

Metacognition and transfer within a course or instructional design rules and metacognition

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ABSTRACT

A metacognitive strategy for doing research, included transfer, was taught in a course of nine afternoons. The success of this course raised some questions. How do the students learn? How does metacognition play a role? The course was designed in accordance with several instructional principles. The course was divided into three domains in which the strategy was introduced, practised, and applied respectively. Literature research revealed four possible metacognitive variants that correlate so it was supposed that implementing them all helped to reach the objectives of the course. The relation of the metacognitive variants with the instructional principles is described. To study learning the students were divided into three groups (weak, moderate, good) by their marks for other courses. The performance of the groups in each domain was monitored by their marks, scoring of metacognitive skills, questionnaires, observations, and time keeping. The moderate students scored as high as the good ones for the strategy in the last domain, a unique result. The metacognitive development of the other metacognitive skills was not linear. The conclusions are that the success of this course can be explained by a system of double sequencing and an interaction of all metacognitive variants, and that instructional design rules for metacognitive and cognitive objectives are different.

If teachers in higher education want their students to learn a strategy of permanent value they usually have to do that within the course for which they are responsible. Since such a strategy can be presented in the form of heuristics only and not in the form of a procedure, cookbook, or algorithm, it is difficult to teach and learning usually takes a long time. This case study is about a successful first year's lab course of two month in which nine afternoon sessions were available to learn a strategy for doing experimental research. The course was about electrical Network Analysis and ran parallel with lectures on theory and problem solving classes.

Another problem usually is that the teachers can not guide the students themselves but depend on teaching assistants (TA's). TA's can help the students with calculations, measuring instruments, and other practical things, but are not well able to teach a strategy. For instance, the students had to determine by themselves whether the outcome of a measurement was correct in stead of asking the TA's is this correct, sir? Therefore the students had to learn the strategy from the lab guide and the assignments.

Due to the high requirements the passing rates of this course in the past were below 50 % of the graded students. The course was redesigned with a significant increase of passing rates to over 80 %, stable over 8 years (84 % in the year of this research). The outcome was that more students learned the content and the strategy in less time with less effort of the TA's (Tattje and Vos, 1995). It was found that more of the moderate students were able to pass. The present analysis of the improved course should explain the reasons for this from a metacognitive viewpoint.

Permanent value means that the strategy learned should be transferable to other courses. This transfer cannot be left to the students since few will apply the strategy in other domains out of themselves. Preferably such transfer should be trained by learning the strategy in one domain and applying it in another domain. The question was how the students learn the strategy. From an empirical point of view this was a kind of action research on instructional design, from a theoretical viewpoint metacognition could play an important role here.

Metacognition can roughly be defined as cognition on cognition where cognition involves all aspects and determinants of intelligent behaviour. A strategy of permanent value is applicable to

several domains of knowledge, i.e. it is about or above cognition of the domains, and thus must involve metacognitive aspects. The strategy under study contained e.g. the instruction to find the necessary information by oneself. This is considered here as metacognitive task information. More information can be found in the author's Ph.D. thesis (Vos, 2001). The objective of this course thus is to learn a metacognitive strategy.

The central idea was that metacognition also played other roles in learning, e.g. because the topic was difficult to imagine, and required a high effort from the students to integrate different representations of objects, in words, in formulae, and in schematics. The theoretical problem thus was how metacognition was involved in the course, both in the objectives and in the instructional principles used in the course. The further questions are how development of metacognition was stimulated and how metacognition did develop.

This research contributes to an understanding of the form, place, and role of metacognition in learning in higher educational practice. It adds data on metacognition in content to other research on metacognition in educational practice (e.g. Hacker, Dunlosky, and Graesser, 1998; Elshout-Mohr, 1992; Forrest-Presley et al., 1987). This study presents an outline of the metacognitive variants that can be met in a course, both variants that are learned and variants that stimulate the learning.

This research brings instructional principles (or instructional design rules, cf. Dijkstra, 1997) and metacognition closer together. It makes the difference between instruction for cognitive objectives and for metacognitive development more clear. And it contributes to an explanation of how instructional principles work in terms of metacognitive development. Such an outline has implications for the theory about metacognition, for new explorations, and for future experiments.

The central question addressed here is how metacognitive development can explain the success of the course. To answer this question the following subquestions are successively answered. How was the course designed from an instructional viewpoint to teach students a strategy including transfer? What are the cognitive and metacognitive variants that can be distinguished? What are the relations between the instructional principles and the metacognitive variants, and how was development of metacognition stimulated? How did metacognition develop? These questions were studied by describing the design of the course, by a theoretical study of metacognition based on a literature survey, by measurement of progress in metacognitive performance, and an analysis of the data.

In the following an overview is given of the methods used to answer the subquestions. The methods are elaborated in later sections.

To start with, the design of the course included the following features. For learning transfer the students had to practise transfer from one domain to another. The lab course was divided into three domains of three afternoons each. The three domains were characterised as introductory, time domain, and frequency domain. In these three domains the electrical objects and the necessary calculations differed fundamentally. The frequency domain is the most difficult to understand because frequency as a domain variable is even more abstract than time is.

Secondly, a literature search on metacognition was carried out. Theoretical considerations revealed four possible metacognitive variants: task information, experiences, strategies, and knowledge. Note that where in literature metacognitive tasks are mentioned, it is preferred here to call this variant metacognitive task information to distinguish it from metacognitive actions in executing the task. A major subproblem here was how to separate metacognitive from cognitive aspects. The characteristics of the variants are described.

Thirdly it is described how the metacognitive variants are implemented in the instructional principles used. Metacognitive variants strongly correlate and thus it was supposed that an implementation of these all into the course would give faster results in metacognitive development. It also turned out that to stimulate metacognitive development, instructional design rules for cognitive development had to be ignored or adapted.

Fourthly, the experimental problems were how to monitor the learning of the metacognitive strategy and the metacognitive development. A restriction was that no control group design was possible because of ethical reasons: a redesigned, better course should not be reserved to a selection of students but to all. The way the students learned in this course was studied by measuring the progress of weak, moderate, and good students, and their efforts (differential development design).

The students were divided into three groups by their marks for other courses. The students had to

report on their thinking, doing, and results in a logbook for each domain. The logbooks were assessed on insight and a systematic approach to experimentation. The performance of the students was monitored by marks for the entrance test and for the logbooks. Also some metacognitive skills were scored from the logbooks, interactions among the students and with the teaching assistants were observed, and questionnaires were filled in by the students in each session, among others to monitor the use of time for home work.

The results are presented in the following chapters. The limitations of this research, possible generalisation, and implications will be discussed before a conclusion is reached.

1 DESIGN OF THE COURSE: INSTRUCTIONAL PRINCIPLES

The course was designed to teach application of the content of electrical Network Analysis and a systematic strategy to approach experimental research. The content of the course was the behaviour of electrical networks, based on their physical components, the physical connections among these components, the signals the components exchange, and the properties of the network as a whole like structure and linearity. This behaviour has to be calculated, measured, represented, described, and validated. This article focuses on the features of the course that have to do with higher order skills and learning the systematic strategy, another higher order skill. Higher order skills include metacognitive components. At the end of section 3 an integrated overview is given of the instructional design rules used and the metacognitive variants involved (see Table 1).

1.1 THE OBJECTIVE: THE STRATEGY TO BE LEARNED

The main objective of the course was to teach a systematic approach to experimental investigation, i.e. the goal was to develop a strategy. The strategy to be learned consisted of many constituent skills, like being able to formulate a hypothesis (a metacognitive skill) and the skill to operate a measuring instrument (a cognitive skill). The term metacognitive skill is used here when the skill has mainly metacognitive components, cognitive skills contain more cognitive components (see later). The objective of the laboratory course was comparable to teaching thinking skills as investigated by Reif and St. John (1979).

