Timing of information presentation and the acquisition of complex skills

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Timing of Information Presentation and the Acquisition of Complex Skills

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Voorwoord

And now for something completely different (Monty Python, 1972), zoiets moet ik gedacht hebben toen ik 30 juni 1999 mijn spullen pakte bij de ABN, in de trein stapte naar Maastricht en de volgende dag mijn Aio-carrière bij de Open Universiteit begon. Het was gelijk feest want juist die dag aanvaardde Jeroen het ambt van hoogleraar in 'Onderwijs Technologie' aan de OU. Dit was voor mij een aangename kennismaking met het academische wereldje dat de komende vier jaar mijn thuis zou zijn. Inmiddels zijn deze vier jaar alweer voorbij en ligt er een proefschrift getiteld 'Timing of information presentation and the acquisition of complex skills' dat niet tot stand zou zijn gekomen zonder de begeleiding, de hulp, het advies, de gezelligheid, de betrokkenheid en belangstelling van een heleboel mensen.

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Heerlen, 7 Juli 2003

Contents

Chapter 1 – An introduction to just-in-time information presentation[1]

Abstract

This thesis focuses on just-in-time information presentation during complex cognitive skill acquisition. In this introductory chapter an instructional design model is presented that forms the constructing framework for the just-in-time information presentation model presented in Chapter 2. Modern instructional theories stress authentic, realistic tasks or problems as the driving force for learning, but due to the complexity of those tasks learning may be hampered by the limited processing capacity of the brain. The theoretical and practical implications of the instructional design model presented here, as well as, different strategies for just-in-time information presentation to manage cognitive load, are discussed. Furthermore, a brief overview is given of the rest of the thesis.

Introduction

Modern instructional theories tend to focus on real-life tasks as the driving force for learning (Merrill, 2002; Reigeluth, 1999; van Merriënboer & Kirschner, 2001). The general assumption is that such learning tasks or practice problems help learners to integrate the knowledge, skills and attitudes necessary for effective performance; give them the opportunity to learn to coordinate constituent skills that make up complex performance, and eventually enable them to transfer what is learned to their daily life or work settings. This focus on authentic, realistic tasks can be found in practical educational approaches, such as project-based education, the case method, problem-based learning, and competency-based learning; and in theoretical models, such as Collins, Brown and Newman's (1989) theory of Cognitive Apprenticeship Learning, Jonassen's (1999) theory of Constructive Learning Environments, Nelson's (1999) theory of Collaborative Problem Solving, and Schank's theory of Goal Based Scenario's (Schank, Berman, & MacPerson, 1999).

A severe risk of all these approaches is that, especially novice, learners have difficulties learning from the tasks because they are overwhelmed by the task complexity. This is due to the fact that working memory capacity is limited and exceeding this capacity hampers learning (Baddeley, 1992; Miller, 1956; Sweller, 1988). To avoid this, cognitive overload of working memory should be avoided. Cognitive load theory (Sweller, 1988) provides guidelines to accomplish this goal. Three types of cognitive load are distinguished: intrinsic cognitive load, extraneous cognitive load and germane cognitive load. *Intrinsic* cognitive load is inherent to the task itself and is determined by the degree of element interactivity of the task. *High* element interactivity requires the learner to process several elements and their relationships simultaneously in working memory in order to carry out the task or solve the problem. *Low* element interactivity allows the learner to serially process a small

[1] *This chapter is partly based on: Van Merriënboer, J. J. G., Kirschner, P. A., & Kester, L. (2003). Taking the load of a learner's mind: Instructional design for complex learning. Educational Psychologist, 38(1), 5-13.*

number of elements at a time (Sweller, Van Merriënboer, & Paas, 1998). *Extraneous* cognitive load is inherent to the design of the instructional material and arises from processes that a learner engages in during task performance which are *not* directly *beneficial* to learning. For instance, searching for relevant information sources, combining different information sources in order to understand the learning material, or weak-method problem solving yield extraneous cognitive load that uses up cognitive resources at the cost of learning processes. *Germane* cognitive load is also inherent to the design of the instructional material but arises from processes that a learner engages in that are *beneficial* for learning. For instance, attending to important features of the task or problem (Van Merriënboer, Schuurman, De Croock, & Paas, 2002), or carrying out a variety of learning tasks so as to construct more general and abstract cognitive schemata (Spiro, Coulson, Feltovich, & Anderson, 1988; Sweller et al., 1998) causes germane cognitive load. With a given intrinsic cognitive load, well-designed learning material minimizes extraneous cognitive load and optimizes germane cognitive load within the thresholds of totally available cognitive resources.

