COMPREHENSION EVALUATION AND REGULATION IN LEARNING FROM SCIENCE TEXTS

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Abstract
Metacognitive variables influence students' learning from science texts. This article deals with the comprehension monitoring abilities of secondary school science students, one of the areas of metacognition which has drawn considerable attention from researchers. The aims of the study are, in particular: (a) to know the extent to which comprehension is monitored by secondary science students as revealed by inconsistency detection in manipulated science texts, and (b) to identify the strategies used to regulate comprehension by the students who detect the inconsistencies. The results indicate that knowing that one understands or fails to understand science texts could be as important a problem as understanding proper. Besides, some incorrect regulatory strategies used by students who notice the inconsistencies in the texts are identified. These could also have an annoying influence in the regulatory behavior of students when studying regular science texts.

Introduction
The role of science textbooks and the effects of their use can be diverse depending on the country and grade level (Comber & Keeves, 1973). In some countries, like the U.S., "... textbooks exert an overwhelming dominance over the science learning experience" (Harms, 1981, p. 115). Textbooks are used, for example, as information sources to prepare or reinforce lecture and discussion. Although an overemphasis on textbooks as information sources has also been criticized—"learning by reading" has been pointed out to be the basic mode of learning elementary science in the U.S. (Stake & Easley, 1978, cited by Anderson, 1981, p. 40)—this remains one of the important uses of textbooks (Spiegel & Wright, 1984). In relation to this function of textbooks, researchers have studied, for example, students' recall from science text (Finley, 1983), the readability of science passages (Williams & Yore, 1985), techniques for analyzing the structure and improving the understandability of science prose (Mayer, 1983, 1985a, 1985b), the text features used by novice scientists to determine what is important (Dee-Lucas & Larkin, 1986), the effects of decision making in learning chemistry from text (Pedersen et al., 1988), and ways in which students extract meaning...
from science textbooks (Wandersee, 1988). Studies like the preceding ones on learning
has been directed towards identifying the ideas which students already have when they
in science education has also concerned about the role of the learner's previous knowledge. Much effort
has been directed towards identifying the ideas which students already have when they
start the formal study of scientific fields. This point is illustrated by the fact that Duit
(Phillips & Duit, 1988) already includes more than 150 quotations in his bibliography on
students' alternative frameworks.

Learning from text is influenced by other types of variables initially studied by developmen
tal psychologists in the 70's: metacognitive processes. A classical definition of metacognition is that offered by Flavell (1976): "Metacognition" refers to one's knowledge concerning one's own cognitive processes and products or anything related to them, e.g., the learning-relevant properties of information or data. Metacognition has been criticized for its ambiguity and questionable utility (for example, Reynolds & Wade, 1986). Its meaning is often made more precise by distinguishing between metacognition as knowledge about cognition and as control of cognition: "The first component is concerned with the ability to reflect on one's own cognitive processes...

The second component of metacognition is concerned with the use of self-regulatory strategies that enable us to control our cognitive efforts" (Baker, 1988, p. 2).

There are some areas of educational research, like research on reading, where metacognitive problems have been of special concern as researchers. Metacognition is also being taken into account in education (Novak & Gowin, 1984) and, specifically, in science education (Baird, 1986; Baker, 1988). This work deals with a metacognitive problem: the control of one's own comprehension when reading science text. Comprehension monitoring is one of the areas of metacognition which has drawn considerable attention from researchers. Baker (1979, 1985a, 1985b), Baker & Anderson (1982), Epstein, Glenberg & Bradley (1984), Glenberg & Epstein (1987), Glenberg, Wilkinson & Epstein (1982), Markman (1977; 1979), Markman & Gorin (1981), Ryan (1984), Schommer & Surber (1986). These studies have not used, in general, science texts. This work attempts to examine the characteristics of comprehension monitoring by second year science students when reading science texts.

