Does Physics Instruction Foster University Students' Cognitive Processes?: A Descriptive Study of Teacher Activities

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Abstract

This study aims at giving a systematic description of the cognitive activities involved in teaching physics. Such a description of instruction in physics requires a basis in two models, that is, the cognitive activities involved in learning physics and the knowledge base that is the foundation of expertise in that subject. These models have been provided by earlier research. The model of instruction distinguishes three main categories of instruction process: presenting new information, integrating (i.e., bringing structure into) new knowledge, and connecting elements of new knowledge to prior knowledge. Each of the main categories has been divided into a number of specific instruction processes. Hereby any limited and specific cognitive teacher activity can be described along the two dimensions of process and type of knowledge. The model was validated by application to lectures and problem-solving classes of first year university courses. These were recorded and analyzed as to instruction process and type of knowledge. Results indicate that teachers are indeed involved in the various types of instruction processes defined. The importance of this study lies in the creation of a terminology that makes it possible to discuss instruction in an explicit and specific way.

Current theories of meaningful learning emphasize that learning is an active, constructive, and complex process. Information supplied to the learner by books, lessons, or lectures has to be processed, that is to say critically assessed, structured, and practiced, in order to yield knowledge. This has implications for the task of instruction, which cannot be limited to supplying information to students, but must also support and stimulate students in their learning process. In this study we have attempted to extend earlier research on knowledge and learning in the domain of physics to cover instruction, in particular the task of supporting and stimulating learning in this domain. In other words, we attempt a first step in the direction that Resnick

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(1989) has described as moving from theories of expertise and acquisition to a theory of intervention. This first step is a systematic description of teacher activities in physics instruction, as seen from the point of view of fostering students' cognitive processes.

With the growing emphasis of recent research on the role of subject matter knowledge in expertise (see for instance the overview in Chi, Glaser, & Farr, 1988), and on the need of teaching cognitive skills in the context in which they are to be used (Perkins & Salomon, 1989), there are reasons to supplement general theories of learning and instruction (Ausubel, Novak, & Hanesian, 1978; Gagné & Briggs, 1979; Reigeluth, 1983, 1987; Merrill, 1983, 1987) with theories tailored to the needs of specific types of subject matter. This study approaches the teaching-learning process from the point of view of content and structure of the knowledge base to be acquired.

Cognitive theories of learning stress the central role of the cognitive activities of the learner (Resnick, 1983, 1984, 1989): Knowledge acquisition requires processes of bringing structure into new information and relating it to prior knowledge, processes that go much further than simply encoding information provided by the teacher. In other words, the result of teaching is strongly dependent on the active processing of the content by the learner. The teacher does not shape the result of the learning process in the sense that the student acquires a copy of what is taught. All the same, the teacher can play an important role in stimulating students to carry out learning processes that are essential in knowledge acquisition. This can be done in instruction activities that explicitly demonstrate various ways of structuring knowledge, and that stimulate students to carry out this type of process on their own. Our discussion illustrates the close relation between the instruction process of the teacher and the study process, or specific cognitive activities of the student.

A Systematic Description of Physics Instruction

Research into the specific aspects of instruction in physics has been reported by several authors. Reif, Larkin, and Brackett (1976) have developed a method of teaching learning and problem-solving skills in physics. They conclude that by this method, consisting of programmed instruction, practice, and feedback, students can be taught cognitive skills that are essential in physics, but which are not acquired by students in usual lecture courses. Hestenes (1987), a physicist, has approached the problem of teaching from the point of view of the cognitive skills needed for problem solving in physics. He stresses the important role of constructing and working with models as a strategy, and concludes that this type of strategy is what students need to be taught. His principles were tested in an experimental course on mechanics. Weak students profited from this approach (Halloun & Hestenes, 1987). Caillot and Dumas-Carree (1990) have reported on an experiment of the same type, which involved secondary school students who were taught specific "cognitive aids" for the building of problem representations in mechanics. Students in the experimental group showed better conceptual understanding and performed better than students in the control group.

These experiments indicate that it is possible to design instruction that fosters students' understanding and performance. Keeping in mind the central role of learner activities in acquisition of knowledge, we conclude that the stimulation of cognitive activities in the learner must be central in this type of instruction, and that a systematic description of instruction activities must be based on a model of the study processes found in students learning physics (Ferguson-Hessler & de Jong, 1990).

