The project's goal is to supplement the regular junior high-school science curriculum with learning activities designed to foster higher order thinking and scientific argumentation. The contents of the learning activities match topics from the regular biology syllabus, so that teachers may incorporate the learning activities in course of instruction whenever they come upon a topic covered by one of these activities. The activities are designed to foster the growth of both scientific concepts and scientific reasoning skills. Some of the thinking activities evolve from 'hands-on' experiments conducted by students, others from 'invitation to inquiry' (Schwab, 1962; 1963), critical reading of information sources or investigation of microworlds (Zohar, Weinberger, and Tamir, 1994, Zohar and Weinberger, 1995, Zohar, 1996).

Students are active during the learning process. Much of their work takes place in small groups with rich scientific argumentation. The rationale and methods of the TSC project are discussed in staff development workshops. Part of the workshop consists of a reflective analysis: selective parts of videotaped lessons are transcribed and then analyzed by a team of teachers and researchers.

The study presented in this article constitutes qualitative research. Data presentation consists of excerpts from classroom discourse and from teachers' workshops. It should be noted that the data presented here are part of a much larger database, that was collected as part of research on teachers' cognition in the context of teaching higher order thinking skills. In course of analyzing that database, the problem of difficulties in distinguishing results from conclusions became apparent. As is common with qualitative research, the present study does not look for confirmation or rejection of an hypothesis that was drawn at a preliminary stage of the research. Instead, perception was crystallized as data accumulated, and the research is therefore grounded research (Glaser and Strauss, 1967; Spradley, 1980; Bogdan and Biklen, 1982; Sabar, 1990).

The data presented below originated from:

a) 15 videotaped lessons taught by six biology teachers in grades seven, eight, and nine; and

b) audiotaped discussions between teachers and researchers about selected parts of those lessons.

Results

a) Description of class discussion

Towards the end of the school year, a seventh-grade biology class conducted an experiment to investigate whether various parts of living organisms contain water. Flowers, stems, leaves, and a piece of meat were put into four glass containers covered with a glass cover. After heating the containers, little drops of water accumulated on all four glass covers. When asked about the conclusions from the experiment, several students responded by describing the experimental results (i.e. little drops of water accumulated on the glass covers). The teacher then asked (in the following excerpt T stands for teacher, S stands for various students):

1. T: The little drops on the glass cover -- what is it, a result or a conclusion?
2. S: (several students say at the same time): A result.
3. T: What is the difference between a result and a conclusion?
4. S: A result is what's out there, what we could see. A conclusion is what we can learn from the result.
5. S: Conclusions are like a summary of all the results.
6. S: The conclusion is what you can conclude from the results.
7. T: We can't explain a word by using the very same word. 'A conclusion is what you can conclude'. What does it mean?
8. S: A conclusion is just like a result. They are the same.
9. T: If it is the same, why do we need two separate words?
10. S: Results are like, facts ... We saw the drops of water. Conclusions are our ideas, what we think.

Although none of the students drew the correct conclusions from this experiment (i.e. that all the parts of living organisms which were examined contained water), some children could explain the difference between :results and conclusions (e.g. lines 4 and 10). Others, however, were unable to tell the difference between the two concepts either at the operational or at the procedural level (see lines 5, 6, and 8).

b. Teacher's perspective

After the lesson, the researcher and the teacher (J) watched parts of the videotaped lesson. The teacher's reaction sheds some more light on the background of her students regarding the difference between results and conclusions. J explained that at the beginning of the year she had taught scientific inquiry, explaining the meaning of several concepts including 'conclusions'. Conclusions were discussed in general terms and defined as 'what one learns from an experiment'. However, later on during the year, when students had to describe results and conclusions after having conducted experiments, many were unable to complete the task successfully. Finally, J said:

'We discussed it theoretically, in general terms, but then in each experiment, they kept telling me 'But J, it's the same thing' (i.e. results and conclusions). Each time anybody said so, we immediately discussed whether results and conclusions are indeed the same thing or not ... and it happened several times during the year. That's why I was a little surprised (to see that they still found it so hard).'

c. Description of group discussion

The next excerpts are taken from a group of four students who collaborated on solving a problem. The Photosynthesis problem is a computerized simulation which asks students to determine which of several variables (e.g. temperature, light intensity or natural growth area) affect the rate of the photosynthesis process. The students in that group generated 2 experiments to investigate whether natural growth area affects the rate of the photosynthesis process (as measured by the amount of oxygen released). A plant taken from growth area A was compared with a plant taken from growth area B. The results of both experiments are the same: 1/4 test-tube of oxygen. The valid conclusion from this experiment is that growth area does not: affect the rate of photosynthesis. However, drawing that conclusion was not an easy task for the four students (in the next excerpt, T stands for the teacher, S stands for various students. Since some of the transcription was done from an audio-tape it was not always possible to determine which students said what):

