

# Studying Physics Texts: Differences in Study Processes Between Good and Poor Performers

Monica G. M. Ferguson-Hessler  
*Department of Philosophy and Social Sciences*  
and  
*Department of Physics*  
*Eindhoven University of Technology*

Ton de Jong  
*Department of Philosophy and Social Sciences*  
*Eindhoven University of Technology*

The experiment reported aims at finding differences in study processes between students who are good problem solvers and students who are not. Twenty-one students from the Eindhoven University of Technology studied a 10-page text on a physics subject, reporting at regular intervals on their study processes. Protocols of five good performers and five poor performers were analyzed; that is, each statement was classified into 1 of 32 different study processes, and the type of knowledge involved was determined: declarative, procedural, or situational. Good and poor performers did not differ in the number of study processes scored, indicating that both groups studied in an equally active way. They differed in the type of study processes scored: Good students applied more deep processing and less superficial processing than poor students. Poor performers were found to pay more attention to declarative knowledge, whereas good performers tended to pay more attention to procedural and situational knowledge.

Students preparing for an examination in physics attend lectures, do laboratory work, and, last but not least, study texts. To gain insight into what happens during this process of learning, it is necessary to examine specific, individual activities during learning. In an experiment, we explored a possi-

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Requests for reprints should be sent to Monica G. M. Ferguson-Hessler, Department of Physics, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands.

ble relationship between the specific study processes of individual students studying a physics text and the quality of the resulting knowledge base, as measured by examination results on a problem-solving test. Analyzing the process of learning required defining basic study processes in such a way that they could be delimited and discriminated, and also specifying the type of information on which they act.

Research into the learning process has been strongly influenced by the work of Craik and Lockhart (1972), who introduced the notion of information processing at different levels. Although later studies (Craik & Tulving, 1975) elaborated on the concept of *depth of processing* by adding the concept of *breadth of processing*, and although other studies criticized the approach (Morris, Bransford, & Franks, 1977, who introduced the notion of *transfer appropriate processing*), the influence of their ideas was not restricted to basic memory research but had an impact on educational research as well. Marton and Säljö (1976a, 1976b), for example, distinguished between *deep processing* and *surface processing* of information. In surface processing, the student approaches information with the main objective of reproducing it; in deep processing, an effort is made to grasp the meaning of the information and to relate this to prior knowledge. Pask (1976a, 1976b), in his analysis of cognitive style, defined the concepts of *holism* and *serialism*: Holism is a tendency to try to grasp the whole, the main lines, as opposed to serialism, which is a tendency to process information piece by piece.

More recent research has related the learning process to the knowledge base of the learner. The Rumelhart and Norman (1981) theory of learning by schema construction and restructuring, and Larkin's (1979) notion of the "chunking" of physical principles in the memory of experts, have been followed by other studies in the field of science. Chi, Feltovich, and Glaser (1981) used the concept of schemata to contrast the knowledge base of experts to that of novices. Resnick (1983) stressed the importance of constructive cognitive activities of the learner and the role of prior knowledge in these activities. A general discussion of the structure of the knowledge base was given by Resnick and Ford (1981), who, following Greeno (1978), distinguished three qualitative aspects of this structure: *integration* (the internal relatedness of the knowledge base), *connectedness* (its relationship to other things the person knows), and *correspondence* (the agreement with the knowledge base of experts), the last of these encompassing the first two aspects.

To examine individual learning activities, we defined a *study process* as an action on one or more elements of information, for example, relating two statements. Combining the approaches just mentioned, we described the process of acquiring an adequate knowledge base in a subject such as physics in terms of study processes belonging to one of three global categories:

1. *superficial processing*, for example, reading the text, comparing symbols in text and figures;
2. *integrating*, that is, bringing structure into the new knowledge;
3. *connecting*, that is, relating new knowledge to previous knowledge.

The first main category corresponds to superficial processing in the theory of Marton and Säljö (1976a, 1976b), and the second and third to their deep processing.