The strategy was presented as a list of 62 items ordered into six phases: (a) problem formulation; (b) information acquisition including calculations; (c) formulation of hypotheses; (d) test experiment; (e) discussion and conclusion; (f) reporting (Vos, 2001, Appendix B, Table B.1). The strategy was formulated by a Delphi method, starting from an adaptation of an earlier strategy (Ruijter, 1979). Some features of this strategy are elaborated here: validation of knowledge, gathering information, 'cookbook' construction, and detecting the influence of the measurement instruments.

Firstly, to validate knowledge, the results of the calculations and the experimental results should be compared in the conclusion: the outcome of an observation (or measurement) and the outcome of a theoretical description (or calculation) should match within the limits of the accuracy of the measurement. The model of the strategy thus included a kind of validation of knowledge in an empirical way (cf. De Groot, 1961). In any case it should diminish uncertainty as to whether the outcome of a measurement was 'correct' or not.

Secondly, the model also contained the instruction to gather information. In this way it was clarified that information acquisition should be the responsibility of the student, not of the teacher or TA, and also that information should not always be available at the right place or time. The instructional principle of just-in-time information, i.e. providing information when needed, cannot be applied here.

Thirdly, another feature was the instruction to construct a 'cookbook' procedure of the measurements. In old fashioned labs the 'cookbook' is the recipe to carry out measurements, and this recipe is prepared by the teachers. Such a recipe includes a choice of steps to be taken, an ordering of these steps, the schematics to build the experimental set-up, the tables in which the measurement results have to be noted, the outline of the graphs for the representation of the results, etc. Here the recipe has to be constructed by the students.

Finally, detecting the influence of the measurement instruments was sometimes necessary when the

comparison of calculation and measurement results showed a misfit. Such a misfit is not obvious. The results always contain statistical variations, thus never are exactly equal. Any deviation outside the statistical range may be the effect of a wrong calculation or a wrong measurement. Only when these sources of deviations are not the case, the effect of the measurement instrument on the quantity that has been measured has to be taken into account. This effect can sometimes be diminished by a different set-up or a different instrument, but otherwise has to be calculated and corrected for.

The way to validate knowledge was presented in the general lab guide of the faculty as the way that engineers and scientists work (Kluft et al., 1988). The strategy with its six phases was explained in the lab guide of the course by an example of a simple investigation in which all phases were present (Tattje and Vos, 1990).

1.2 THE INSTRUCTIONAL PRINCIPLES

As in all good instruction the students were motivated, goals were set, and prior knowledge was activated, but in a different way from the usual one: the goals were higher and prior knowledge needed to be better organised. The motivation was focused on higher goals: the students were invited, challenged, and forced to think about their own knowledge and skills in relation to the task and to take a metacognitive viewpoint.

The instructional principles used in the construction of the course were preventing cognitive overload, scaffolding, fading, learning from peers, and multiple representations. These principles were adjusted to a higher level in relation to the metacognitive objectives of the course. Learning the strategy and practising transfer were made possible by the division of the course into three domains.

Scaffolding and fading

In the first domain the strategy was taught by presenting a description of its application in four assignments. These descriptions served as examples of application of the strategy. By carrying out the assignments of the first domain the students should detect the structure of the strategy: the meaning of its components, and their relations, and thus develop a mental schema of the strategy. Cognitive overload was avoided because the introductory domain used electrical objects and calculations that both were familiar from high school.

In the second domain some hints to apply the strategy were given but no description. Here the strategy had to be practised in a domain with new theoretical properties (like linearity) and new calculations (solving differential equations and convolution integrals). The structure should be clear by now, but the choice of items to apply should get attention. Here access to the strategy was trained. In the third domain neither hints nor a description were given. Now the strategy had to be applied on the students' own initiative, in the most difficult domain (calculating and using the complex (in a mathematical sense) transfer function). Thus fading of scaffolding the strategy in written instruction was applied across the domains.

Another type of fading was applied. The information needed to carry out the assignments was intentionally separated from the assignments and spread over the sections of the lab guide. In the first domain hints to study the lab guide were given together with the assignments. In the second domain references were made to the relevant parts of the lecture notes. In the third domain no references to any information needed were given. In the third domain even information was needed from lectures that still had to be delivered.

It has to be noted that this instructional procedure is different from providing information just in time to carry out the assignments. The information provided was information about gathering information. This was information on a higher level. Fading was here applied with respect to the written instruction to gather information. The information needed was not provided at the moment it was needed in the assignments, but was present somewhere else in the lab guide, in lecture notes that were already treated, or even in lectures notes that were not yet.

To diminish the need for help (i.e. for scaffolding) the students were told to work in pairs. Constructing a 'cookbook' for the experiments was facilitated by co-operation of the students. To detect the influence of measuring instruments discussions could be held with the other student, but also with other pairs. Thus the students could ask each other questions and explain to each other what

they knew. This can be considered as a form of reciprocal teaching, learning from peers, or co-learning.

The role of the TA's was not scaffolding, not giving an orientation on the task to be done, and not checking the results of the measurements. Their roles were to help with the electrical equipment, to grade entrance test and help with remedial assignments, to grade the logbooks, to give oral feedback to the students, and to help the students to help themselves. The TA's should help mainly by asking facilitating questions, and by referring to sources of information in stead of giving explanations.

Stimuli and feedback

The criteria used for grading the logbooks were a systematic approach in the students' work and insight shown. The actual performance of the students was usually not taken into account, but in stead the performance as they described it individually in the logbooks. To give the students the opportunity to learn and make mistakes, the final mark was mostly based on the mark for the third domain, especially when the trend in the marks was a rising one. When a declining trend was visibly the TA's could take into account earlier marks to calculate the final mark.

By grading from the start of the course on, the students should be able to compare the effort they put into the lab course with the marks they got. This feedback by early marking gives the students opportunity to adjust their effort, allocate more or less study-time, or to choose between continuing or dropping out. The TA's also gave oral feedback on the work of the students before the next logbook was started. In this way feedback came just in time for the students to be able to improve their approach and/or their reporting (just-in-time feedback).

Increasing complexity

Another way to prevent cognitive overload was to sequence the assignments in each domain from simple to complex. Increasing complexity here means that knowledge and skills practised in earlier, simple, assignments are integrated and added into new knowledge and skills in later assignments. Some assignments were given as homework, others were done during the labs. In homework assignments the students had to read information, answer questions and solve simple problems with that information, and solve cognitive conflicts (see later).

During the labs preparative, comparative, and open assignments were given. In preparative assignments the students had to practise the use of new instruments or a new use of familiar instruments. In comparative assignments the students had to compare two methods. This could be either because a choice had to be made among two methods of measurement, or because a calculation and a measurement had to be compared. Finally open ended assignments were added in which the students had to choose the goal and the method by themselves.

The intended final level of the course was comparative assignments. The open assignments were given in domain one and two only, but not in domain three (cf. Table 2). The idea was that in this way the students practised their knowledge, skills, and the strategy in an open environment, and that this would promote the mastery of strategy beyond that in comparative assignments, the final level required. This educational strategy was called boosting.

One could also say that the students in this way got an impression about the difficulty of the final level (maybe a little bit deceptive because the difficulty in the third domain was of a different character). This is similar to the principle of 'added difficulty' that gives poorer performance during the acquisition phase in learning but better retention (Schmidt & Bjork, 1992).

Organising knowledge

Cognitive overload was prevented by introducing the strategy in a familiar domain, and by sequencing assignments from simple to complex. A third method to prevent cognitive overload was to give an advance organiser in the sense of Ausubel (Ausubel, Novak, & Hanesian, 1978; Vos, 1991; Vos, 1995). Such an advance organiser should activate prior knowledge, and should present a framework in which the topic to be treated fits.

An advance organiser should preferably consist of not more than seven chunks of knowledge. Reading the advance organiser should contribute to the access of a coherent structure of knowledge and the further development of such coherence. Concentrating the knowledge of electrical Network

Analysis into a coherent framework of a few chunks, was done by a Delphi method.

The networks represent real electrical circuits with components like resistors, batteries, and measuring instruments. The representations of these electrical components in words and symbols (to communicate), in formulae (to calculate with mathematics), and in schematics (for measurement purposes) needed to be integrated with the components as they can be observed in reality. Also the structure of the real circuit and the representation of it in a schematic are different models that need to be integrated into one mental model. The same applies to the form of the real electrical signals, the pictures the students get from measuring instruments, and the mathematical expressions they get from calculations.