The aim of this introductory chapter is to discuss managing cognitive load when realistic learning tasks or practice problems are used in education. First, an instructional design model for complex learning is described. Second, methods for just-in-time information presentation are discussed, including timely presentation of information to support practice on realistic tasks and the direct, step-by-step presentation of procedural information. These methods are expected to manage cognitive load in an effective way.

A Design Model for Complex Learning

Over the last decade, van Merriënboer (1997; van Merriënboer, Jelsma & Paas, 1992; van Merriënboer, de Croock & Clark, 2002; van Merriënboer, Clark & de Croock, 2002) developed an instructional design model for complex learning. This four-component instructional design model (4C/ID-model) presupposes that well-designed learning environments for complex learning always consist of four components, namely: (1) learning tasks, (2) supportive information, (3) procedural information, and (4) part-task practice. In Figure 1a, learning tasks are represented as circles and organized in an ordered sequence of task classes (dotted lines) that represent simple-to-complex versions of the whole task (i.e., realistic problems). These learning tasks will typically be performed by the learners in a simulated or real task environment and, ideally, confront them with all constituent skills that make up the whole complex skill. Furthermore, and as indicated by the shaded areas of the circles, each task class starts with one or more learning tasks with a high level of embedded support, continues with learning tasks with a lower level of support, and ends with conventional tasks without support. This is repeated for each subsequent task class, yielding a saw-tooth pattern of support throughout the whole training program.