An important aspect of study processes is the type of information on which these processes act. Meyer (1975) and Dee-Lucas and Larkin (1986) characterized information in a text on the basis of its position in the hierarchy of information and on the basis of its functional role in the physics content, for example, verbal definition. A different approach that is of special interest for subjects such as physics is based on the function of the information in a criterion task, for example, problem solving (de Jong & Ferguson-Hessler, 1986; Ferguson-Hessler & de Jong, 1987). The content of an adequate knowledge base is described in terms of four major types of knowledge:

1. *Situational knowledge* is knowledge about situations as they typically appear in a particular domain. Knowledge of problem situations enables the solver to sift relevant features out of the problem statement (selective perception) and, if necessary, to supplement information in the statement (Braune & Foshay, 1983).
2. *Declarative knowledge*, also called *conceptual knowledge* (Greeno, 1978), is "static" knowledge about facts and principles that apply within a certain domain.
3. *Procedural knowledge* is a type of knowledge that contains actions or manipulations that are valid within a domain. Procedural knowledge is seen here as existing alongside declarative knowledge in the memory of problem solvers, and not merely, as in the case of Anderson's adaptive control of thought (ACT) theory (Anderson, 1983), as a more advanced form of declarative knowledge.
4. *Strategic knowledge* helps the student to organize the problem-solving process by showing the student which stages he or she should go through in order to reach a solution. A strategy can be seen as a general plan of action in which the sequence of solution activities is laid down (Posner & McLeod, 1982).

Elements of knowledge belonging to the first three types are specific, applicable to certain types of problems in a domain, whereas the last type, strategic knowledge, is applicable to a wide variety of types of problems within a domain.

The adequacy of the knowledge base is determined not only by its con-

tent but also by its organization. We found (de Jong & Ferguson-Hessler, 1986) that poor performers organized their knowledge of physics in a superficial manner, whereas good performers had their knowledge organized according to problem schemata with each problem schema containing all the knowledge—declarative, procedural, and situational—required for solving a certain type of problem. Some authors have claimed that this way of organizing knowledge is the most adequate or expert-like way (Chi et al., 1981), but others have stated that the knowledge base of experts has a hierarchical structure (Reif, 1984). These views, however, are not incompatible: Problem schemata may be incorporated as elements of the lower levels of a hierarchical knowledge base (Ferguson-Hessler & de Jong, 1987).

The intention of the present study was to collect detailed information on the study processes that students use when studying a physics text and on the types of knowledge on which these processes act. Marton and Säljö (1976a, 1976b) deduced the nature of the learning processes from the results of the learning (e.g., summaries made by students) or from retrospective questionnaires. For the present study, however, a shift in methodology was necessary. On the basis of earlier studies in the field of reading (Olshavsky, 1976; Waern, 1980), Wouters and de Jong (1982) showed that the thinking-aloud method could be applied to the observation of subjects studying an instructional text. A disadvantage of this method is the enormous wealth of data, including all kinds of irrelevant material. We adapted the method, reducing the amount of data. The students studied a physics text and, at predetermined points, reported orally on their thought processes. A realistic instructional text that discussed a physics topic at the level of the students involved in the study was used.

## METHOD

### Subjects

The method of contrasting groups analysis was used. The subjects in the experiment were first-year physics students taking a course in electricity and magnetism. They received a small financial compensation. On the basis of a previous examination in this domain, they were selected from a larger group (approximately 100 students), as being either good ( $n = 10$ ) or poor ( $n = 11$ ) performers. After the experiment, two groups with sharply contrasting performances were selected by combining the marks mentioned above with the marks obtained on a test that was part of the experiment and the marks scored on a second curriculum examination on electricity and magnetism, which was held a couple of weeks after the experiment. Five students (i.e., the good performers) scored high on all three criteria, and five others (i.e., the poor performers) scored low in all cases. The data of the remaining subjects were not used.

### Experimental Set-Up and Instructional Material

The experiment was designed to imitate a normal study situation. There were, however, two points at which, by necessity, the experimental setting differed from the normal situation: (a) Because of the limited amount of time available for this experiment, the text used was substantially shorter than a normal study text, and (b) in addition to studying the text, the students were asked to perform a few tasks to provide information on their study processes.

The text, written especially for the experiment, dealt with a topic within the domain of electricity and magnetism: the Aston mass spectrometer. Ten pages in length, it contained eight figures and a number of formulae. Interspersed in the text were five exercises that were not compulsory. After studying the text, the students were given a test consisting of seven short problems on the subject of the text.