To integrate the difference between reality and representations a higher viewpoint has to be taken. To challenge the students to do this, cognitive conflicts were introduced. For instance, the difference between reality and representation was shown in the schematics of a circuit. A schematic is a representation of a circuit. The same circuit can be represented by different but equivalent schematics (see Figure 1). Some assignments contained a conflict between frequent misconceptions and the task. For examples, see Vos (2001). Cognitive conflicts were also intended to arise spontaneously between the students within a pair because their conceptions about what happens or what is the task differ.

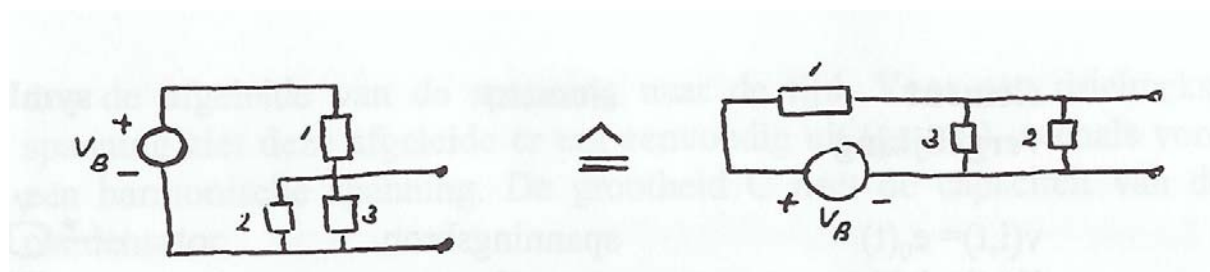


Figure 1. Equivalent representations of an electrical circuit.

Finally, it must be taken into account that co-operation of students in learning (co-learning) often leads to results that were not intended but still useful. Some examples are the knowledge of a student that she is good in explaining things to others. Or the knowledge that a fellow student often starts too fast to do something with the apparatus and jumps to a solution, often in the wrong way, and therefore has to be asked what he is doing and why. Other examples have to do with the content: sometimes a resistor starts to smoke and burn, or a capacitor explodes and forms a beautiful spiral across the lab tables.

The description of these instructional principles or instructional procedures made it already necessary to introduce terms like metacognitive information, cognitive conflicts, and to take a higher level viewpoint. This suggests that what happens here may be clarified from the viewpoint of metacognition.

2. COGNITION, METACOGNITION AND THEIR VARIANTS

Cognition is often taken as an equivalent of knowledge, and metacognition can be taken as something that extends cognition or as a part of cognition in general. The later view is taken here: metacognition is a part of cognition.

In this article cognitive and metacognitive variables are used to describe instruction and learning on a high level. This means that a complete set of variables is needed, on an abstract level: all aspects of instruction and learning have to be spanned. Thus metacognition here involves more variables than sometimes is the case.

Therefore cognition is analysed first, then metacognition. The differences between cognition and metacognition are described, as well as the characteristics that distinguish metacognitive from cognitive variables.

Cognition

In the past metacognition was not **distinguished** as a part of cognition (e.g. Posner, 1989), nor as a part of intelligence to which cognition is strongly related. Simon and Kaplan (1989) described cognition on an abstract level as the capacity to use intelligence in executing tasks, or the capacity to execute cognitive tasks. De Groot and Van Peet (1997) understood cognition as equivalent to cognitive functioning. By this definition, all combinations of psychological functions can play a role, like observing, memory, thinking, making a sound choice and deciding, but also intuition and processing emotions. Cognition can be the act or process of knowing, including both awareness and judgement, and can also be a product of this act (Wellman, 1985).

Cognition thus involves knowledge (the act of knowing, the faculty of being able to recall, as well as the results of it), skills (both as the capacity to execute a task and as actions), emotions (emotional states, including feelings like the effect of an electrical shock), and task information. Task information is the information that comes to the student and is needed to execute a task, and includes lab guides, lecture notes, books. On the other hand, task information also includes the results of the task: the answers given, products assembled, reports produced.

Task information represents for the students' cognition the interaction with the outer world: teachers, TA's, and fellow students. Seel and Winn (1997) pointed out that sharing of cognition takes place between an individual and a medium in which the signs that carry the information are represented (distributed cognition). The idea of distributed cognition extends cognition to include signs, as in task information. Task information can also come from the subconscious mind, e.g. when one realises that something needs to be done and the task becomes aware.

The variables knowledge, skills, emotions, and task information are independent in the sense that you can have e.g. persons with much knowledge on pedagogy, who cannot raise their own child well, or persons who are very enthusiastic to start a task but do not understand the assignment well, etc. This does not mean that the variables are uncorrelated as independent random variables are. The variables are correlated in the sense that they may vary in a correlated way for certain populations of subjects. It may be e.g. that for trained students more knowledge on research methodology correlates with better skills in doing research, but this may not be the case for students who attended a lecture on research methodology.

The content of knowledge and the focus of the other variables can be oneself (intrapersonal, e.g. Flavell, 1979), another person (interpersonal), or all people, and the world (universal). In this paper world content is extended to include the world of science with its physical objects, construction technology, observation instruments, and scientific methods.

Cognition thus is a generic term for several variables that interact in human behaviour. It cannot be measured itself, but its variables can, here distinguished in knowledge, skills, feelings, and task information, that relate to persons, objects, or the world. The view in this paper is that all four variants are needed to give a complete description of cognitive enterprises in specific cases such as studying electrical Network Analysis. But also a metalevel within cognition can be distinguished.

Metacognition

Knowledge of **metacognition** was developed in research on memory (e.g. Flavell & Wellman, 1977). Flavell (1971) first used the term metamemory, and later the term metacognition. Metacognition involves "active monitoring and consequent regulation and orchestration" of cognitive processes to achieve cognitive goals, according to Flavell (1976, 1987). Monitoring, regulation, and orchestration could take the form of checking, planning, selecting, and inferring (Brown and Campione, 1977); self-interrogation and introspection (Brown, 1978); interpretation of ongoing experience (Flavell & Wellman, 1977); or simply making judgments about what a person knows or does not know about how to accomplish a task (Nelson, 1996; Metcalfe & Shimamura, 1994).

Kluwe (1982) stresses that human beings can understand themselves as agents of their own thinking, and can also evaluate themselves as such, as self-regulatory organisms. Thus it is often stated that metacognition is thinking about thinking. In the present paper metacognition is 'defined' as cognition about cognition.

The **concept** of metacognition has been used and studied in many domains. Different authors in different fields use different terms, often with overlapping meaning (cf. Cox, 2005). Where the terms

self-appraisal, social intelligence, etc. are used, different variants of metacognition or combinations of variants are, in fact, being studied in different contexts, often mixed with cognitive variants.

In order to separate cognition from metacognition a more precise analysis of both is required. We start here with the variants of metacognition. To illustrate the **variants** of metacognition an example in learning from Flavell (1979) follows. Suppose that you prepare yourself for an examination. "You wonder (metacognitive experience) if you understand the chapter well enough to pass tomorrow's exam, so you try to find out by asking yourself questions about it and noting how well you are able to answer them (metacognitive strategy, aimed at the metacognitive goal of assessing your knowledge, and thereby, of generating another metacognitive experience)".

Flavell called the variants metacognitive strategies (or actions), metacognitive tasks (or goals), metacognitive experiences (involving feelings), and metacognitive knowledge (or beliefs). Flavell distinguished three types of metacognitive **knowledge**: the knowledge "that you can learn most things better by listening than by reading" (intrapersonal metacognitive knowledge), "that one of your friends is more socially sensitive than another" (interpersonal), or "that you may forget later what you can easily bring to mind now, and you may remember later what you cannot bring to mind now" (universal).