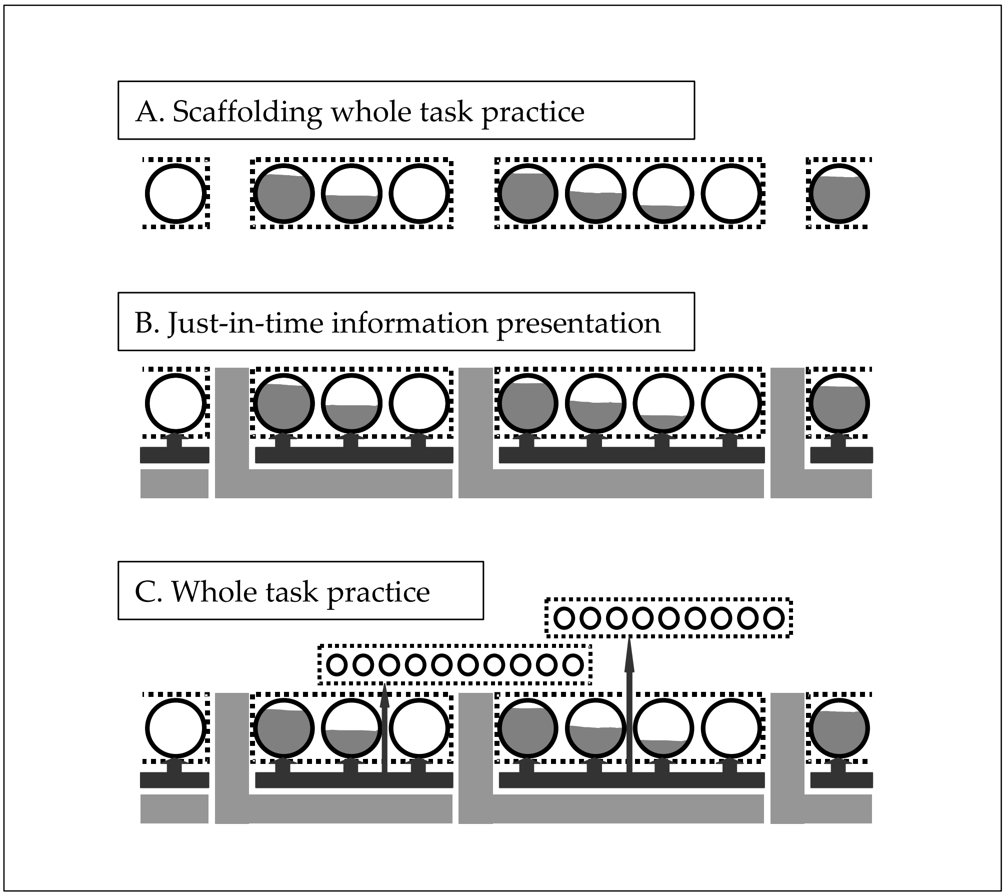

Figure 1. Schematic representation of a training blueprint for complex learning that is fully consistent with cognitive load theory.

The second and third components are depicted in Figure 1b and pertain, in order, to supportive and procedural information. The supportive information (indicated by the gray, L-shaped figures) is presented in a just-in-time fashion to work on the—variable, non-routine aspects of—learning tasks within the same task class. The learning tasks within the same task class are equivalent in the sense that they may be performed on the basis of the same, general knowledge (i.e., mental models and cognitive strategies that allow one to perform a version of the task with a particular complexity). For each subsequent task class, additional supportive information is presented to enable the learners to perform the more complex version of the whole task. The procedural information (indicated by the vertical black arrows), in contrast, is presented just-in-time to perform the consistent, routine aspects of the learning tasks. It preferably takes the form of direct, step-by-step or 'how-to' instruction and is quickly faded away for subsequent learning tasks.

The fourth component, part-task practice, is indicated in Figure 1c. This component is related to a shift from a whole-task to a part-task paradigm. The whole-task approach that is characteristic of our framework and other modern instructional theories implies that routine aspects of performance are not trained separately but only practiced in the context of 'whole' learning tasks. In general, an over-reliance on part-task practice is not helpful to complex learning. But if a very high level of automaticity is desired for particular routine aspects, the learning tasks may not provide enough practice to reach this level because the responsible learning process, strengthening (Anderson, 1993, 1996), requires large amounts of not available repetition. For those aspects, additional part-task practice may be provided – such as children drilling multiplication tables or musicians practicing music scales. According to the 4C/ID-model, additional part-task practice only starts after the learners have been introduced to the routine aspects in the context of the learning tasks, so that part-task practice takes place in a fruitful cognitive context that allows learners to identify the activities that are required to integrate the routines in the whole task (Carlson, Khoo & Elliot, 1990).

This thesis is restricted to the components 2 and 3, namely supportive and procedural information, and predominantly concerns the just-in-time presentation of these information types (see Figure 1b).

Just-in-Time Information Presentation

Learners need relevant task-specific *information* to perform the learning tasks and to learn from them. If, for example, students are confronted with a learning task requiring them to find relevant research literature for the first time, they need information on how to approach this task (e.g., select one or more appropriate databases, formulate a search query, perform the search using appropriate search tools, and select relevant results), how typical bibliographical databases are organized (e.g., with separate fields for titles, abstracts, authors, keywords, etc.), and which procedures are useful for operating search programs or composing search queries with Boolean operators. Without such information it will be very difficult, if not impossible, to carry out the learning task(s). This necessary information must be active in working memory when performing the task to guide or influence behavior. Simply stated, there are two ways to reach this goal. One way is to present necessary information before the learners start working on the learning task or series of tasks. They study this information prior to beginning so that it is encoded in schemata in their long-term memory to be subsequently activated in working memory when needed for performing the task. The other way is to present the necessary information precisely when the learners need it during task performance. They do *not* learn it beforehand, but the external information is directly activated in working memory when it is necessary for performing the learning task.

There is no unequivocal answer to the question of which of the two ways is best. For information with *high* element interactivity, it seems advisable to present the information *before* the learners start on the learning tasks. Since working on complex tasks with high element interactivity uses much cognitive capacity, learners have little cognitive capacity left for additional processing while working on the tasks. The simultaneous processing of intrinsically complex information can then lead to cognitive overload. If the information is studied beforehand, a cognitive schema may be constructed in long-term memory that can subsequently be activated in working memory during task performance. Information with *low* element interactivity, on the other hand, may better be presented precisely when learners need it *during* their work on the learning tasks. Because of its low complexity, there is no or little risk for cognitive overload.