Learning Physics: Creating an Adequate Knowledge Base From External Information

The concepts of information and knowledge were contrasted in the introduction: Information is outside the learner and may take on a wide variety of forms, from printed matter to digital signals from a satellite; it is the object of learning activities. Knowledge on the other hand is the result of the learning process, and is inside, in the memory of the learner. Ideally, it is tuned to the type of application for which it is intended, and may be a simple copy of external information, like a telephone number, but in meaningful learning it is more often a highly structured selection of elements from the information studied.

In general, the objectives of a first year university physics course are centered on problem solving and experimental work. A knowledge base that is adequate for these applications has a well-defined content, and this content is not only to be described in terms of elements of subject matter, but also in terms of types of knowledge. Declarative knowledge (definitions, facts, laws, etc.) has to be supplemented by knowledge of procedures (actions that can be carried out on elements of declarative knowledge), characteristics of situations where principles and actions are applicable, and knowledge of strategy (a systematic approach to problem solving).

Success in problem solving requires not only a complete knowledge base, but also a well-structured knowledge base. Resnick and Ford (1981) have distinguished different aspects of the quality of a knowledge structure, two of which are related to the organization of the content: integration or the internal relatedness of the elements of the knowledge base, and connectedness or the relations of elements of the knowledge base to other domains.

One way of organizing knowledge so as to realize integration and connectedness is building (conceptual) problem schemata. This concept was used by Chi, Feltovich, and Glaser (1981) to describe knowledge of mechanics. A problem schema consists of elements of knowledge, centered around a fundamental concept or law, and contains all the knowledge necessary for the solution of a certain type of problem. This type of knowledge structure facilitates both the creation of an initial representation of the problem (de Jong & Ferguson-Hessler, 1991) and the subsequent solution. In the further discussion of learning and instruction in physics, we consider a set of interrelated problem schemata to form a model of an adequate knowledge base (de Jong & Ferguson-Hessler, 1986; Ferguson-Hessler & de Jong, 1987).

The acquisition of a knowledge base consisting of a set of problem schemata requires a considerable amount of cognitive processing of incoming information and attention to the various types of knowledge. In an earlier study we investigated the cognitive aspects of this learning process by observing individual activities of first year students learning physics from a text, and classifying these specific cognitive activities with the aid of a taxonomy of study processes (Ferguson-Hessler & de Jong, 1990). This taxonomy has two dimensions: the type of process and the type of knowledge forming the content of the process. Three main categories of study processes were defined:

1. Collecting and encoding new information.
2. Integrating or bringing structure into new information.
3. Connecting or relating new knowledge to prior knowledge.

The first category is typical of what Marton and Säljö (1976a,b) call "superficial processing" whereas the second and third categories correspond to their "deep processing." By subdividing the three main categories and defining specific study processes within these, such as "drawing conclusions," "verifying a derivation," or "thinking of examples" we created a taxonomy that defines the process dimension of the model.

With the aid of this model we were able to classify the study processes observed along the two dimensions of type of process and type of knowledge. The result of the observations of two groups of students, good and poor performers, can be summarized as follows: Good students devoted more effort to deep processing than weak students did, and poor performers tended to concentrate on declarative knowledge, whereas good performers also paid attention to procedures and situations.

Research Questions

Our study of learning in physics suggested that two types of instructional intervention are needed in this process: demonstrating and stimulating deep processing, and directing attention to procedures, situations, and strategy. In addition, some attention is needed for meta-knowledge, that is, knowledge of the different types of knowledge that are characteristic of the subject matter. (Our concept of meta-knowledge is not to be confused with "meta-cognition" or knowledge of monitoring and regulation.) This instructional principle is what Glaser and Bassok (1989) call "the teacher as model and coach": In addition to presenting examples of well-integrated and/or connected elements of knowledge the teacher demonstrates deep processing activities and the active construction of meaning. In this study we develop a systematic description of the teaching activities needed to produce this type of learning in physics, and investigate the activities actually found in university lectures and problem-solving classes. Individual coaching is not included in the description, being irrelevant in lectures and, in our experience, infrequent in problem-solving classes.

The following specific questions were investigated:

1. Is it possible to create a taxonomy for instruction processes, analogous to that for study processes, that makes it possible to describe in a systematic way the cognitive teaching activities of teachers giving physics instruction?
2. Can this description be validated from actual teaching? If so,
3. Do teachers engage in instruction processes that have the potential of demonstrating and stimulating deep processing of subject matter?
4. Do teachers, in their teaching, give explicit attention to procedures, situations, knowledge of strategy, and meta-knowledge?