Metacognitive experiences are combinations of cognition and affect (Efklides, 2003), or in the present definition: affects on cognition. They influence e.g. the handling of tasks. For instance, the feeling of difficulty may lead a person to start a task or not. Both metacognitive knowledge and experiences can lead human beings to select, evaluate, revise, and abandon cognitive tasks and the strategies used in the execution of the task. This suggests that metacognitive thoughts are **deliberate**, planned, intentional, goal-directed, and future-oriented mental actions that are used to accomplish cognitive tasks. Thus many researchers use the label metacognition for conscious and deliberate thoughts that have other thoughts as their object, but others include also nonconscious processes as is done in this article.

Flavell (1979) stated that most metacognitive knowledge contains **interactions** between metacognitive knowledge, task variables, strategy variables, and experiences. Sternberg (1998) pointed out that metacognition interacts with many other aspects of the student: abilities, personality, learning styles and so on. In the abilities domain many variables correlate and "it is easy to slip into causal inferences from these correlations, despite admonitions to the contrary from elementary statistics teachers". This could mean that a sequence of variants identified in a case study, is not necessarily a causal chain, but may involve parallel processes, or processes constructed by the author as equivalents of what was going on. Care has to be taken here.

With the definition of metacognition as cognition on cognition it is easy to extend these examples. E.g. the knowledge that you can keep only seven chunks of information in your working memory or short term memory (Miller, 1956) can be considered as universal metacognitive knowledge. The same applies to the knowledge that concepts and skills can be distinguished and are different (declarative metacognitive knowledge), as well as the knowledge that a concept can be taught by giving examples, by defining it, and by presenting a prototype (procedural metacognitive knowledge).

Metacognition is **related** to several psychological constructs. It includes motivation for a task as a metacognitive experience on the presentation of task information. It is broader than self-regulation in that it includes metacognitive knowledge as well (Flavell, 1979). The relation between intelligence and metacognition is not yet very clear. Intelligence seems to be more a characteristic of human behaviour without any internal hierarchy involved (e.g. Veenman et al., 2002).

Metacognition is in the present view considered as a general phenomenon in human mental and social cognitive behaviour. It includes four variants just as cognition does. Metacognition is the higher level part of cognition. From now on the word cognition means the lower level part of cognition, unless otherwise stated ('cognition in general'). It has to be kept in mind that knowledge, skills, tasks, and strategies often are a mixture of metacognition and cognition. Nevertheless an attempt is made to separate metacognition and cognition.

Metacognition vs. cognition

The descriptions found show that it is possible to separate the phenomena of cognition and

metacognition in two ways. First their content or **objects** differ: metacognition is about cognition, i.e. about mental processes and the accompanying feelings. This entails that metacognition can be an object of metacognition itself, however confusing this may be. Human beings somehow are able to know, monitor, regulate, "observe and construct", their own processes that cannot be observed or formed otherwise.

When we take this feature as a definition of the objects of metacognition, it leaves for the objects of cognition the concrete things in the real world, which can directly, unprocessed, be observed, and remembered. Cognition involves observing and handling the things in the world. The objects of cognition not only include material objects, persons, events, physical phenomena, etc. but also signs in the forms of words, figures, diagrams, and graphs.

The second difference lies in the **functions** of cognition and metacognition. The function of cognition is to solve problems, to bring a cognitive task to a good end, and to keep contact with the real world outside. The function of metacognition is to regulate a person's cognitive functioning in solving a problem or handling a task. For instance to understand the task information, to feel how difficult the task is, to choose to start the task or not, and to value the knowledge that is generated by the task. The function of metacognition may extend to future cognitive functioning as well, i.e. may involve learning.

Flavell (1979) assumed in his model on metacognition that metacognition and cognition differ in their content and function, and are **similar** in their form and quality. These assumptions are taken here as defining statements. This means that both cognitive and metacognitive variants can be acquired, be forgotten, be correct or incorrect, etc. Metacognitive knowledge can be conceptual as well as declarative and procedural (Chi, 1987). Conditional knowledge, being knowledge on the application of cognition, is in this view by its nature metacognitive. Information on task information ('you have to collect the necessary information yourself') is metacognitive task information.

Knowledge, task information, strategies, skills, and feelings or experiences can all be both cognitive and metacognitive in character (Flavell, 1987). Therefore it is useful to highlight distinguishing characteristics.

Metacognitive or cognitive?

Some characteristics are useful to tell the difference.

When input of mental activity comes from things that other people can observe too, this activity is supposed to be cognitive of nature. When the input of mental activity is from mental processes that cannot be directly observed by others, it will be considered metacognitive. Relating cognition to observation and metacognition to imagination is in accordance with the six levels that Van Parreren (1979) has discovered in the act of abstraction.

On the first two levels (which are identified here as cognitive) mental actions take place with objects that are visible as concrete materials, or of which a vivid memory is available. On the highest two levels mental actions take place on imaginary objects, created by thinking itself (like the set of all numbers; cf. Vos, 1987a, 1987b), which can be identified as metacognition now. The intermediate levels relate to the use of signs as an aid.

Cognition thus embraces knowledge about concrete objects/ signs (including memories thereof), skills to handle them without reference to their meaning, information about tasks on such objects, and the emotional states that come with the handling of concrete objects and signs.

This means, e.g., that reading a text (just by processing its words) is a cognitive task, while 'turning on the meaning' (understanding or comprehension) is a metacognitive one (Garner, 1987, p. 121). The last skill, understanding, involves monitoring meanings and making comparisons.

Comparing different activities, or methods to calculate, or methods to measure something, involves monitoring one's own skills and mental processes, and thus is a metacognitive skill. The assignment to compare several methods thus stimulates metacognitive development. In problem solving, monitoring the progress in terms of checking the steps already taken is cognitive, but monitoring the progress in terms of nearer to the goal, is metacognitive.

To make deliberate choices about the next step in problem solving is regulation of mental processes and thus metacognitive. Regulation can be done on the basis of monitoring the ongoing cognitive process (this is called executive control), but always a comparison is needed with the meaning of the

task information and the goal.

Such a comparison leads to a choice for the most efficient or the most accurate method. Making a choice for the most efficient method or activity is thus a metacognitive action. Choosing an action or a goal always involves a metacognitive action. This applies e.g. to reasoning and discussion. Here the choice between different arguments is a metacognitive action, but reproducing arguments a student had learned by heart, not.

The knowledge of the reason for this choice ('most efficient method') is metacognitive knowledge. Similarly, knowledge about the validity of a research result is metacognitive knowledge, as is knowledge about the truth of a statement. This metacognitive knowledge may be personal (e.g. 'it is true for me', 'I know I am strong in explaining things') or universal ('It can be proven that this is true', 'everybody knows I am good at explaining things').

Reflecting on the execution of a task, on your ideas and your approach, is a metacognitive skill because it involves monitoring your (mental) actions. Keeping a diary is as metacognitive as individually writing a logbook is. For the formulation you have to choose what is important, and to regulate your wording such that the meaning of your words and your thoughts during the task are equivalent, aspects that make writing metacognitive (cf. Katz and Warner, 1988). However, the formation of the letters on paper, or typing the words in your computer, are cognitive skills.

Reading, taken as reading the signs and words, is a cognitive skill. However, understanding requires a comparison of different parts of the text, a choice of the most important parts of the text (not the biggest letters but most important for its meaning), and thus is a skill that requires again metacognition. In reading for understanding readers 'turn on the meaning': they monitor the meaning of what they read in comparison with what they already know. They regulate the reading by reading back, or skimming forwards to find definitions of unknown words.

Making a good summary of a text is a metacognitive skill, highlighting words is not necessarily metacognitive. Thus it remains difficult to decide what is metacognitive or not. For instance, giving an argument for a conclusion in reasoning is not necessary metacognitive (but any regularities in the truth values of the arguments certainly are, as is argued in Vos, 2004).

3. METACOGNITION AND INSTRUCTION

An attempt will be made to relate the instructional design rules and metacognition. The metacognitive elements put forward are a selection from those that play a role in the lab course. They are the most important and the most easily related to the instruction. Many more metacognitive elements than those presented could be found, however.