The study is carried out within the "contradiction paradigm." The subject reads science texts containing contradictions, if the contradiction remains unnoticed, this means an inadequate control (evaluation) of one's own comprehension. In the case that the contradiction is detected, the subsequent behavior of the individual in the regulation phase is examined. Research findings indicate that subjects reading a text containing inconsistencies are better prepared than is shown by an examination of their answers. Although readers frequently detect the inconsistencies in a text they do not report their existence, even when instructed to do so. This is because "its up" procedures are used to notice the inconsistencies. The procedures used by secondary science students are identified in this article. It is assumed that the procedures used when reading these texts, of a special kind because of the existence of contradictions, will be similar to those used by students having comprehension difficulties in the study of regular science texts. The study was designed as follows: (a) to know the extent to which comprehension is monitored by secondary science students as revealed by inconsistency detection in manipulated science texts and (b) to identify the strategies used to regulate comprehension by the students who detect the contradictions.

Although Markman (1979, p. 644) points out that "the study of comprehension processes should provide a basis for theorizing about comprehension monitoring," much of the work done in this latter area has been carried out without being grounded on any comprehension model. We attempt to base our interpretations in the text-comprehension model proposed by Kintsch and van Dijk (1978; van Dijk & Kintsch, 1983).

Method

Four intact groups of secondary school students from two public schools in Madrid, of a middle SES, were chosen. One class from grade 12 (final year in the Spanish secondary education; 18-year-old students) and another from grade 10 (16-year-old students) were tested in each of the schools. The total number of grade 12 students was 63, and 65 from grade 10.

The students were tested during one of their regular class periods. They were initially informed that the test was a part of a research project on science text comprehension. Their help was requested to evaluate the understandability of some science passages. A booklet containing six texts, supposedly taken from physics or chemistry textbooks like those used in secondary school or the first year at the university, was handed to students. The typographical presentation of each text, obtained with a laser printer, was similar to that of a textbook; apparently, it could have been a photocopy of a paragraph in a science textbook. On the first page of the booklet there were instructions recommending a careful reading of the texts with the purpose of evaluating their understandability. Although the students were asked to judge the understandability of the paragraphs, they were not informed of the existence of problems in the texts.

Each paragraph had six sentences and 74 to 97 words. Each of the paragraphs was presented on a different page of the booklet. As a heading, they all had a reference indicating a book, unknown to the students, from where the text was supposedly taken. They also had a title describing the paragraph's content. The paragraphs occupying the second, third, fifth, and sixth positions included an explicit contradiction in the second and last sentences (see the appendix). Care was taken that the contradiction involved a main point in the text; differences in the detection of inconsistencies have been found depending on whether a main point or a detail is involved (Baker, 1979).

The paragraph content was also chosen so that it would be relatively unknown to students. We tried to prevent the students from using external instead of internal consistency criteria to detect the problems (Baker, 1985b).

According to the instructions in the booklet, the students had to rate the comprehensibility of the paragraph on a four-point scale (1 = difficult to understand, 4 = easy to understand). The subjects were also instructed: (a) to underline the conflicting sentence or sentences if they found any problems in understanding the paragraph, and (b) to explain, in the space provided below, the nature of the difficulty. As the students were completing this part of the text and returning it, a new booklet was handed to them. This second booklet informed the students about the contradictory sentences in texts 2, 3, 5, and 6. The purpose of this second part of the text was to ascertain whether the students who did not underline the contradictory sentences had been conscious of the problem or not. The students who indicated that they had realized the existence of a contradiction without reporting it or underlining the contradictory
sentences were invited to explain the reasons for not having done so in the space provided in the booklet. Also, these students were individually interviewed at the end of the session to determine more clearly their reasons. The students who, while detecting some of the inconsistencies, rated the comprehensibility of the paragraph as good or fairly good (4 or 3) were also interviewed. All of the interviews were taped and transcribed. The protocols were analyzed in order to classify student behaviors according to the categories presented below.

Results and Discussion

Several distinctions can be made in students' behaviors by examining their responses to the questionnaire and interview. The first distinction is made between detecting or not detecting the contradiction. As mentioned above, detecting a contradiction does not imply that the student spontaneously reports the problem. Inconsistency detection pertains to the evaluation phase of one's own comprehension, while deciding that there is a problem attributable to the text and reporting it pertains to the regulation phase. As an adequate evaluation does not imply an adequate regulation, further distinctions can be made in the behaviors of the subjects who detect the contradiction according to the ways in which comprehension is regulated. Thus, three categories can be distinguished in the behaviors of students reading the texts. First, there can be absence of evaluation—that is, the contradiction can remain undetected. Second, there can be an adequate evaluation—the contradiction is detected—but the regulation is inadequate or is lacking. Lastly, there are behaviors showing an adequate evaluation and an appropriate or quasiappropriate regulation.