A Descriptive Model of Activities Involved in Physics Instruction

Using the taxonomy of study processes described above as a model for learning skills, we constructed a descriptive model of cognitive activities involved in physics instruction, defining the concept of instruction process as a limited and specific cognitive activity of the teacher, analogous to the study process of the student. Consequently, instruction processes are described along two dimensions, process and content. As for the process dimension, three main categories are defined:

1. Presenting new information.
2. Stimulating the process of integrating new knowledge.
3. Stimulating the process of connecting new knowledge to prior knowledge.

Presenting new information can take on several forms, such as describing a phenomenon, introducing a law or relation and explaining its meaning, demonstrating a procedure or the

symmetry properties of a situation. Live experiments, film, television, video(disk), computer simulations, and other techniques can play a role in this category of instruction processes.

Stimulating integration is a teacher activity that helps the student to bring structure and meaning to new information, thereby contributing to the creation of knowledge. Examples of instruction processes of integration are: indicating main issues, relating elements (for instance relating a formula to the characteristics of situations where it is valid and useful), comparing situations or laws, drawing conclusions, and giving explicit arguments for choices.

By stimulating the process of connecting new information to knowledge already present, the teacher helps the students to bring sense and understanding to the new information, thereby contributing to the creation of knowledge. Examples of instruction processes are introducing real-world examples, offering a new explanation for a well-known phenomenon, and showing how known results are special cases of a new, wider theory.

The processes belonging to the main categories “integrating” and “connecting” are important, not only because of their content (e.g., the comparison between two formulae and the situations in which each of them is useful), but also because they demonstrate ways of processing information so as to yield knowledge (in this case the explicit comparison of parts of problem schemata).

The elements of knowledge on which the instruction process acts can belong to any of the four types of knowledge or be a combination of these types of knowledge. Of special importance is knowledge of strategy, which is seldom found in textbooks and is often treated in an implicit way in problem-solving classes. In addition, instruction processes that teach meta-knowledge are needed. For instance, reference to the various types of knowledge and to the role they play in the steps of the problem-solving strategy is effective stimulation for the construction of problem schemata.

A Taxonomy of Instruction Processes

To create a taxonomy of instruction processes that could be used for the classification of teacher activities, we subdivided the three main categories above into specific instruction processes. The examples mentioned in the previous section were organized in a logical structure and complemented so as to cover all aspects of each main category.

In order to describe all aspects of instruction it was necessary to add a fourth main category, which contains processes of organization and motivation, intended to create suitable conditions for learning, such as “specifying learning goals” and “activating prior knowledge.” A few examples of instruction processes so defined are given in Figure 1.

The second dimension of the model is the type of knowledge forming the content of the process.

The taxonomy so created can be considered to form a tentative answer to the first research question, asking whether it is possible to create a taxonomy for instruction processes.

Observation of Teaching

Answering the second research question (validation of the descriptive model of physics instruction) required observation of physics instruction, given in practice by experienced university teachers to first year students. The data so collected also make it possible to answer the third and fourth research questions: What instruction processes and knowledge types do teachers employ in their teaching?

0. Creating suitable conditions for learning.

0.1. Specifying the learning goal of the lecture/class or the coming part thereof. Example: "What would happen in this situation if.....? That is what we are going to investigate."

1. Presenting new information.

1.1. Presenting new facts or definitions, laws or phenomena, procedures or situations; demonstrating an experiment, live or via film, television or video, using a computer simulation. Example: Demonstrating the fact that $E = 0$ inside a conductor by placing a volunteer inside a large Faraday cage with a bunch of thin paper strips in his or her hand.

2. Integrating knowledge.

2.3. Relating, comparing, formulating expectations. Example: "Now, this is true for an isolated conductor, but is not valid for a conductor connected to ground."

3. Connecting new to prior knowledge.

3.1.2. Relating to knowledge of other subjects. Example: Comparing an electrostatic field to the field of gravity.

Figure 1. Examples of instruction processes.

Sources of Data

With the cooperation of a number of colleagues it was possible to record and analyze lectures and problem-solving classes in various first year courses on the subject of electricity and magnetism. All the lectures and classes were given by different members of staff of the Eindhoven University of Technology. Lectures, attended by 60–150 students ($n = 4$), and problem-solving classes, attended by 20–25 students ($n = 5$), were audiotaped and notes were taken of what was written on the blackboard. One deviation from this technique was the videotape recording of a couple of lectures given by a senior lecturer in the last term before his retirement, at which time the preparations for data collection were not yet finished.

Prior to analysis, the integral text of the tape recordings of lectures and problem-solving classes was transcribed.