It will be clear by now that metacognition plays a dual role in the instruction. Firstly, the objective of the course is to develop a metacognitive strategy to be able to systematically approach experimental research. Secondly, metacognitive variants are used to attain this goal. So metacognition is both learned and used to learn.

The instruction to apply a systematic strategy, is cognitive information as long as the strategy does not have any meaning in terms of mental action or cognitive process. The words of the hint are empty for the students, in the beginning. Later, when examples of the strategy have been met, both the strategy and the hint to apply it, become metacognitive.

By fading of the written scaffolding of the strategy, the students get metacognitive task information: they have to do it on own initiative. The instruction to gather information yourself, is in itself metacognitive information. Fading of this instruction is again metacognitive task information.

The strategy item "Construct a 'cookbook' procedure" starts as cognitive task information but its meaning is to make a planning of actions. Thus it is intended as metacognitive task information. This (metacognitive) understanding develops by co-operation and discussions among the students about what is meant. The same applies to other items.

The stimuli given by early marking are intended to give the students that do not understand the objective of the course, a push. Especially the students who get low marks in the beginning while they think that their usual effort is enough to pass this course, will get a feeling that more effort needs to be made. This metacognitive experience can have varying effects: the students raise their effort, or they

drop out.

Combining the mark with just-in-time feedback gives the students another metacognitive experience: the feeling that they still are able to improve their disappointingly low mark. This depends of course on the quality of the SA's: they should be able to explain how the students can improve.

Boosting across the domains again gives the students a push: their metacognitive experience is that the difficulty of the course is higher than the actual requirements at the end of the course. Finally the introduction of cognitive conflicts gives another metacognitive feeling: there is a need for a solution of the conflicting conceptions (or for consensus if the conflict is between the students of a pair).

The sequencing of the assignments serves preventing cognitive overload by sequencing metacognitive skills. The homework assignments are intended to reconstruct knowledge and to solve simple cognitive conflicts. In preparative assignments new skills are synthesised from (parts of) existing skills under the influence of task information. In comparative assignments methods have to be compared, a metacognitive action. In open assignments a goal and a method have to be chosen, again metacognitive actions.

Reporting has already been discussed as a metacognitive skill: the students have to reflect on their thoughts and actions, and word the most important characteristics thereof, i.e. give a summary of what they did. All these elements are highly metacognitive. In this way TA's can assess in how far the students know what they did, and give feedback on lacking insight or systematic in approach.

The advance organiser not only served to activate prior knowledge, but also to give coherence to the knowledge on the topic in about seven chunks. For this also coherence in the representations is needed: words, formulae, schematics should be considered as different representations of one abstract entity behind it, the electrical network. Also mental models are formed of properties of the circuits like linearity, based on the invisible real entities that the electrical signals are. Such knowledge is about measurements and calculations and thus metacognitive.

Other aspects are just mentioned. Co-learning leads to better knowing oneself and each other. Ones strong and weak points. Also emotional states may play a role, especially when students feel that the required effort is too high in the circumstances of the moment (illness, family problems). Although these emotional states or their effect on coursework may not be aware, they can have important effects (e.g. Case and Gunstone, 2004),

In Table 1 an overview is presented of the metacognitive variants, the related instructional material, and the instructional procedures as described here. The sequencing is discussed in the next paragraph.

Table 1

The instructional principles, the instructional form, and the related metacognitive variants

Instructional principles	Instructional form	Metacognitive variants
<i>Objective</i>		<i>MC strategy (goal)</i>
Practise transfer of strategy	Course divided into three domains	Systematically approaching experimental research, with insight
<i>Fading and scaffolding</i>		<i>MC Task information</i>
Fading of written scaffolding	Examples/ prompting/ nothing	Apply a systematic strategy
Fading of referencing	References to information/ - / -	Get information yourself
Information separated from assignments	In different sections of lab guide In lectures parallel/ later	
Learning from peers	Co-operating pairs of students Discussing with fellow students	e.g. Construct a 'cookbook' procedure e.g. Detect influence of measuring instrument
<i>Stimuli</i>		<i>MC Experience</i>
Early marking	Entrance test Mark for logbook in first domain	Feeling of more effort to be made
Just in time feedback	Oral feedback before next logbook	Feeling of being able to improve
Boosting across domains	Open assignments in domain 1 & 2	Belief about difficulty of the course
Cognitive conflicts	In content/ tasks/ conceptions	Feeling of need for solution/ consensus
<i>Increasing complexity</i>		<i>MC skills (implicit)</i>
Sequencing assignments within domains	Homework assignments (reading, problems) Preparative assignments Comparative assignments Open assignments	Reconstructing knowledge Solving cognitive conflicts Synthesising new skills Comparing methods
Reporting	Individual logbook writing	Choosing a goal and method Reflecting on task execution & wording
<i>Organising knowledge</i>		<i>MC Knowledge</i>
Activating prior knowledge	Advance organiser	Coherence of topic
Representing objects	In words, formulae, schematics	Coherence of representations
Forming mental models	Structure of schematic vs. circuit Form of picture vs. electrical signal	Difference between representation and reality
Co-learning	Asking, explaining, scaffolding	Inter-, intrapersonal knowledge

Sequencing here involves two types. First the sequencing within a domain to prevent cognitive overload by slowly increasing complexity. Second the sequencing across the domains to learn the strategy including transfer by introducing the structure, practising access, and application in a new domain (cf. Vos, 1992). The double sequencing in the instructional design of the lab course is represented in Table 2. The distribution of the types of assignments has to be read from the bottom of the table upwards for each session consecutively.

Here the exposition of the metacognitive variants in instruction ends. The following section will describe the way the development of metacognition was determined, some expectations, and the results.

4. THE DEVELOPMENT OF METACOGNITION

4.1 DESIGN OF THE STUDY

From observations in the past it was known that large individual differences existed among the students. It was usual to split the students into two categories, weak students and good students. Weak students were supposed to be a category that in general would fail courses, while good students could

Table 2

The number of tasks in each category for the sessions of the course

Domain: Strategy learning:	Introductory structure			Time domain access			Frequency domain application		
Sessions	1	2	3	4	5	6	7	8	9
Assignments									
Open-ended	-	-	1*	-	1*	-	-	-	-
Comparative measurement	-	2	-	2	-	1	2	1	1
Preparative assignments	2*	2	-	2	1	-	-	1	4
Homework assignments	-	10*	5	4	6	-	14	3	4

Note: The sequence has to be read from bottom to top for all sessions. In homework assignments the students read and combine information. Preparative assignments introduce new concepts, new functions of instruments, or a new method to determine a variable. In comparative assignments (the final level), the students compare and improve the fit of results acquired by two separate methods (metacognitive strategy). In open-ended assignments the variables to be determined and the methods are not specified.

*An assignment containing a major cognitive conflict.

be expected to pass. In this study it was thought useful to distinguish an intermediate category of moderate students, the students that probable failed in the past but passed after the redesign of the course.

It was also assumed that differences existed among the students with respect to their ability to monitor their cognitive processes and differences there in. Since learning is dependent on the ability to monitor whether one knows something or not, it was expected that good students have better learning results than other students through this metacognitive skill.

The development of different metacognitive variants was supposed to be related. Therefore, the observation of the development of a number of metacognitive skills could be seen as representing the development of the metacognitive variants in general. The acquisition of metacognitive skills was tracked in two ways: (a) by assessing the logbooks with respect to several of these skills; and (b) by assessing the logbooks with respect to specific assignments in which metacognitive skills were necessary.

These variables were also the basis for giving marks. Thus the marks were strongly dependent on demonstration of metacognitive skills (in general the criterion for assessment was "Do the students understand what they are doing?"). The development of the students' metacognition during the course was also supposed to be reflected by the marks on their logbooks.

After categorising the students into three groups: weak, moderate, and good, the development of metacognitive knowledge and skills could be monitored during the course because the three logbooks provided observations of the performance of the students in the three domains. An increase in performance was expected. The study could be denoted as a time-series treatment design, of the form $X_1-O-X_2-O-X_3-O$. After each phase in the treatment X, the metacognitive performance was observed (O).