1. S (to the teacher): Please read this and tell us whether it's correct.
2. S (reading out loud from his work-sheet): The conclusion is that the same amount of oxygen is released in both growth areas.
3. T: Wait a minute. Both of them are 1/4?
4. S: Yes.
5. T: Well ... now what is your conclusion? What can you conclude if it's the same amount in both areas?
6. S: That the photosynthesis ...
7. S: takes place anywhere, in all areas.
8. T: No. That the photosynthesis process is ... (waiting to let students complete the sentence)
9. S: the same rate.
10. T: The same intensity. Correct, i.e. what did you want to find out?
11. S: Growth area.
12. T: Growth area, i.e. what about the growth area -- does it or doesn't it affect the rate?
13. S (two talking at once): Growth area makes no difference.
14. T: Makes no difference. We got the same results when we changed growth area. Right? And what about the other variables?
15. S: The same.
16. T: You did not change them. So you can conclude that if ... if there would have been a difference ... what would you say then?
17. S: Result, we would say ...
18. S (two talking at once): that it's the same.
19. S: That's what we wrote here.
20. T: Yes. This is a conclusion. Because what you wrote here is a result ... write it down and then I'll check it. OK'?
21. S (dictating): The amount of oxygen released in both growth areas
22. S: all other conditions are the same.
23. T: The same, only ...
24. S (together): different growth areas.
25. T: Different growth areas ... we can therefore conclude that ... growth area does not ...
26. S: Growth area has no effect.
27. T: Great. (turning to another student) Do you understand?
28. S: Yes, yes, no problem.
29. T (turning to another student): What is your conclusion?
30. S: The same.
31. T: Is it clear that those are results?
32. S (all four at once): Yes, yes, yes.
33. T: The amount of oxygen which was released is a result and not a conclusion (turning to another group).

Initially, students were confused between results and conclusion, writing results when asked for conclusions (line 2). Upon realizing their confusion, the teacher helped them to correct their response. Analysis of the teacher's contribution to the discussion reveals that she:

a) first led them to the right conclusion by starting a sentence and letting students 'fill in' the correct answer (lines 8-10 and 23-26);

b) then, made sure that all four members of the group 'knew' the correct answer (lines 27-32); and

c) finally, she repeated once more that the amount of oxygen which was released is a result and not a conclusion.

On the surface it seemed as if those four students now understood more than they had prior to the teacher's intervention: Once the correct answer was produced through a common effort of teacher and students (lines 24-26), all four members of the group declared that they understood it. However, a reasonable doubt may be raised as to whether any meaningful learning has taken place.

Indeed, following the same group of students during the next phase of their work shows that they continued to confuse between results and conclusion. In the next experiment they chose to investigate whether changing the temperature affects the rate of photosynthesis. They described the result by writing: 'More oxygen is released when the temperature is 25 degrees C than when it is 17 degrees C'. When they turned to describe the conclusion, the following conversation took place:

1. S: Now, what's the conclusion? The amount of oxygen changes when the temperature changes.
2. S: No. We wrote the same thing up here (pointing to where he wrote the results).
3. S: No. The conclusion is: as the temperature increases, the amount of oxygen increases.
4. S: Oh (laughing). You are a real shark (all four children laugh).
5. S: Wait a minute. I didn't understand.

S (dictating): As the temperature increases, the amount of oxygen increases.

As can be seen from line 1, the student once again repeated the result when he tried to formulate a conclusion, but this time, another student objected to this (line 2). The revised conclusion 'as the temperature increases, the amount of oxygen increases' (line 3), was accepted by all four students, despite the fact that it is merely another formulation of the same results which were just rejected (in line 2). However, it seems that now the students are uncertain of what they wrote:

1. S: I'm not sure that we did it right.
2. S (calling to the teacher): Please come over to check what we did. Please.
3. S: I called you fifteen minutes ago.
4. T: Sorry. I can't be with all of you at the same time. But I'll come soon. Promise.
5. S: OK. You know what, let's write.
6. S: We could write and skip the conclusions. Let's continue with the experiment. We'll investigate the light now.
7. S: Exactly. Our behaviour is really rotten (e.g. because we are skipping the difficult part). OK.