A special case was a so-called "press-the-button" lecture during which each student could answer questions on problems by pressing a button. After the presentation of each part of the subject matter, a problem was posed by the lecturer, and the students were guided through the solution in a series of yes/no or multiple choice questions. At the time of this study, press-the-button lectures were advocated at our university as an efficient and cheap replacement for problem-solving classes (Poulis, Massen, & Monhemius, 1986, 1987). We were interested in comparing the cognitive activities of students who attended these lectures and traditional forms of teaching.

Analysis of Protocols

The examples of instruction processes given in Figure 1 show the complexity of the processes defined in the classification scheme, and demonstrate the impossibility of separately scoring each proposition spoken by the lecturer. As in an earlier study (Ferguson-Hessler & de Jong, 1990), we used the concept of a meaningful unit, the smallest unit of text that made sense both from the point of view of the context and from the point of view of the processes defined in the classification scheme. The segments of the text column of Figure 2 are examples of meaningful units. The limits of such a unit are not always self-evident, which makes it impossible to carry out a straightforward measurement of interrater reliability. Therefore each protocol was

Cat.	ToK.	Seq.	Text
1.1	DSP	Begin	Thus, this sphere, having a charge Q , will assume
	An		a potential $Q/4\pi\epsilon_0 R$. In other words; in this case, what is Q divided by the potential of that thing? That is $4\pi\epsilon_0 R$, and that is the capacity of a sphere. And then, on the sly, I add: with respect to infinity.
2.1	DS		What I am really calculating is the capacity of a system of bodies; the sphere being one and something at infinity the other body. I am not interested in the shape because that does not make any difference.
3.1.1	DSP		But somebody might be so clever as to say: a couple of weeks ago you just told us that one can make a choice of one's own as far as potential goes. We could very well fix the potential of the sphere at zero; only differences of potential make sense, is that not so?
2.2	D		And with a potential zero Q/U becomes infinite, and I would have a capacitor with infinite capacity. But, obviously, it does not work that way.
3.1.1	DS		Because when we are talking about potential in this context, we really talk about the work I have had to carry out in order to charge that sphere; that is the concept of potential that plays a role here. And that charge comes from infinity; it does not come from this surface.
2.4	SP		And that is the reason that I have to take the potential with respect to infinity. So, really, I am calculating the system sphere with respect to infinity.
1.1	D	End	The capacity of such a sphere is also called the
	An		selfcapacity to indicate that there is something special with this concept.

Cat. = (sub)category of instruction process: 1.1 New information;
 2.1 Main issues; 2.2 Confronting, evaluating; 2.4 Conclusions;
 3.1.1 Relating to prior knowledge of subject.
 ToK. = type of knowledge: Declarative, Procedural, Situational;
 DS etc. combinations of these.
 Seq. = Sequence of instruction processes, e.g. An = Analysis.

Figure 2. Part of the protocol of a lecture (translated from Dutch). Each coded element is a meaningful unit of instruction. The full description of the codes for instruction processes is given in the Appendix.

scored by two persons who decided together on the limits of meaningful units and their classification as to type of process and type of knowledge.

Because, in our view, a classification scheme should consist of processes of the same degree of complexity, processes such as "analyzing" or "synthesizing" could not be included in the scheme, but were considered as a sequence of less complex processes from the taxonomy.

The taxonomy described above was used as a first version of a classification scheme for the analysis of the protocols. It was first tried out on the lectures that had been videotape recorded. Some adjustment of the level of complexity of the processes defined was necessary. Also, a few definitions were clarified, and examples from the protocols were added to the scheme.

All recorded lectures and problem-solving classes were analyzed with the aid of this classification scheme; Meaningful units were identified and coded as to process in accordance

with the classification scheme and as to content according to the type or combination of types of knowledge. (During the course of the analysis, a few minor additions to the classification scheme were necessary; they were recorded and entered into all protocols.) The final classification scheme for instruction processes is found in the Appendix. The result of this analysis was a classified protocol of the type shown in Figure 2.

In view of the small number of protocols available, we reused the videotapes, contrary to the usual habit of discarding protocols used for the development of a classification scheme. We chose an explorative approach to the data collected. The information from each classified protocol was condensed into a frequency matrix, specifying the frequency of each combination of instruction process and knowledge type found.

Results

The tentative answer to the first research question was given in the terms of a descriptive model of physics instruction. The previous section described the adjustment and application of this answer in the analysis of protocols of physics instruction. Thus the first two research questions have been answered: It was possible to construct a taxonomy for instruction processes, which could be validated as a description of physics teaching, given in practice. All the categories defined in the model were found in the protocols of physics teaching collected. Also, all propositions spoken by the lecturers could be classified as belonging to one of the categories of the taxonomy.