In the next sections is argued that the complexity of to-be-presented information and its optimal timing in instruction are closely related to the nature of different task aspects. The element interactivity of information supporting the performance of variable task aspects is typically higher than that for information specifying the performance of highly consistent, routine task aspects. In the theoretical framework, the first is called 'supportive information' and is best presented before equivalent learning tasks; the second 'procedural information' and is best presented precisely when it is needed during task performance (Kester, Kirschner, Van Merriënboer & Bäumer, 2001).

Supportive Information

For expert task performers, some task aspects require reasoning and problem solving while other aspects are performed as routines. In order, these are called variable or non-recurrent and routine or recurrent task aspects (van Merriënboer, 1997). Experts can effectively perform non-recurrent task aspects because they have cognitive schemata available to reason about the domain and guide their problem solving. An experienced researcher searching for relevant research literature can, for example, reason about the effectiveness of different queries thanks to a well-developed mental model of the organization of bibliographical databases; and (s)he can effectively approach new search tasks thanks to the availability of cognitive strategies for translating research questions into relevant search terms. Such mental models and cognitive strategies are examples of complex schemata with a general or abstract nature. They allow for multiple use of the *same*, general knowledge for performing different tasks. Teachers often call this supportive information 'the theory'.

How does one help novice learners construct such helpful mental models and cognitive strategies? Since the information describing mental models (e.g., how bibliographical databases are organized) and cognitive strategies (e.g., phases and rules-of-thumb for translating research questions into relevant search terms) typically has a high element interactivity, it is preferable not to present it to learners while they are working on the learning tasks. Simultaneously performing the tasks and studying the information would almost certainly cause cognitive overload. Instead, supportive information is best presented before learners start working on the learning tasks. Then, a cognitive schema may be constructed in long-term memory that can subsequently be activated in working memory during task performance. Retrieving the already constructed schema is expected to be less cognitively demanding than activating the externally presented complex information in working memory during task performance.

It is critical that cognitive schemata are constructed in a process of *elaboration*, whereby non-arbitrary relationships are established between new information elements and the learner's prior knowledge. This allows for structural understanding and ensures that the schemata provide a bridge between what learners already know and what they need to know to perform the learning tasks. While working on those tasks, the schemata guide the learners in performing the task. At the same time, learners mindfully abstract away from the concrete experiences offered by the learning tasks and thus reconstruct, modify, or embellish the existing schemata to make them more in agreement with their concrete experiences. This process of *induction* is important for constructing new knowledge and, especially, for adapting existing schemata to make them more appropriate to the given experiences (Holland, Holyoak, Nisbett & Thagard, 1986).

It is important to note that the presentation of supportive information followed by elaboration and induction, does *not* yield an algorithmic description of how to perform particular task aspects, but rather general heuristic knowledge that may be helpful for performing particular non-recurrent aspects of the learning tasks. It does not guarantee that the problem will be solved. It, therefore, makes no sense to couple the presentation of supportive information to one particular learning task. Instead, it should be connected to a *task class*; a category of equivalent learning tasks which share the same body of underlying knowledge (e.g., mental models and cognitive strategies). The just-in-time presentation of supportive information entails presenting this information just before the task class for which it is relevant using instructional methods that ensure that the information is elaborated. This, in fact, reflects a traditional educational perspective, namely first study for understanding, then practice for application.

This does not preclude the interchange of presentation and practice. The supportive information for each subsequent task class is an addition to, or an embellishment of previous information – allowing learners to do things they could not do before. A continuous mix of presentation and practice arises, where presentations of supportive information for a task class alternate with practice sessions for learning tasks in the same class. Supportive information is, thus, best presented explicitly just before the task class for which it is relevant. Typically, it is kept available for the learners while working on the learning tasks within this task class. For subsequent task classes, only new (additional) supportive information should be presented – extending the set of interacting elements (Pollock, Chandler & Sweller, 2002). Repeating supportive information from previous task classes may even be harmful. Since it is redundant with what the learners already know, it may increase extraneous cognitive load because learners have to determine whether the presented information is actually identical with their prior knowledge (Kalyuga, Chandler & Sweller, 1998).