It was expected that good students would also be more successful in learning the required metacognitive strategy and using other metacognitive variants: the quality of the student (the independent variable) was expected to be positively related with the use and development of metacognitive skills in new domains (the dependent variables). It was expected that students with low metacognitive skills would perform especially poorly when the external regulation was diminished because of fading.

Further, it was expected that because of timely feedback on the first logbook, metacognitive performance would improve in the second domain of the course, and so on. Finally, because good students better know what they do not know (Chi, Feltovich, & Glaser, 1981), it was expected that they would better prepare their work at home.

Elshout (1983) showed that good beginners differ from less good beginners in the way they handle their being a beginner. Good beginners will work in such a way that there is a great chance to learn from their experiences, even if this means that they are not so readily finished.

The development of the metacognitive skills as a function of the general quality of the students was measured in the three domains.

4.2 METHODS OF MEASUREMENT

Situation and Participants

The lab course was redesigned in the past. It turned out that it was possible to maintain the high requirements (the metacognitive level) and at the same time to raise the passing rates from below 50 % to a significantly higher and stable level above 80 %. Both the educational efficacy and efficiency improved: more students learned it, in less time, needing less assistance. The results were published as a backward reasoning solution to a practical instructional problem (Tattje and Vos, 1995).

In the year of this research the passing rates were 84 % of the remaining students at the end of the course, while 13 % of the enlisted students dropped out. This year about 137 students participated in the lab course, which ran in parallel to lecturing and tutoring hours on NA in the second trimester of the first year. In the lectures the more abstract central concepts of NA and the coherence of the theory were highlighted. In problem solving classes the theory was applied by solving calculation problems (cf. Vos and De Bruin, 1995; De Bruin and Vos, 1995).

Each of the lectures (28 h in all) was presented to the entire group of students at one time, problem solving classes (18 h) contained about 25 students, as the laboratory classes did. The lab course consisted of 9 sessions of 3½ h each (half days). The students were expected to spend a total of about 55 hours of study at home, including making homework for the labs. Attendance for the lab classes was obligatory, whereas attendance for the lectures and tutoring hours was voluntary.

A general outline of the course programs for electrical engineering in the Dutch system of higher education can be found in Vandamme (1990). Basic concepts such as electrical current, voltage, resistor, capacitor, voltage source, electrical lead (connection), Ohm's law, and measurement instruments like ammeter and voltmeter had been treated and examined in the Dutch high school system.

The data on the performance of the students were of six general types: (a) the final marks for the lab course and all other courses available from a large database at the university; (b) the marks for the entrance test and the logbooks recorded by the TA's; (c) the scores on grading sheets to be filled in by the teaching assistants while assessing the three logbooks; (d) the answers to the questionnaires at the end of each session given by the students; (e) observation notes on the behavior of the students during the labs; and (g) structured interviews held with the TA's.

The classification of the participants (in good, moderate, weak students) was done on the basis of the results for the four theory courses and three lab courses in the first trimester. The students with a mean score of 7.5 or higher on a 1 to 10 scale were defined as good students. The students who scored from 5.5 to 7.4 were called moderate students, while the category of weak students had a failing mean score of 5.4 or lower.

The performance of the students with respect to metacognition was assessed from the grading sheets. The grading sheets were filled in by the teaching assistants while assessing the logbooks. The grading sheets drew the TA's attention to metacognitive skills during grading. The marks for the logbooks were recorded by the TA's on the grading sheets, which could be read automatically. In these detailed grading sheets, relevant performances were scored on a five-point scale.

4.3 ANALYSIS OF THE DATA

The classification of the students was combined with the data of the grading sheets and the questionnaires. The mean scores for the questions on the grading sheets of the TA's were calculated for each logbook and for each category of students.

The mean scores for some questions were combined as described in Vos, 2001, Appendix D4 in order to get a measure of the metacognitive performance of the students with respect to: (a) open

assignments; (b) measuring assignments. Further, the performance in metacognition was monitored on the basis of six metacognitive skills: (a) the capability to reason logically; (b) to study the laboratory manual; (c) to study the lecture notes on Network Analysis (i.e. showing theoretical knowledge); (d) to understand the functions of the measurement instruments; (e) to compare several (measuring) methods with each other; and (f) to work methodically according to the strategic framework presented.

Comparisons were made between the performances of the categories of students: good vs. moderate, moderate vs. weak, and weak vs. good. The null hypothesis was in each case that the performance variables came from the same distribution. If this hypothesis had to be rejected, it was concluded that there were indeed differences in metacognitive performance between the categories involved. The experimental hypothesis was tested against the null hypothesis by a t-test for the results from each logbook.

The activities of the students and details of their work, both on the labs and at home, were monitored by questionnaires (see Vos, 2001, Appendix D3; see also Oosterhuis, Tattje and Vos, 1991). The students were required to fill in a questionnaire after each lab session to estimate the frequency of the activities during the lab classes and the time spent on these activities, and also to estimate the time spent on each homework assignment and the degree of success. A 5-point scale was used. The questionnaires could be read automatically. The mean scores for the answers on the questionnaires have been calculated for each category of students for each of the sessions. The mean time spent on homework assignments has also been calculated for each category of students.

The observation notes of the behaviour of the students and the TA's during the labs were made by three faculty members who focused on a few pairs of students. Together with the results of the structured interviews with the TA's, the notes from the observations were analysed qualitatively by discussions among the 3 staff members involved.

Graphic representations were made of most results.

4.4 RESULTS

The boundaries chosen for the categorization of the students into three groups resulted in 45 good students (about 30 % of the population), 84 moderate students (about 60 %), and 15 weak students (about 10 %).

The metacognitive performance during the course

The progress of performance over time could be observed from the grading data of the logbooks.

The average performance with respect to open-ended assignments and comparative measurement assignments for each category of students in the three domains of the lab course is presented in Figure 2. Although all differences seemed quite large, only the largest differences between the scores of the weak students and the others were found to be statistically significant at $p < 0.05$ or 0.01 , due to the large spread in the data (see Table D.1 in Vos, 2001, Appendix D4). The increases in performance of the good and moderate students on the open-ended assignments from logbook 1 to 2 are significant ($t(88) = 5.6$ and $t(166) = 5.8$ respectively, $p < 0.001$ for both).

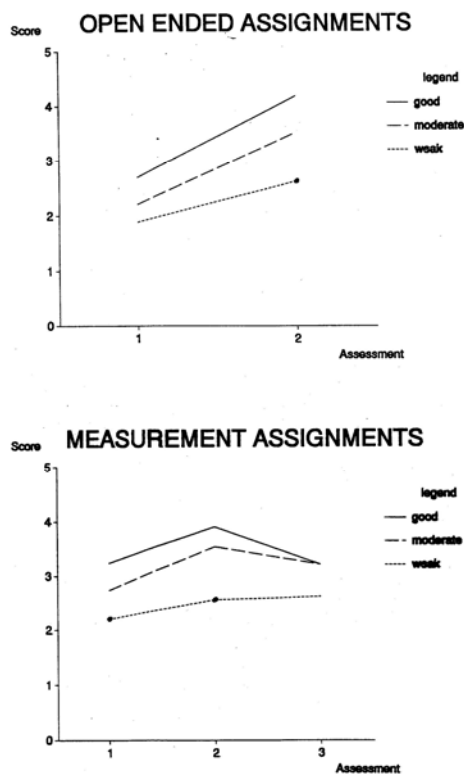


Figure 2. The performance in the application of the metacognitive strategy in NA for the three categories of students in the three domains of the course. The means of the scores of good, moderate and weak students on measurement and open-ended assignments in the assessments of the three logbooks are presented. Assessments 1, 2 and 3 relate to the logbooks from the three domains, respectively. Where the weak students differ significantly from the others, this is indicated by a dot.

The performance for four of the six metacognitive skills monitored is presented in Figure 3 (the other graphs are similar). T-tests showed that in most cases the differences between the weak students and the others were significant at $p < 0.01$ (see Vos, 2001, Appendix D4, Table D.2). The significant differences between the good and moderate students are indicated in Figure 3. They occur in logbook 2, and for working methodically also in logbook 1, but not in logbook 3.