The answer to the third research question, on the instruction processes teachers engage in, can be found in the information contained in Table 1, in which the information on instruction processes from the frequency matrices has been condensed. A first glance at Table 1 makes it clear that the total number of instruction processes in a period of twice 45 minutes shows a large variation. Partially this is due to differences in style of teaching, partially to the amount of subject matter treated. Lecture 4 is the press-the-button lecture; inherent to this method is a great number of short instruction processes caused by the division of each problem solution into yes/no or multiple-choice questions. In the case of the problem-solving classes the differences in numbers of processes are partially accounted for by the fact that some teachers let the students work in couples or small groups during part of the time allotted for the class.

Noticeable in Table 1 is the fact that two important instruction processes, belonging to main category 0, "creating suitable conditions for learning," get very little attention. These are the processes 0.2, "motivating students," and 0.3, "specifying and activating prior knowledge."

Looking into the main categories of instruction processes we see from Table 2, where the distribution of Table 1 has been summed up, that all teachers engage in all main categories of instruction processes. The individual differences are large, however, and are not caused by random variations only: $X^2(24, N = 9) = 95.26; p < .001$. Despite these differences between individuals, systematic differences also exist between the distribution of instruction processes in traditional lectures, press-the-button lectures, and problem-solving classes ($X^2(6, N = 3) = 60.60; p < .001$). In the traditional lectures we find more processes of presenting new information than in problem-solving classes and press-the-button lectures. Processes of stimulating integration and connecting new to prior knowledge are more frequent in problem-solving classes than in traditional lectures, and connecting plays a greater part in press-the-button lectures than in the other forms of teaching. These results fully agree with the different teaching goals of traditional and press-the-button lectures and problem-solving classes.

In Table 3 we look more closely at the instruction processes related to deep processing. Three types of processes have been selected: 2.1, specifying main issues; 2.2–2.4, relating,

Table 1
Distribution of Instruction Processes: Type of Process: Percentage of Total Number

Instruction processes	Lectures (1-4)				Problem-solving classes (5-9)				
	1 (%)	2 (%)	3 (%)	4 ^a (%)	5 (%)	6 (%)	7 (%)	8 (%)	9 (%)
0.1	4	4	11	5	4	6	4	3	3
0.2	1	2	0	1	1	1	1	0	0
0.3	5	1	2	1	0	0	0	6	0
0.4	9	12	5	15	6	4	1	9	1
0.5	4	4	1	1	2	4	3	11	8
1.1	40	29	34	15	15	27	21	31	29
1.2	0	2	0	6	0	0	2	3	4
2.0	3	4	3	0	7	14	1	11	7
2.1	9	11	10	3	15	11	9	6	6
2.2	1	2	4	1	0	1	4	3	10
2.3	5	9	9	6	6	1	9	3	11
2.4	8	3	8	3	11	3	12	3	4
2.5	0	0	0	16	2	1	6	0	3
3.0	5	5	4	14	14	9	16	6	8
3.1.1	5	10	5	10	8	4	4	6	3
3.1.2	2	1	2	2	6	0	0	0	3
3.1.3	1	0	1	0	1	1	4	0	0
3.2	0	0	0	0	3	11	2	0	0
Total number	183	161	136	287	160	97	164	35	72

Note. The full description of the processes belonging to the codes are given in the Appendix. 0.1 = specifying goal; 0.2 = motivating; 0.3 = specifying prior knowledge; 0.4 = practical remarks content; 0.5 = other practical remarks; 1.1 = new information; 1.2 = repeating; 2.0 = using without comment; 2.1 = main issues; 2.2 = confronting, evaluating; 2.3 = relating comparing expecting; 2.4 = conclusions; 2.5 = questions; 3.0 = using prior knowledge; 3.1 = relating knowledge; 3.1.1 = within subject; 3.1.2 = other subject; 3.1.3 = world knowledge; 3.2 = other.

^aPress-the-button lecture.

confronting, and concluding; and 3.1, relating to prior knowledge (see the Appendix for a full description). The differences between individual teachers seem to dominate this Table, and a X^2 test confirms this impression: $X^2(16, N = 9) = 41.51; p < .001$. However, the press-the-button lecture contributes 37% to the X^2 sum, and if the test is repeated without this lecture, the individual differences do not reach the confidence level of $p < .05$, this in spite of the fact that one of the lecturers and two of the other teachers have a high percentage of processes of the type "relating, confronting, concluding" (approximately 25%), but some of the others have few or very few of these essential instruction processes. Between the traditional lectures and the problem-solving classes there is little difference in the occurrence of this type of instruction processes, whereas the press-the-button lecture shows less attention than the rest for instruction processes stimulating integration.