Under observation of a researcher or an assistant, students studied the text individually in two sessions at approximately 1 week's interval. They were instructed to study as if they were preparing for an examination. The first session lasted 2 hr, with 90 min for studying the text and 30 min for additional tasks (see next section). The second session allotted 30 min for studying the text and another 30 min for the test. In the analysis, data from the two sessions were grouped together.

In normal examinations, students are allowed to use limited personal notes. In this experiment, they were instructed to make such notes for use during the test; the amount was restricted by the sheet provided, which was approximately 6 × 8 in.

### Observation Methods

The most important technique used was the "red dot method." Red dots were placed in the text (spaced one half to one page apart) at suitable locations. The student was instructed to stop studying at the dot and to orally report what he or she had done in the section since the preceding red dot. The responses were recorded. The observer interrupted to provoke precise statements; for example, if the student said, "I related two parts of the text," he or she was prompted to say, "I related Part X to Part Y." Each red dot thus produced a series of distinct statements. Advantages of this method over full thinking-aloud while studying are (a) less interference with study processes and (b) reduction of the amount spoken.

A second technique used was a form of "cued recall" (see, e.g., Peterson, Swing, Stark, & Waas, 1984). During the study session, the researcher made notes of students' observable activities. At the end of the session, these notes were used as cues for questioning the subjects on their study activities: For example, "In Section 2 you underlined two lines of text. Why

did you do that?" While the students were working the exercises that were included in the text, full thinking-aloud protocols were collected. Finally, use was made of the notes students had made during the study.

### Analysis of the Data

The red dot data were analyzed by labeling each statement with its study process and its knowledge type or combination of knowledge types. This required a complete classification scheme (Wouters & de Jong, 1982) that had two functions: (a) to classify a statement and (b) to determine the limits of the statement; that is, where did it end and the following statement begin? The protocols were scored not by propositions but by *meaningful units*, a meaningful unit being a part of a protocol that can be defined by one class from the classification scheme. This implied that the classes of the scheme had to be sharply defined and mutually exclusive.

The four knowledge types were well defined (de Jong & Ferguson-Hessler, 1986; Ferguson-Hessler & de Jong, 1987) and could be attributed in a straightforward way. For the study processes, a classification scheme was developed. To the three main categories (superficial processing, integrating, and connecting), a fourth one was added (other activities) and the four main categories were specified into 21 categories (some of which were subdivided), and a total of 32 different study processes were defined (see Appendix). A few examples will clarify the categories used. Under superficial processing, we find "superficial checking" (e.g., comparing symbols in a figure with symbols mentioned in the text). Integrating contains study processes giving structure to the new knowledge, such as distinguishing major points from side issues (e.g., underlining or boxing an important formula or definition). Connecting is associating knowledge from the text with knowledge already present (e.g., thinking of examples). The main category, other activities, combines miscellaneous study processes, such as giving value judgements (e.g., "This is interesting"). This classification scheme was first applied to data collected in a try-out experiment and successively modified in the final form.

During the analysis, the raters classifying the statements recorded were not aware of the identity of the subjects.

## RESULTS

The results reported in the first two subsections are based on data stemming mainly from the red dot method. The remaining data were used for validation, as described in the third subsection.

TABLE 1  
Total Number (and Percentage) of Study Processes for Each Major  
Category for Good and Poor Performers

<i>Main Category</i>	<i>Good Performers</i>	<i>Poor Performers</i>
Superficial processing	28 (10%)	52 (19%)
Integrating	190 (66%)	155 (56%)
Connecting	33 (11%)	30 (11%)
Other activities	37 (13%)	41 (15%)
Total	288 (100%)	278 (101%)

TABLE 2  
Total Number of Study Processes for Subcategories Falling Into  
the "Integrating" Category for Good and Poor Performers

<i>Subcategory</i>	<i>Good Performers</i>	<i>Poor Performers</i>
2.1 Recognizing integration	58	73
2.2 Integrating by own activities	34	31
2.3 In-depth study of the text	22	2
2.4 Imposing structure not present	24	13
2.5 Making procedures explicit	49	31
2.6 Visualizing	3	5
Total	190	155

### Study Processes

The first interesting result is the fact that the average number of study processes reported for the full text was about the same for good and poor performers, 58 and 56, respectively, whereas individual variations from 38 to 70 were observed.