Being unsure of the conclusion they wrote, students wanted the teacher to come and check their work. When they realized it would take her a while to come, they decided to carry on with their investigations (studying the effect of light), but skip the conclusions.

The data show that although those four students spent a considerable amount of time on formulating conclusions and although the teacher did try to help them out, they definitely still had a hard time differentiating between results and conclusions. At that stage of their common work they still felt that they could not cope with it, and therefore decided to postpone the writing of conclusions until some more help from the teacher was available.

d. Teachers' workshop

The case of the group described above was presented in a session of a teachers' workshop which took place a few weeks later in the same school. The teachers' first reaction was that they are not surprised to learn of the difficulties the four boys had experienced in differentiating results from conclusions, because such difficulties are very common among their students. It should be noted that H, a teacher of a 12th-grade accelerated biology class, remarked that even her senior students are not immune from making such mistakes. She described how students who are about to take the laboratory matriculation exam, still supplant results for conclusions and vice versa when they conduct laboratory investigations or independent research projects. In the ensuing conversation, several interesting points were raised by the teachers.

Several teachers testified that students' difficulties are not limited to differentiation between results and conclusions in laboratory experiments, but are also prevalent in cases which require description of observations in the context of independent research projects conducted by eighth graders, as can be seen in the following excerpt:

A student told me that each morning her cat sits waiting for her grandmother to give her breakfast ... Her goal was to describe what the cat did ... She thought that what I was asking her to do was weird ... She actually sees it waiting for breakfast ... the result is that the cat sits there for 10 minutes ... What I was asking her was to differentiate between an observation and a conclusion. She can't do it. Observations are more complicated than lab experiments ...

Observations and experiments are different in many ways that are beyond the scope of the present study. However, the most interesting parts of the conversation with those teachers consisted of their ideas about why the differentiation between results and conclusions is so difficult for their students.

One group of explanations proposed by teachers is that the requirement to differentiate results from conclusions stems from a contradiction between common, everyday ways of reasoning in which results and conclusions are undifferentiated, and school science reasoning which requires such a differentiation. Students are alienated from scientific thinking, and therefore find it difficult to reason according to strict scientific rules. Such ideas are reflected in the next quotation:

- T: In everyday life the conclusion is often defined as a result.
- Y: What was the result of throwing the stone? She was scared. They don't say the result was that she jumped back. In everyday language, the word 'result' is a conclusion. There is no reason to differentiate them in everyday life.
- T: Yes, yes, (nods in agreement). We are always thinking that way, and then suddenly comes this alienated thinking and it doesn't flow ...

A second group of explanations refers to students' inability to understand basic concepts of scientific investigation. Teachers feel that students do not comprehend the relationship between their data and the theoretical-conceptual aspects of their investigation. Teachers discussed this issue by proposing the following ideas:

a) The goal of experiments should go beyond manufacturing a result. The objective of experiments should be on the level of explanations, implying that conclusions should also be on that level, as expressed in the next two transcripts:

- O: I think we should have told them that the conclusion is related to the objective. Experimental objectives never remain at the level of results, because the colour of the Phenol Phthalein (an indicator for CO_2) is not an experimental objective. The objective is to find out whether the respiration process takes place in seeds.
- O: Then your objective is the interpretation. You must explain that this is the goal which goes beyond the result.

b) Such explanations should be responses to 'why' questions, attempting to establish causal relationships. Mechanisms and procedures are an accepted form of response to 'why' questions. Teleological explanations are unacceptable. Examples of those ideas are expressed below:

- X: The question is what caused the increase in tile amount of oxygen.
- O: Why was there an increase in the amount of oxygen? This is the question.
- T: They must understand the relationship between the conclusion and the 'why' question ...
- O: You should ask him about the procedure. OK, the result is an increase in the level of oxygen. So what is the mechanism? What is happening in there that causes the increase in oxygen level?
- X: In tests when you ask them why things happen, they write - because the body needs it, and they don't answer about the mechanism. If you teach them thai a mechanism, a scientific process stands behind all phenomena ... this would work for diffusion, and for physical processes ...

c) School experiments are different from real scientific experiments, because what are considered 'conclusions' in school experiments are not real conclusions. A plausible interpretation of this idea is that school experiments are usually very simple and 'lean' in terms of their experimental design. Often, they do not address real questions leading to hypotheses which can be tested through experimentation. In other words, school experiments are often conducted merely for the sake of having a 'hands-on' experience. In such cases, there is no real connection between the experiment and a theory, and therefore the distinction between results and conclusions is artificial.

d) Finally, one teacher suggested that lack of scientific knowledge is responsible for students' inability to distinguish between results and conclusions:

• Y: The problem in making the connection between amount of oxygen and photosynthesis is not in distinguishing between result and conclusion. Rather, the problem is about knowledge. More oxygen is more photosynthesis. If you don't know this relationship ...