An answer to the fourth research question, on the type of knowledge the instruction processes are directed to, can be found in Table 4, which contains information on the way teachers divide their attention between different types of knowledge and combinations of types. Again, the differences between the distributions of the teachers are larger than random variations to be expected: $X^2(56, N = 9) = 249.1; p < .001$. A comparison of the group of traditional

Table 2
Distribution of Instruction Processes: Main Categories; Percentage of Total Number

Main category	Lectures (1-4)				Problem-solving classes (5-9)				
	1 (%)	2 (%)	3 (%)	4 ^a (%)	5 (%)	6 (%)	7 (%)	8 (%)	9 (%)
0	23	23	19	23	13	15	9	29	12
1	40	31	34	21	15	27	23	34	33
2	26	29	34	29	41	31	41	26	41
3	13	16	12	26	32	25	26	12	14

Note. 0 = creating suitable conditions for learning; 1 = presenting new information; 2 = stimulating the integration of knowledge; 3 = connecting new to prior knowledge.

^aPress-the-button lecture.

lectures with press-the-button lectures and problem-solving classes indicates that systematic differences exist between these groups ($X^2(14, N = 3) = 86.3; p < .001$). Press-the-button lectures have a high fraction of instruction processes without subject matter content, traditional lectures devote more processes to declarative knowledge than problem-solving classes do, and procedures and situations get more attention in problem-solving classes than in lectures. Looking into the combinations of types of knowledge, we find a relatively large amount of attention for DS (declarative + situational knowledge) in all types of teaching, but less for the other combinations, especially in the press-the-button lecture. DPS combines the types of knowledge that function together in applications (declarative + procedural + situational knowledge). Two of the lecturers (2 and 3) and one of the instructors (8) tune their teaching to this combination, but the rest have relatively few instruction processes where the three types of knowledge are treated together.

A striking result is the absence of strategic knowledge in all protocols except one, and also the total absence of meta-knowledge.

The interaction between the two dimensions of the model is investigated in Table 5, where the average percentages of some important (main) categories of instruction processes are divided according to the content of the process. The most striking feature of Table 5 is the fact that very few instruction processes belonging to the main category "Creating suitable conditions for learning" have any subject matter content. This means that processes such as "specifying goals," "motivating," and "specifying prior knowledge" are mostly not directed at specific elements of knowledge, but mainly at names of chapters and numbers of exercises. In present-

Table 3
Instruction Processes Related to Deep Processing: Percentage of Total Number

Category	Lectures (1-4)				Problem-solving classes (5-9)				
	1 (%)	2 (%)	3 (%)	4 ^a (%)	5 (%)	6 (%)	7 (%)	8 (%)	9 (%)
2.1	9	11	10	3	15	11	9	6	6
2.2-4	14	14	21	10	17	5	25	9	25
3.1	8	11	8	12	15	5	8	6	6

Note. For a full description of the instruction processes see the Appendix. 2.1 = main issues; 2.2-4 = confronting, relating, conclusions; 3.1 = connecting to prior knowledge.

^aPress-the-button lecture.

Table 4
Distribution of Instruction Processes: Type of Knowledge; Percentage of Total Number

Instruction processes	Lectures (1-4)				Problem-solving classes (5-9)				
	1 (%)	2 (%)	3 (%)	4 ^a (%)	5 (%)	6 (%)	7 (%)	8 (%)	9 (%)
None	17	20	19	26	15	19	9	20	14
D	37	24	27	26	30	22	26	17	13
P	6	3	3	11	12	15	8	3	3
S	10	4	3	11	9	12	11	14	14
DP	7	1	10	2	16	10	11	6	0
DS	15	20	25	17	12	8	20	17	35
PS	5	10	2	2	4	7	7	0	12
DPS	3	18	11	2	1	4	9	23	8
Str	0	0	0	0	0	2	0	0	0
Total number	183	161	136	287	160	97	164	35	72

Note. D = declarative knowledge; P = procedural knowledge; S = knowledge of situations; Str = strategic knowledge. DP, etc. = combinations of types of knowledge.