The nature of the study processes observed can be seen in Table 1, which gives an overview of the total number of study processes in each of the four main categories of the classification scheme. For both groups of students, by far the greatest number of study processes in Table 1 fell into the main category of integrating, structuring the new information presented in the text. Poor and good performers differed in the number of study processes falling into the main category of superficial processing: The poor students applied this process almost twice as often as the good ones ( $t = 2.42$ ,  $p < .05$ ; as the normality of the distribution is not proved, the distribution-free test of Wilcoxon was also applied and confirmed,  $p < .05$ ). This difference is mainly due to the poor students applying the study process "taking for granted" (see Section 1.3 in the Appendix) far more frequently than did good students (14 times vs. 5 times), as illustrated by the following quotation: "If you put that in, you will get Formula (9); I haven't done it but it'll be right."

Table 2 gives a closer look at integrating, the category that was applied most frequently. Categories 2.2, "integrating new knowledge by own activi-

TABLE 3  
Total Frequency of Knowledge Types in the Study Processes  
of Good and Poor Performers

<i>Knowledge Type</i>	<i>Good Performers</i>	<i>Poor Performers</i>
Declarative knowledge	84	115
Situational knowledge	32	17
Procedural knowledge	52	25
Declarative/procedural knowledge	1	3
Declarative/situational knowledge	23	20
Procedural/situational knowledge	7	3
Declarative/situational/procedural knowledge	3	1
Total	202	184

ties," 2.3, "in-depth study of the text," 2.4, "imposing structure not given in the text," and 2.5, "making procedures and assumptions explicit," (see Appendix) are representative of deep processing. Here differences were found between good and poor performers. If the four categories are combined, a significantly higher score is found for good students ( $t = 2.6$ ,  $p < .05$ ). The difference is most obvious for Category 2.3 ( $t = 3.6$ ,  $p < .01$ ; these results were confirmed by the Wilcoxon test). The two study processes in this category are "confronting," that is, confronting the text with other ideas or arguments from the text, doubting the correctness of the text, generating alternatives (12 processes scored with good students and none with poor students), and "deciding that information is missing" (10 processes scored with good students and 2 with poor students). For the other categories, the differences found were not statistically significant, with the exception of one specific study process, "making a derivation independently of the text" (20 vs. 8 processes for good and poor performers, respectively).

Category 2.1, on the other hand, "recognizing and emphasizing integration in the text" was observed more frequently in poor students than in good students; this difference, however, was not statistically significant.

In the main category, connecting, most of the study processes in both groups belong to the type, "recognizing subject matter" (15 and 20 processes for good vs. poor students, respectively), whereas the remaining study processes under connecting were too few to warrant any conclusions.

The fourth main category, "other activities," shows one striking result: The remark, "Everything is clear" (4.3), was scored 6 times by good performers and not less than 18 times by poor performers.

### Knowledge Types

The assessment of the knowledge types involved in the study processes led to the results shown in Table 3, which shows that poor students tended to pay more attention to declarative knowledge than did good students, al-



though this difference was not statistically significant. For procedural knowledge, we found a significant difference in favor of good students ( $t = 2.64$ ,  $p < 0.05$ ; confirmed by Wilcoxon), whereas the difference for situational knowledge did not reach the level of significance. As far as combinations of knowledge types are concerned, hardly any differences existed between good and poor performers.

### Validity

The validity of the scoring of the red dot data was assessed by comparison with the results of the cued recall. For the knowledge types, a second comparison was made with the notes that the students made for the test.

For each subject, the red dot data were classified, and then the cued recall data were classified. A number ( $n = 29$ ) of study processes was observed that had not been reported at the red dots. In all other cases ( $n = 59$ ) except one, the statement made in response to the cue confirmed the classification made of the red dot data.

Poor students worked fewer exercises than did good students (average 2.2 vs. 4.0); therefore, the thinking-aloud protocols provided a limited amount of useful data. The number of study processes per exercise solved supported the general trend of the results from the other methods but were too low to give statistically significant results.