The amount of time that the students spent on homework is shown in Figure 4 (see also Vos, 2001, Appendix D4, Table D.3). The data show that the good students spent significantly more time on homework than the weak students for session 2 ($t(28) = 2.56, p < 0.01$). For session 7, both the moderate and good students spent significantly more time on preparations ($t(59) = 2.22$ and $t(20) = 2.17$ respectively, both $p < 0.05$).

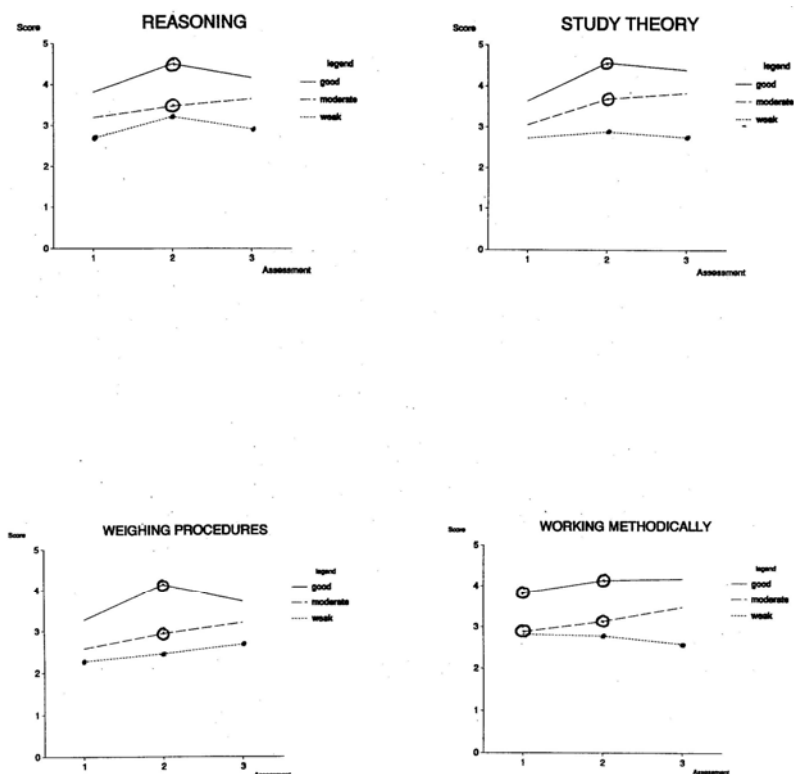


Figure 3. The performance in four of the six metacognitive skills for the three categories of students in the three domains of the course (mean scores). Significant differences between mean scores of the good and the moderate students are indicated by two circles. Where the weak students differ significantly from at least one of the other categories, this is indicated by a dot.

Interactive Behavior in Class

The students asked for assistance from the TA's at an average of two times per session, with these questions taking a mean of five minutes to answer. Next to writing in the logbook, most of the time was spent on deliberations with the partner and handling instruments (both 50 minutes). Consulting other pairs of students amounted to 1.5 times taking 3 minutes in the beginning of the lab course, and 3 times taking 16 minutes at the end of the course (e.g. for moderate students the mean number of interactions were 1.8 and 2.8 on sessions one and six respectively, with $t(79) = 3.92, p < 0.01$). Some differences among the categories of students were observed.

In the first session the weak students asked more questions to the TA's ($M = 2.5$) than the good students (2.1), and both categories more than the moderate ones (1.8), although the differences were not significant. The time used for the answers differed significantly between the weak and the moderate students, $M = 9.2$ and 3.6 minutes respectively, $t(58) = 4.7, p < 0.01$. This difference disappeared in the next session. The good students used significantly more time for answers on questions in the sessions seven and nine than the moderate students, 7.5 against 5.0 minutes with $t(45) = 2.27 (p < 0.05)$ and 5.5 against 2.2 minutes with $t(70) = 1.78 (p < 0.05)$ respectively.

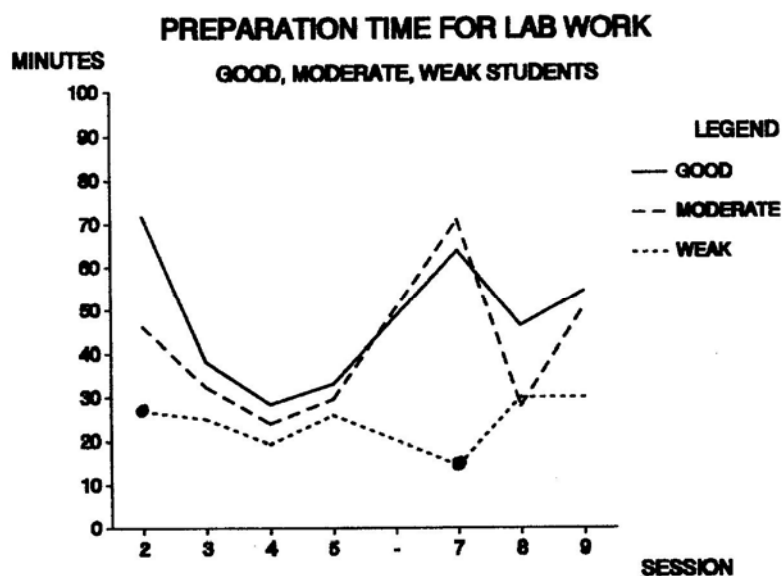


Figure 4. The time spent by the students for the preparation of the lab tasks at each session. The first and sixth sessions require no preparation and are omitted from the graph. Where the mean scores of the weak students differ significantly from the others, this is indicated by a dot.

Early marking and its impact

The marks for the entrance test and each of the three logbooks provided data about the performance of the students during the course and were intended to give early feedback on the required efforts. The percentage of the students performing sufficiently (above 5.4 on the 10-point scale) was calculated. This analysis was carried out for the classes of about 25 students.

In Table 3 the relative rates at a sufficient level of performance (5.5 and larger on a 10-point scale) are presented. The data are shown for all classes of students.

Table 3

The percentage of each class with a sufficient mark on the entrance test and the logbooks (percentages of the number N of students enlisted in the beginning of the class)

		Domain of the course:		Introductory		Time domain		Frequency domain				
		Learning of strategy		Orientation		Practice		Application				
		Sessions:		1	2	3	4	5	6	7	8	9
Class #	N	Dropouts										
Class 1	21	1		14		47		76				43
Class 2	22	1		44		45		68				90
Class 3	24	5		42		41		58				62
Class 4	25	4		52		60		80				80
Class 5	18	0		22		44		72				89
Class 6	11	5		91		28		46				55
Totals	121	16		41		47		69				71

Note. Marks on the entrance test were obtained in session 1, marks on the 3 logbooks shortly after sessions 3, 6

and 9.

The results on the entrance test and the first logbook (handed in after session 3) showed that 41 % respectively 47 % were performing at a sufficient level. About 13 % of the students dropped out after the entrance test. The results of the second and third logbooks showed an increase in general. Class 6 can be neglected because it contained students who had to repeat the course. The passing rate of class 1, being weakest at the entrance test, is below the level of the others, and in fact the same as before the redesign of the course.

5. DISCUSSION AND CONCLUSION

Development of metacognitive skills

The results show that students who have good marks for courses in general, have a higher score on the metacognitive skills in the lab course from the beginning on, and weak students a lower one. In all significant cases and in all other cases except one, the performance of the good students is better than that of the moderate ones, and the performance of the moderate ones is better than the performance of the weak ones, with respect to the observed metacognitive skills.

So being a good student (i.e. having good marks) goes together with having better metacognitive capabilities and staying better, in accordance with the expectations. The weak students show significantly less metacognitive capabilities.

The development of the performance in the metacognitive strategy shows itself most directly in the performance in working methodically. A nearly linear development can be observed, the good and moderate students differing significantly in the first and second domain but coming nearer to each other in the third domain. For the weak students a steady decline can be observed, that is significantly differing from the other groups.