^aPress-the-button lecture.

ing new knowledge we see a fairly even division between the types of knowledge and their combinations in the lectures, little attention for combinations in the press-the-button lecture, and attention for procedures and situations but few processes directed at the combination DPS in the problem-solving classes. In the processes that stimulate deep processing we see most of the attention devoted to declarative knowledge and to the combination DS. The problem-solving classes, however, divide these activities between all types and combinations. A statistical

Table 5
*Interaction Between Process and Type of Knowledge:
 Average Percentage of Instruction Processes, Divided According to Content*

Process	Group	None	D	P	S	DP	DS	PS	DPS
0	1-3	19	1	0	0	0	0	0	0
	4	21	0	0	0	0	1	0	0
	5-9	12	0	0	0	0	0	0	0
1.1	1-3	0	7	3	4	4	7	3	7
	4	0	3	5	3	1	1	0	1
	5-9	0	2	4	6	3	2	3	1
2.1-4	1-3	0	9	0	1	1	8	2	1
	4	0	3	0	2	0	6	0	0
	5-9	0	9	5	3	3	6	2	3
3.1	1-3	0	5	0	0	0	2	0	0
	4	0	4	1	0	0	4	1	1
	5-9	0	4	0	1	1	3	0	0

Note. D = declarative knowledge; P = procedural knowledge; S = knowledge of situations; DP, etc. combinations of types of knowledge; 0 = conditions for learning; 1.1 = presenting new knowledge; 2.1-4 = deep processing, integration; 3.1 = Idem; connecting to prior knowledge. 1-3 = lectures; 4 = press-the-button lecture; 5-9 = problem-solving classes.

analysis has not been carried out as these fairly small frequencies have relatively large uncertainties.

Discussion and Conclusions

The most important conclusion to be drawn from the results is that the teaching of experienced university teachers can be described in terms of instruction processes belonging to the two-dimensional model developed in this study. In addition, all types of instruction processes defined on the basis of a description of the knowledge base and the learning process were indeed found in the lectures and problem-solving classes studied. The title of this article raised the question whether physics instruction fosters students' cognitive activities. The results of the study of teacher activities indicate that, to a large extent, this is indeed the case. Intuitively, academic teachers not only supply information but also try to stimulate the cognitive activities of students; some teachers more often and more consistently than others. However, little or no attention is paid to motivating students and to specifying and activating the prior knowledge needed as anchorage (Ausubel et al., 1978) in the learning process. The press-the-button lecture did not emerge as a good alternative to traditional teaching with respect to stimulation of deep processing.

On the whole, teachers divide their attention between declarative, procedural, and situational knowledge and also treat these three types of knowledge in their relation to each other in the way that they are used in problem solving. Again, individual differences are large; some teachers, for instance, pay considerably less attention than others to the combination of various types of knowledge.

Traditional lectures have more attention for declarative knowledge, and problem-solving classes for procedures and situations. On the other hand, knowledge of strategy is given no attention in the lectures and, strikingly, practically no attention in the problem-solving classes either. Nor did we observe any form of meta-knowledge in the lectures and problem-solving classes.

The significance of this study, however, is not primarily the possibility created of comparing the teaching of individual teachers, but the terminology that has been created, and that opens up possibilities for reasoning about instruction:

1. To evaluate the quality (in the sense of stimulating the learning process) of a lecture or a problem-solving class and to relate this to teaching goals and curriculum.
2. To document the activities of experienced and renowned university teachers, for instance with a view to making these available to novice teachers in courses and supervision.
3. To formulate guidelines for the construction of course material, where aspects of instruction such as integration and connecting are included.
4. To formulate guidelines for the construction of programs for computer-assisted instruction, which are based on a cognitive theory of learning and intervention for the specific knowledge base to be acquired.

A systematic description of teacher activities is not more than a first step in the further development of theories on physics instruction. The next step is to investigate the actual effect of these activities on the cognitive processes of students. This investigation will require extensive experiments in laboratory and field situations.

Modern theories of cognitive psychology make a clear distinction between meaningful learning and rote learning. Rote learning leads to the (more or less) literal reproduction of

information received. Meaning, on the other hand, can only be constructed by deep processing of information: evaluation and organization of new elements of knowledge to form an adequate structure. In this view the teacher is not the source of knowledge. Structure and meaning are not ready-made products that can be transferred from teacher to student. What the teacher can do is to stimulate students to construct meaning and structure themselves, in other words to offer students a form of cognitive apprenticeship, where he or she acts as a model (Collins, Seely Brown, & Newman, 1989). The results of this study offer some suggestions for teacher activities. Motivation and activation of prior knowledge can be combined in discussing a demonstration experiment showing a result that could not be predicted from students' prior knowledge alone. Knowledge of strategy can be demonstrated as it functions in problem solving, not as a general prescription for solutions, but by explicitly stating the role of each step taken in the course of finding a solution. In the same way, meta-knowledge can be taught by pointing out the importance not only of what should be learned (declarative knowledge), but also of how this knowledge is applied (procedures), and when it is useful (situations).