The notes the students had taken during the study were scored independently of the other measures and confirmed the results on knowledge types. The average number of elements of declarative knowledge in the notes of good and poor performers were practically the same, 22 and 21, respectively, whereas situational knowledge showed a great difference, 23 as compared with 7.

## CONCLUSION

Our study shows that good and poor performers are equally active in studying instructional text. This contradicts earlier results of Bransford et al. (1982), and of Wittrock (1974), who stated that good readers are more active than poor readers. We found, however, that this question cannot be approached in such a global way. Good students are more active in some kinds of study processes, particularly those requiring in-depth processing of the information given in the text. Poor students are more active in other processes, especially those associated with superficial processing. Despite this, we conclude that for all students the most important activity in studying a physics text is trying to deduce or to impose structure on the information given. Our results confirm those of Chi, Bassok, Lewis, Reimann, and Glaser (1989) on learning mechanics from the study of examples. The types of self-explana-

tion they found in good, but not in poor students, would typically fall into the deep processing categories in our classification scheme.

The difference in depth of study processes was also reflected in the results for knowledge types. In the text, which was intentionally representative of normal instructional texts, declarative knowledge dominated, whereas procedural and situational knowledge were more implicit and had to be extracted, often by deep processing. Superficial processing led poor performers to concentrate on declarative knowledge and to overlook procedural and (though this difference was not significant) situational knowledge implicitly present in the text.

Today, more and more researchers pay attention to the notion of metacognition, the management of one's own cognitive behavior (Forrest-Pressley, MacKinnon, & Waller, 1985; Garner, 1988). Our study indicates that this is an important area for researchers to explore. Poor students, stating "everything is clear," lack insight into their own knowledge and into the knowledge required in order to solve problems and, thus, are not sufficiently motivated to try to bridge the gap between the two. Here, again, we agree with Chi et al. (1989), who concluded that good students are better than poor students at detecting and monitoring comprehension failures.

In previous studies (de Jong & Ferguson-Hessler, 1986; Ferguson-Hessler & de Jong, 1987), we found that the knowledge base of good performers is organized around problem schemata, whereas poor performers lacked this type of organization. In order to acquire a knowledge base that is structured according to problem types, the learner must restructure information given in the text and also include all necessary types of knowledge. The present study shows that good students, when studying a text, applied these types of processes more often than did poor students and that good students gave more attention to the various types of knowledge than did poor students.

The results of this study suggest that instructional measures aimed at stimulating specific, deep study processes (e.g., explicating, relating, and confronting) might encourage some poor students to change their learning habits and support good students in theirs. Measures in the field of metacognition, such as teaching the existence of functional knowledge types and the role of problem schemata, are another suggestion that follows from our results.

This study also showed that it is possible to assess study processes of students in detail. Research into educational measures intended to influence study processes by means of instruction, either personal or computer assisted, can profit from the results of the present study, and the methods presented here can be used as tools for evaluating the impact of new measures.

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## APPENDIX

### Classification Scheme for Study Processes

Examples in the classification scheme are taken from the protocols obtained in the experiment. Sometimes a description of the student's response is given, sometimes the literal statement.

1. Superficial Processing
  - 1.1. Reading
  - 1.2. Superficial checking: For example comparing symbols in the text with symbols in a figure. *Example*: "Capital *P* and small *p* are confusing; in the figure, small *p* is used a couple of times and that needs a closer look."
  - 1.3. Taking for granted: Not being able to work something out, or not bothering to work it out and deciding that it is probably right. *Examples*: "Formula 3, I am not taking the time to sort that out properly, so I'll take it for granted." "If you put that in, you will get Formula 9; I haven't done it, but it'll be right."
  - 1.4. Memorizing the information given: That is, rote learning.
2. Integrating
  - 2.1. Recognizing and emphasizing integration within the text.
    - 2.1.1. Distinguishing major points from side-issues (e.g., indicating the importance of a part of the text by underlining or boxing a formula or definition). *Examples*: "Formulae 10 and 11 are the most important." "It is especially important that the angle of deflection depends on the mass."
    - 2.1.2. Emphasizing relations given in the text. *Example*: The student goes back to Equation 7 when this relation is referred to in the text.
    - 2.1.3. Quickly glancing through the text at the beginning of the study-