If true does not know the scientific background and/or facts which underlie an experiment, s/he cannot possibly make sense of anything beyond what can be seen in the test-tubes. Constructing 'real' conclusions, i.e. conclusions that go back to the level of scientific theories, then becomes impossible as does the distinction between conclusions and results.

Discussion

The excerpts analyzed in the previous sections demonstrate that while learning biology in school, students, indeed, have difficulties in differentiating between experimental results and conclusions. Due to their qualitative nature, the data described in the present study cannot establish the frequency of this phenomenon, but the excerpts from conversations with teachers indicate that it is quite common as shown below:

- J reported that in several experiments throughout the year her students had confused results with conclusions, although she often addressed this issue;

- H reported that confusion between results and conclusions is very common among her high-school students, and even among those who take elective accelerated biology;
- and finally, several teachers described examples of eighth graders' difficulty in differentiating between observations and conclusions in their independent experimental projects.

Our data also show that students' difficulties cannot be attributed to teachers' insensitivity: the five teachers who were quoted in this study were aware of their students' difficulty in differentiating between results (or observations) and conclusions. The teachers hold a rich set of ideas about the sources of those difficulties, and address them in their instruction. However, it is also clear from the data that their means of instruction are insufficient for this particular purpose.

In the introduction section above, two contradictory views were described regarding children's ability to distinguish between theory and evidence. The findings of the present study are in accordance with Kuhn's findings, indicating that when children are faced with the need to differentiate between theory and evidence in the context of classroom science learning, many of them are unable to do so. This finding raises two further questions:

a) What is the cognitive source of this difficulty?

b) What educational means can be effective in helping students overcome this difficulty?

At least two hypotheses can be raised regarding question A. The first hypothesis builds on Kuhn's ideas, suggesting that the source of students' inability to distinguish between results and conclusions in science classrooms, is the problem of co-ordinating theory and evidence: because theory and evidence are melded into a single representation of the 'way things are', students cannot distinguish between theoretical aspects of school experiments (i.e. conclusions) and evidence (i.e. experimental results or observations). This hypothesis assumes that while conducting experiments in science classrooms, children are considering theories as well as evidence. However, our data suggest a second hypothesis, that this might not be the case: perhaps in the context of classroom scientific experimentation, students are simply unaware o[' theories.

In the terms of Klahr et al. (1988,1993), one could say that the source of the difficulties is that classroom experimentation is limited to the space of experiments, not reaching the space of hypotheses. Indeed, recent proposals for introducing changes in science education include the critique that science education often highlights processes that focus on data-gathering, while construction of meaning through data analysis and reasoning via scientific argumentation lag behind. Changes that introduce methods for scientific argumentation leading to theory revisions are therefore proposed (e.g. Duschl, 1990; Gitomer and Duschl, 1995).

To conclude, the difference between the two hypotheses is that according to hypothesis 2 children do not think about theories while formulating conclusions, and according to hypotheses 1 children do think about theories, but theories and evidence are merged together in their thinking. It should be noted that the two hypotheses are not necessarily mutually exclusive. A distinction between the two hypotheses is important because knowing the source of children's difficulty can be helpful in designing effective educational strategies to improve children's reasoning. Further research is needed to test these hypotheses.

Meanwhile, based on the findings of the present study some preliminary recommendations for teachers can be made:

a) Students' difficulties in differentiating between results and conclusions should not be overlooked.

b) As is the case with any other concept or skill, simply 'programming' children to perform correctly by leading them to differentiate between results and conclusions in a specific case, does not lead to meaningful learning, and therefore is unhelpful in transferring the skill to additional problems.

c) Discussing the issue in a declarative manner, gene:rating a general rule, does not help students to use it in a procedural manner. In other words, learning to define 'conclusions' and 'results', does not necessarily help students to differentiate between them in the contexts of specific experiments.

Recommendations for appropriate instructional means must await the findings of future research. Acceptance of hypothesis I implies instruction that will focus on differentiation between the theory and evidence, while acceptance of hypothesis 2 implies instruction that will focus on clarifying the theoretical background of experiments.

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By Anat Zohar

Dr Anat Zohar is a researcher and lecturer in the School of Education, The Hebrew University, Jerusalem, Israel. E-mail: AZOHAR@VMS.HUJLAC.IL

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