Ohlsson (1990) states that it would appear that the constituting idea of most modern theories of cognitive psychology can be summarized as follows: "Cognitive processes are caused by the execution of stored programs that operate on an internal symbolic representation of the world" (p. 563). He concludes that this theory is a theory of action rather than of knowledge, and thus can serve as a basis for theories of acquisition of skills, but not of knowledge: Such theories are of limited use in a theory of instruction. A theory of the content, structure, and growth of knowledge is needed before a theory of teaching abstract knowledge can be formulated; this according to Ohlsson.

This analysis is wholly in line with the principles of research on knowledge acquisition and instruction in physics that have been reported in this study. One reason for the choice of physics is that in this field the construction of meaning is more difficult than in many other subjects. The same is true, however, for other fields of science and technology. An extension of the study described here to other science and technical subjects is straightforward, but requires extensive analysis, which can only be carried out by an interdisciplinary team: Knowledge of cognitive theories of learning and instruction have to be combined with subject matter expertise and teaching experience.

We would like to express our sincere thanks to the colleagues who trusted us to record and analyze their lectures and problem-solving classes and thereby made this investigation of teacher activities possible. Our thanks are also due to the late Wim Vaags and to Wim van Haeringen who supervised this study, to Christine ter Huurne who assisted in typing and analyzing the protocols, and to Niels T. Ferguson who wrote the conversion programs for the analysis.

Appendix

Classification Scheme for Instruction Processes

0. Creating Suitable Conditions for Learning

0.1. Specifying the learning goal of the lecture/class or the coming part thereof. Example: "What would happen in this situation if . . . ? That is what we are going to investigate now."

0.2. Motivating students to acquire the knowledge (to be) presented. Example: Mentioning a well-known application.

0.3. Specifying the prior knowledge that forms the point of departure in the treatment of a new theme; activating this knowledge. Example: "Last week I treated . . . , and we came to the conclusion that . . . But, as I told you, this is not the whole story, and today we are going to look at some other aspects of that law."

0.4. Practical remarks, relevant for the content. Example: "This question is discussed in the lecture notes on page . . ."

0.5. Other remarks or activities, which are not relevant for the content. Example: "There is too much noise in the class."

1. *Presenting New Information*

1.1. Presenting new facts or definitions, laws or phenomena, procedures or situations; demonstrating an experiment, live or via film, television or video, using a computer simulation. Example: Demonstrating the fact that $E = 0$ inside a conductor by placing a volunteer inside a large Faraday cage at high voltage with a bunch of stripes of thin paper in his/her hand.

1.2. Repeating elements of new information without integrating or connecting. Example: Repeating in other words what has already been said.

2. *Integrating Knowledge*

2.0. Using elements of new knowledge without any explanation. Example: Applying a new formula or definition.

2.1. Specifying main issues; indicating relevant elements of a procedure of a situation. Example: "What you do here is essentially this: proving that αv^2 is a constant; then the rest follows logically." "Crucial in this situation is that the charge of the conductor is a constant."

2.2. Confronting; evaluating. Example: "With potential $V = 0$ and $C = Q/V$ we find C to be infinitely large, but that is not the way it works!"

2.3. Relating, comparing, formulating expectations. Example: "Now, this is true for an isolated conductor, but is not valid for a conductor connected to ground."

2.4. Drawing conclusions. Example: "We have to conclude, that in addition to the charge on the plates of the capacitor another type of charge is present."

2.5. Posing questions that require an actual answer from the students (in the press-the-button lecture). Example: "Who says alternative a is correct?"

3. *Connecting New to Prior Knowledge*

3.0. Using elements of prior knowledge without any explanation, tacitly assuming them to be known. Example: Applying a formula or a definition that has been treated in an earlier lecture or class.

3.1. Relating elements of new knowledge to prior knowledge.

3.1.1. Relating to prior knowledge of the subject, reminding students of this knowledge. Example: "A couple of weeks ago we concluded that the point where the potential is zero can be chosen freely, because only differences of potential make sense."

3.1.2. Relating to knowledge of other subjects. Example: Comparing an electrostatic field to the field of gravity.

3.1.3. Relating to general knowledge of the world. Example: "We fancy an atom to be made up of a nucleus and a cloud of electrons, bound together by a rubber band."

3.2. Other activities. Example: Answering questions by a student on some detail.

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