- ing to gain a first impression of major points and general structure of the text.
- 2.2. Integrating new knowledge by own activities.
    - 2.2.1. Drawing conclusions. *Example:* "Suppose  $\beta$  is small; then the arc can be replaced by a straight line."
    - 2.2.2. Finding relations oneself: seeing connections between essential points, organizing the subject matter. *Example:* "Formula 7 has been given before in a different form."
    - 2.2.3. Finding contradictions between one's own conclusions or between one's own conclusions and information from the text. *Example:* The student feels uneasy about his answer to Exercise 2 and wants to check it.
    - 2.2.4. Finding that one fails to see a connection. *Example:* "I do not see what relation this bit of text has to the whole, what they are getting at with the derivation."
    - 2.2.5. Looking for relations.
    - 2.2.6. Making a summary or an outline.
  - 2.3. In-depth study of the text.
    - 2.3.1. Confronting the text with other ideas or arguments, doubting the correctness of the text, generating alternatives for information from the text. *Example:* "I wonder where they have left that  $\frac{1}{2}$ ; they multiplied by 2, but you surely can't do that just like that?"
    - 2.3.2. Deciding that information is missing, observing that something will perhaps be dealt with later, or giving suggestions for additions. *Example:* "I would like to see it proved that there is no separation according to mass in an electric field, but I suppose they will come back to that in the next section."
  - 2.4. Imposing structure that was not already explicitly present in the text.
    - 2.4.1. Structuring without explicit reference to the subject matter. *Example:* "This section is a general introduction to what is coming later."
    - 2.4.2. Comparing a given structure to an ideal structure. *Example:* "Usually the text will say: 'using (6), we substitute here,' but here it doesn't say so."
    - 2.4.3. Structuring of the subject matter. *Example:* "First they treat the formulae, and later they will actually start discussing a mass spectrometer."
  - 2.5. Making procedures and assumptions more explicit.
    - 2.5.1. Checking or verifying derivations. *Example:* "From the first line of Equation 15 to the second is a substitution."
    - 2.5.2. Making a derivation of one's own, independently of the text. *Example:* "Starting from the figure and the initial information

from the text, I tried to deduce the formulae myself. Well, I got somewhere, and I will check whether it is the same as what is said in the text.”

- 2.5.3. Deciding that one can follow a deduction or derivation. *Example:* The student has noted the starting points and says he can derive the formulae himself, which saves rote learning.
  - 2.6. Visualizing, making pictorial images or drawings from information in the text. *Example:* The student tries to visualize Formula 2.
3. Connecting
    - 3.1. Recognizing subject matter or parts of it that one has encountered before. *Examples:* “Secondary schoolwork.” “ $\frac{1}{2}mv^2 = qV$ , I’ve had that before.”
    - 3.2. Recognizing new knowledge in the text as being the cause or result of knowledge already present. *Example:* “Then I just checked why it was like that; it was because at higher temperatures the movement of the molecules is faster, and they can get ionized when they collide.”
    - 3.3. Having prior knowledge available. *Examples:* “The derivative of a constant is zero.” “Using the lefthand rule.”
    - 3.4. Thinking of examples. *Example:* “Then I think of the cyclotron that we are always shown at the university introduction, and then I can indeed imagine that these particles have to travel a long way, and that it is very important that it is focused very precisely.”
    - 3.5. Having associations that are not directly applicable.
    - 3.6. Reformulating in one’s own words (apart from making a summary). *Example:* “So the one leaves it with a slightly larger velocity than the other; therefore, that relation is not quite correct.”
    - 3.7. Finding that one does not know a term. *Example:* “I don’t know what *mg* means.”
  4. Other Activities
    - 4.1. Giving value judgements. *Examples:* “Interesting.” “Whatever could be the use of that?” “That tickles my curiosity!”
    - 4.2. Something was not clear at first reading but became clear later. *Example:* “ $\Delta\beta$  and  $\Delta\alpha$  weren’t clear to me at first; it is not shown in the figure . . . but in the course of reading it became clear.”
    - 4.3. Everything is clear, a particular part of the text offers no problems.
    - 4.4. Residual category. *Example:* “I could not concentrate.”