Categorization of Responses

1. Absence of Evaluation: The ContradictionRemains Undetected. These behaviors reflect the lowest level of comprehension: contradictory statements are not identified in the first part of the text and the subject declares in the second part to have no awareness of the contradiction. Two categories can be distinguished here.

1.1. Illusion of knowing. All those responses given by subjects not detecting the contradiction and believing to have a good or fairly good understanding of the text (scores 4 or 3). This behavior reflects what Glenberg et al. (1982) call "illusion of knowing." (IK).

1.2. Basic difficulties. In these cases the contradiction remains undetected, as above, but the subject rates the comprehensibility of the text as bad or unsatisfactory (scores 1 or 2). This could be caused by difficulties other than the existence of a contradiction. Unfamiliarity with terms appearing in the text, i.e., lexical problems, could be one of these difficulties:

... I didn't understand very well what "absolute zero" was. ... (2203)

... I think that these sentences could be explained more easily without using such hard words... ... (2207)

Some students indicated during the interviews that finding one of these difficulties at the beginning of the paragraph led them to suspend a careful reading of the text coming next:

... When it got hard, I just gave up. (C029)

Thus, the subjects with the illusion of knowing are probably inadequately monitoring their comprehension because they are not building a model of the situation the text is about. Besides, the subjects are not aware of this, and believe that they have understood the text well. According to this view, the subject having basic difficulties does not detect the inconsistency for the same reason as before. But the student is conscious of the existence of difficulties which prevent him or her from building a situation model.

... I didn't understand the text, it looked a bit complicated so I said, 'no, it was a little involved.' ... I couldn't imagine very well what it said about water in a deep place ... I couldn't imagine very well what it said about the neutrino; although it is a small thing, in a deep place with water... ... (2029)

The model of text comprehension by Kintsch and van Dijk (1978) and Kintsch, 1983, can be of some help in analyzing the mental processes of students who do not identify the contradiction. The first component of text processing considered by the model is the building of a "text base": a coherent chain of propositions representing the meaning of the text. The building of a coherent text base from the texts given to students had some difficulties, as two of the propositions were contradictory. But the behaviors described above indicate that, in this case, the students are not even attempting to develop a text base. They do not try to establish coherence among propositions. What processing strategies are failing here? The strategies to obtain coherence in the text proposed in the last version of the model (van Dijk & Kintsch, 1983) are diverse. A local coherence strategy, by means of which the reader establishes coherence by pairwise comparisons of propositions, should be discarded (van Dijk, 1985, p. 115). Research on comprehension monitoring has shown, for example, that forcing young children to compare contradictory propositions in a text by asking them to repeat the propositions in pairs does not improve inconsistency detection (Markman, 1979). Thus, the criterion of coherence of the text base cannot solely be a local one, for example, argument repetition between propositions as proposed in the first version of the model (1978). The importance of global strategies in establishing text bases is acknowledged in the second version of the model (1983). Thus, the ultimate proposed criterion of coherence is a broad one: "Roughly speaking, a sequence of sentences can be said to be coherent if the sentences denote facts in some possible world that are related" (van Dijk & Kintsch, 1983, p. 150). The so-called "situation model" is the cognitive representation of the events, actions, persons, and in general the situation a text is about (van Dijk & Kintsch, 1983, p. 111) plays an important role here. Although Kintsch and van Dijk primarily address episodic situation models (van Dijk & Kintsch, 1983, pp. 336-342), a generalization could be attempted to situations like those described in the texts, where semantic knowledge plays an important role. It is possible that subjects do not detect the inconsistencies, that is, do not try to build coherent text bases, because they give up building a situation model for the text: "... A prerequisite for coherent text representation is the ability to construct a coherent situation model. Without that, memory for text is stored as incoherent bits and pieces..." (van Dijk & Kintsch, 1983, p. 361). These are some students' statements supporting this supposition:

... the part about water... it was a little involved... I didn't understand what it said about water in a deep place... I couldn't imagine very well what it said about the neutrino; although it is a small thing, in a deep place with water... ... (2029)
When the building of a situation model is deliberately hindered, the text is stated in a noncoherent way, and memory is poor (Bransford & Johnson, 1972); that is, the situation model plays an important role in long-term memory of text (van Dijk & Kintsch, 1983, p. 340). Thus, it should be expected that a subject not detecting the inconsistency in a text would have a poor record of it, in comparison with those texts in which it has been detected—a prediction which we have not had the opportunity to examine in this study.

Of course, this reasoning can be seen as an attempt to understand a cognitive problem: overlooking the contradiction. A different explanation, perhaps in terms of an incorrect use of comprehension criteria, should account for the metacognitive problem—why IE subjects believe that they understand well. To understand this well, a subject must not have detected the contradiction, but also detect the contradiction, the subject seems to have difficulty in regulating, or not regulating at all, their comprehension. The following categories can be distinguished, according to the decision taken:

II. Adequate Evaluation, Inadequate Regulation. Subjects can be aware of the problems in the text: they point out the existence of contradictions in the first part of the text or in the second part, when they are asked about them. However, this does not imply that an appropriate regulation of comprehension has followed. The transition between the two phases, evaluation and regulation, posed some contextual problems to the subjects participating in the experiment. After detecting the contradiction, the students seem to face the choice of regulating, or not regulating at all, their comprehension. The following categories can be distinguished, according to the decision taken:

II.1. Regulation is lacking. Sometimes the student chooses to do nothing after having detected the problem: the contradiction is identified in the first section of the text (the student says so in answering the second section) but the contradictory sentences are not underlined, nor is the problem explained. When asked to explain this oversight, a typical response is "It was not important." One of the strategies used by good text processors to deal with comprehension difficulties, the explicit formulation of the difficulty as a problem (identified by Bird, cited by Scardamalia & Bereiter, 1984, p. 380), is lacking here:

I found the contradiction but I thought it wasn't important ... so I didn't underline it ... I just underlined what I didn't understand ... I only underlined what I think is most important, the general idea I get out of a text ... (2373)

I didn't underline the sentence because I didn't have any difficulty when I read it ... (2014)

There are several possible explanations for these responses. Some of the students explain that they are not familiar with the subject. Because of this, they feel that there could be a possibility for the contradiction to be explained away in terms unknown to them. In fact, previous findings have shown that it is possible for a student to believe that the authority of science can support contradictory statements (Otero, 1987). The following are examples of this kind of explanation, all of them from students who detect the contradiction but do not state the problem:

it seemed to me a bit queer that they should contradict themselves, but, as I didn't understand anything about the subject, I didn't underline it ... perhaps if the contradiction were like that ... (2026)

I have already explained that I didn't understand "neutrinos" and I didn't quite get what was going on ... (C112)

... Yes, I saw one [contradiction] at the beginning and maybe at the end

II.2. Inadequate regulation. There is a second class of reactions reflecting what Baker (1979) has called fix-up procedures. When the inconsistency is detected some subjects try to build a coherent text base by activating some schema. Schemata allow the learner to make inferences in order to save the detected contradiction. It is difficult to find schemata which, correctly applied to the texts, as built, could explain away the contradictions. However, in all of the instances presented below, the student is satisfied with his or her comprehension of the text and does not indicate, in the first part of the text, the existence of a contradiction. From the explanations given in the second section, one can conclude that the schemata used by students were applied in an erroneous way: The information given by the text was forced into the schema's slots ignoring or modifying part of this information. Some of these behaviors have already been described elsewhere (Otero, 1987). The schemata seem to be calling upon modes of language use acceptable, perhaps, when dealing with everyday matters, but unacceptable in the domain of scientific knowledge (Solomon, 1984). The two schemata more frequently used in this case were the following:

II.2.1. "The advance of science". This schema was mainly applied in texts 3 and 6. The contradiction is explained by assigning the contradictory sentences to different developmental stages of science. In text 3 (Superconductivity) subjects assume that in the past superconductivity was achieved by lowering temperature but now it is possible to obtain superconductivity by heating certain materials:

... I thought that some time ago superconductivity was only achieved by using low temperatures, but nowadays some high temperature process could have been discovered ... (C024).

and in text 5 (Neutrinos)

... I didn't underline it because I understood that some apparatus had been discovered, in some country or other, which made it easy to detect them at great depth ... (C006)
It is necessary to ignore or transform the meaning of certain propositions to constrain the text in this schema. The students restore coherence in the text on superconductivity, for example, by interpreting the last sentence: "...Until now superconductivity was obtained by considerably raising the temperature..." as "From now on superconductivity can be obtained by considerably raising the temperature...". The comprehension of normal science texts not manipulated, can be more difficult if the student uses language in such a way. Learning science at this level implies the acquisition of conceptual structures in which the constituent elements should maintain well-defined relations. Language use and interpretation, accordingly, should also be precise. 

II.2. "There are no rules without exceptions". Subjects easily accept that what is stated as valid for all the elements in a category could be invalid for some of them. What is presented as a general rule could have a limited validity because of special circumstances, even without these having been mentioned in the text. Thus, in the last sentence of text 2 it is asserted that moisture and sunlight delay the transformation of sulphur dioxide and the oxides of nitrogen in acids. Nevertheless, this can be true for certain acids but not for nitric and sulfuric acids: 

because in the second sentence it was dealing with acids, in general, perhaps it meant other acids different from sulphuric and nitric... (C11)

A similar schema is used for text 6 about the fragility of ceramics. In the second sentence, it is stated that interatomic bonds are strong and rigid. Some students believe that it is possible that bonds in ceramics with fissures no longer have this property: 

the bonds are rigid but when broken they become weak... (C006)

The text's characteristics apparently have an influence on the possibility of using this transforming strategy. The texts for which this strategy is more frequently used are 3 (Superconductivity) and 5 (Neutrinos). As explained in the previous section, science learning could be hindered if the student maintained this approach when studying normal texts. The inconsistencies found in learning materials, due to an inadequate comprehension, can always be imputed to variations in the applicability of scientific laws and statements.

III. Adequate Evaluation and Regulation. Appropriate (or unappropriate) behaviors are described below. Subjects reject the text because of the importance of the contradiction without imposing any explanatory schema. Two subcategories are distinguished here.

III.1 The difficulty is undervalued. The subject detects the problem in the first part of the test and undermines the contradictory sentences explaining the difficulty. Nevertheless, the text's understandability is rated 3 or 4 (fairly good or good). This behavior has also been identified in previous studies (Glenberg et al. 1985). It should be remembered again that students were instructed to evaluate the understandability of texts, and that all of the inconsistencies involved a main point. The students' explanations in the interviews suggest that, in this case, the subjects are conferring little importance on a discrepancy between the text and the internal consistency criterion: 

...the text is easy to understand but the contradiction puzzled me a little bit, the rest of the text is easy to understand... (C110)

...apart from the two contradictions, the text is easy to understand... (C115)

...really, the text is clear, you can understand it... There is a mistake... If I really study the text I would understand it... (C223)

...the text is easy to understand. That is precisely why I have understood that the sentences are contradictory... the contradictions in the sentences... that is a different business... (C224)

This behavior seems to be influenced by the familiarity with the text. Being more familiar with the text helps to give higher comprehensibility scores, even after the inconsistency has been detected. The following excerpts are taken from interviews with students who had detected the contradiction and explained the problem in the first part of the text, but had rated the comprehensibility as fairly good or good: 

...I think, if it's possible that bonds in ceramics with fissures no longer have this property...

...maybe the text is not so clear, but not for nitric and sulfuric acids...

...the bonds are rigid but when broken they become weak...

III.2. Detection and rejection. This is the behavior deemed appropriate. The student evaluates and regulates his or her comprehension adequately, detecting the contradiction in the first part of the test and judging its comprehensibility as bad or unsatisfactory (scores 1 or 2).