The performance in the (comparative) measurement assignments shows that the development of this skill is not linear. The progress from the first to the second logbook is especially clear for the good and moderate students, but a decline can be observed in the third domain. A remarkable feature is that in the third domain the performance of the moderate students and the good students meet.

For all other metacognitive skills an increase can be observed of the good and moderate groups from the first to the second domain, and a decline in the third domain for the good students, while the moderate students make still some progress in the third domain. So the primary metacognitive development takes place in the second domain, and continues for the moderate students.

The decline of the metacognitive performance of the good students in the third domain can have several reasons: difficulty, fading, or being content. An explanation based on the difficulty of the third domain seems not feasible because the decline in the third domain is less obvious for the moderate students. Maybe the decline is caused by the fading of the written instructions in the third domain, but again, this should also apply to the moderate students who do not show the decline (contrary to the expectations). The most obvious explanation is that the good students were already content with the acquired level of performance and the acquired marks, especially since the examination time came near. They could allow themselves to put less effort in the lab course.

The performance on the metacognitive skills monitored differs significantly between the good and moderate students in the second domain. This difference becomes less or disappears in the third domain where external regulation is diminished (fading) and a new domain is entered. In all cases the performance of the moderate students approaches that of the good students.

This result is quite unique and contrary to the expectations that students with less metacognitive skills always will show a lower performance in the development of new metacognitive skills. It just seems that they start slower in understanding the metacognitive requirements.

To get more insight in the effort of the students, the preparation time at home gives some information. In accordance with the expectations, good students spend the most time of all on preparation at home if new information has to be gathered, as at the start of the first domain of the lab course is the case. Moderate students start out spending less time. However, they spend an equal

amount of time at the first session of the third domain. It seems that they have understood what efforts are required to pass.

The task information, the explanations and examples, and the hints were itself a part of the available information. The students who did not read all material carefully from the beginning missed the metacognitive information. So in the beginning the moderate and weak students needed to be pushed into a different attitude by the stimuli. For the moderate students this push seems successful.

Weak students start low and do not change their behaviour much. Moreover, there were some indications that good and moderate students were better able to select the difficult and most relevant homework assignments than weak students. It seems that weak students are not driven by a metacognitive strategy in their choices of the questions, but just select the questions that have to do with lab work (schematics and measurement instruments), and thus show a superficial approach to their task.

Concerning the capability to reason, weak students improve their performance between the first and second domain, but their performance drops in the third domain. It seems that the weak students do ask a lot of questions in the beginning, and need rather long answers but these have not much effect. Maybe they do not know what they need to know (cf. Chi, Feltovitch, & Glaser, 1981: they do not know what they do not know).

The weak students need longer explanations, as in the first session, but apparently with a reverse metacognitive effect: in the subsequent sessions they ask less and use less time than in the beginning. It turns out that the weak students fail especially in the last domain where the content is new and difficult, and access to the strategy is not prompted: they seem to reason less logically, to be less able to handle instruments, and to work less methodically.

Interactions in Class

From analysis of the questionnaire data and from the observations, the staff members had the impression that during lab hours good students used the least amount of time for information gathering and knowledge acquisition, and the most time for writing in the logbooks. For weak students the reverse was the case. Weak students turned over pages in the manual more often than other students did, probably looking for information, and were fumbling with the instruments.

Good students asked the assistants better questions (more to the point) than the other students did. The same applied to their contacts with other students. In the third and most difficult domain, the good students used more time in questions and answers with the TA's than the moderate students did. Probably they wanted to understand the topic better.

The independent acquisition of the information needed, which is a part of the strategy, works out well. Very few questions are asked to the teaching assistants compared to the old course. A great deal of interaction takes place between the pair of students. The consultation of other pairs of students increases during the course in frequency and in duration.

Frequent interactions among the students are of profit if there are enough good ideas in a class. Most of the students who failed (11 out of 19) were from a single class, class 1. This class performed the worst of all on the entrance test, and so contained fewer good and more weak students than the others. It might have been that a better distribution of the weak and the good students over the classes would have further raised the passing rates.

Discussion

Some remarks should be made about the way the data have been collected and analysed. Verbal reports about the performance and the way of thinking of the students can be found in the logbooks, and are part of the tasks of the students. This is a favourable situation compared to think aloud protocols because now the test cannot interfere with the treatment.

The measurement of the performance, however, is done by a TA without a check by another TA, thus strongly depending on an individual interpretation of the logbook. This dependence on a subjective interpretation of the meaning of the logbook is somewhat diminished by the use of grading sheets, probably leading to a more uniform assessment than otherwise would have been the case. Moreover, each class of students was assisted and graded by four TA's, thus diminishing the influence of subjective interpretations on the trends.

From the results it is concluded that moderate students successfully passed the course because more of them developed the relevant metacognitive skills. These skills approached the level that the good students thought to be enough to pass the course. The moderate students were stimulated to continue developing their skills by the system of early marking. But did boosting, and just-in-time feedback contribute to this effect too?

Another remaining question is whether the intended metacognitive experiences, especially a supposed feeling of success coming from the improvements in the second domain, really played a role. No direct data are available. Also it must be pointed out that the metacognitive skills are supposed to contain metacognitive variables, but in how far is this the case? For determining the metacognitive variables in play a more in depth study is necessary like the one of Vos (2004) for reasoning.

The results in this research are based on a post hoc analysis. The instruction had already been redesigned, the data had been gathered, and was reanalysed. There were a large number of design principles included in the course, related to many metacognitive variables. Since the achievements in all metacognitive skills vary across the domains in a similar way, it is concluded that the interaction of the metacognitive variables probably is responsible for the success. Is this the only theoretical explanation? Are explanations based on empirical instructional design rules satisfactory and valid?

Further research is required to answer these questions. The last question can be partially answered already.

It will be clear from this research that instructional design rules for cognitive and metacognitive development differ. The goals differ because mastery of a skill that can be demonstrated and directly observed (like typing or calculating) is replaced by the requirement to use skills in a systematic way. Knowledge that can be reproduced is replaced by a coherence of knowledge that shows in 'insight'. The way the cognitive information is presented differs, metacognitive information has to be added, just-in-time information has to be replaced by just-in-time feedback. Checking the correctness of results by the teacher or from the 'book of answers' has to be replaced by comparing the results of different methods by the students themselves. Writing a report together has to be replaced by individual logbook writing. An overview of some differences is presented in Table 4.

Table 4. Some differences between instruction for cognitive and metacognitive objectives.

Educational functions	Implementation for cognitive objectives	Implementation for metacognitive objectives
Motivation	Appreciating the sense and the use of the subject matter	Having the will to solve cognitive conflicts
Setting objectives	Mastering a skill	Systematic approach
	Reproducing knowledge	Insight in the coherence of knowledge
Activation of prior knowledge	Summary of terms	Advance organiser
Scaffolding	Just-in-time information	Just-in-time feedback
Executing assignments	Doing what is required	Choosing the best way to do it
	Following a procedure/ plan	Constructing a procedure/ plan
Development	Practising individually	Practising together
Reporting	Co-operative formulation	Individual writing
Assessment	Is this correct sir?	Compare expectation with experimental result

Conclusion

The results show that in well-designed instruction nearly all students can acquire a metacognitive strategy and related metacognitive skills. In addition the metacognitive performance of moderate students at the end of a course can approach that of good students. In such instruction the sequencing of tasks with respect to complexity is separated from sequencing the tasks for metacognitive development (double sequencing).

The relations between the metacognitive variants and the instructional design of the course have been elucidated. Metacognitive experiences are used to stimulate the use of metacognitive skills and to develop metacognitive knowledge, including integration of knowledge into coherent chunks and.

A special aspect of the latter is the use of cognitive conflicts. These have to be solved on a metacognitive level, leading to a kind of conceptual change.

Summarising, a schema of double sequencing has been designed using the three domains of the course. The relation between metacognitive variants and the design of the course has been established - another unique result of this study. Development of metacognitive skills can be non-linear, the development of all metacognitive skills is correlated, and moderate students can approach the skills of good students at the end of the course.

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