Numerical Results

Table 1 shows number of texts processed according to each of the categories explained above. These are global results for both of the schools.
Inconsistency detection is found not to depend on text at any grade level \(\chi^2(3) = 2.09, p > 0.5\) for 10-year-old students, \(\chi^2(3) = 1.34, p > 0.7\) for 18-year-old students. That indicates an acceptable degree of uniformity among texts. There are significant differences between grade levels in contradiction detection, that is, in the ability of students to adequately evaluate their comprehension: the contradiction detection mean for tenth-grade students is 1.42, while it is 3.27 for twelfth-grade students (\(\chi^2(1) = 6.08, p < 0.001\), for the difference). There are also significant differences between grade levels in percentages of correctly processed texts (category III.2): 18.9% for 10-year-olds, 58.3% for 18-year-olds (\(\chi^2(1) = 84.45, p < 0.001\)). Table II shows percentages of students detecting 0, 1, 2, 3, or all 4 inconsistencies.

### TABLE II

Students Detecting 0, 1, 2, 3, or all 4 Inconsistencies.

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<thead>
<tr>
<th>Grade level</th>
<th>Number of inconsistencies detected</th>
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<tr>
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<td>Grade 10</td>
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<td></td>
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<td>Grade 12</td>
<td>4</td>
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Conclusions

The importance of metacognitive problems in science learning is shown in this article, in particular those related to an inadequate control of one’s own comprehension when reading science texts. As shown in the study, the difficulties which science students have in controlling their own comprehension can be as important as the difficulties in comprehension proper. Although the comprehension monitoring abilities of students within a traditional educational system seem to improve with age, addressing this development directly could be a valuable task for science teachers. Both comprehension evaluation and regulation should be taken into account. The improvement of comprehension evaluation when reading science texts could be based on the theoretical framework provided by text comprehension models like those of Kintsch and van Dijk. As far as regulation is concerned, this study has addressed the incorrect use of schemata, in particular, the students' insensitivity to mismatches between the information provided by the text and the information requirements of the explanatory schema. Lastly, we should point out the limiting influence which metacognitive abilities exist on the improvement of meaningful learning, as already found by other researchers (Novak & Gowin, 1984, pp. 159–160). The effectiveness of improved written materials could be severely diminished unless there is an adequate development in science students of metacognitive abilities like those described above.
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Appendix

Text 2: Acid Rain

The agents which are responsible for "acid rain" are sulphur dioxide and the oxides of nitrogen by-product of industrial processes. Moisture and sunlight help the conversion of these oxides in sulphuric and nitric acids. These acids fall afterwards on the earth's surface. Nowadays acid rain effects on the ecosystem are extremely serious and irreversible. The solution to these problems lies in preventing the reaction which produces the acids. Moisture and sunlight retard the conversion of the oxides of nitrogen and sulphur in acids.

Text 3: Superconductivity

Superconductivity consists in the vanishing of electric resistance. Until now it had only been obtained by cooling certain materials to low temperatures near absolute zero. That made its technical applications very difficult. Many laboratories are now trying to obtain new superconducting alloys. Many materials with this property, with immediate technical applicability, have been recently discovered. Until now superconductivity had been obtained by considerably increasing the temperature of certain materials.

Text 4: Neutrinos

Neutrinos are particles with nearly zero mass. Their detection is very difficult because they do not react to magnetic or nuclear forces. In order to detect them a great amount of water is necessary, placed in a deep place underground, where it could be free from other radiations. A great amount of water is necessary because neutrinos seldom interact with matter. Several countries have set up neutrino detectors which try to obtain new superconducting alloys. Many materials with this property, with immediate technical applicability, have been recently discovered. Until now superconductivity had been obtained by considerably increasing the temperature of certain materials.

Text 5: Ceramics

The molecular structure of ceramics is responsible for their properties. The interatomic bindings of ceramics are strong and rigid. It is impossible to move any of their atoms without inducing the fracture of the bindings. A small gap in the material is enough to cause the catastrophe. Under any external pressure the forces concentrate at the end of the gap causing the fissure to grow. Ceramics are fragile because interatomic bindings in them are weak and not rigid.

References


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