Procedural Information

In contrast to supportive information, procedural information pertains to recurrent task aspects that are performed as routines by experts. Experts can perform recurrent task aspects effectively because they have at their disposal more or less automated schemata that associate particular characteristics of the problem situation (i.e., conditions) to particular actions. Experts may even reach a level of performance where they perform routines automatically, without conscious control or the need to invest mental effort. An experienced researcher searching for relevant literature can, for example, operate a familiar search program without consciously paying attention to it; particular low-level goals automatically yield particular key-presses or menu-choices. Such automated schemata connecting particular conditions to particular actions are also called rules or productions (Anderson, 1993, 1996; Newell, 1991). They are highly domain-specific and only allow for the same use of the *same* knowledge for performing recurrent aspects of tasks.

How does one help novice learners automate schemata for recurrent task aspects? The procedural information prescribing the performance of recurrent task aspects, and possibly the facts and concepts procedural to correct performance of the procedures, typically exhibits low element interactivity. Furthermore, automated schemata are constructed as a direct result of practice in a learning process known as *knowledge compilation*, where the information that is active in working memory is embedded in highly domain-specific representations, followed by *strengthening*, whereby schemata accumulate strength each time they are successfully applied (Anderson, 1993, 1996). Elaboration of the procedural information beforehand has no added value whatsoever; therefore, it is preferably presented precisely when learners need it. This is what we see when teachers give step-by-step or 'how-to instructions' to their learners during practice, acting as an assistant looking over your shoulder.

Cognitive load theory not only indicates that procedural information is best presented when learners need it, but also raises two related design issues. First, presenting procedural information *precisely* when it is needed to perform particular actions prevents so-called temporal split attention effects. Information presentation separated in time must be integrated which results in a higher extraneous cognitive load (Mayer & Sims, 1994). Second, presenting procedural information so that it is fully *integrated* with the task environment prevents spatial split attention effects. Such effects may arise when multiple sources of information must be mentally integrated in order to follow procedural instructions and simultaneously manipulate the task environment. Integrating the multiple sources of information by, for instance, using balloon help for procedural information may reduce extraneous cognitive load (Mayer & Moreno, 2002). If temporal or spatial split attention effects are not fully prevented, the presentation of procedural information before the learning tasks even may be more effective than its presentation during practice.

It is also important to note that procedural information presentation and subsequent knowledge compilation yield an algorithmic description of how to perform recurrent aspects of the learning task. Applying the automated schemata warrants that these aspects are successfully performed. Therefore, procedural information is best connected to the *first* learning task for which the recurrent aspect is relevant. This reflects a perspective that is popular in business training: Practice for application and only study when needed ('just in time' learning; Romiszowski, 1997). For subsequent learning tasks, procedural information is quickly faded as the learners gain more expertise. This principle of fading is consistent with the idea that when learners have enough expertise, procedural information will become redundant and should thus be removed in order to decrease extraneous cognitive load (Kalyuga, Chandler & Sweller, 1998).

In summary, a distinction is made between supportive and procedural information. Supportive information may be helpful in performing the non-recurrent aspects of learning tasks. It is best presented before a class of equivalent learning tasks, and it is critical that the learners elaborate upon it so that it can be easily retrieved from long-term memory when necessary for the learning tasks. Procedural information specifies the correct performance of recurrent aspects of learning tasks. It is best presented precisely when learners need it during their work on learning tasks, and it is critical to prevent split attention effects when presenting this information.

Overview

In this chapter, an instructional design model (i.e., 4C/ID model) has been described in which just-in-time information presentation is positioned as a method to manage cognitive load during whole task practice. The chapter started from the observation that modern instructional theories tend to focus on real-life tasks as the driving force for learning. Such tasks are typically associated with a very high cognitive load, which makes it more important than ever to take the limited human processing capacity into account. In the next chapters the relations between the components supportive information and procedural information from the 4C/ID model, just-in-time information presentation, cognitive load management and complex skill acquisition are closely examined.

In Chapter 2 a just-in-time information presentation model is described. This model elaborates on just-in-time information presentation as a method to manage cognitive load. A theoretical framework is outlined for the timing of supportive and procedural information. According to the model, supportive information is best presented before practice while procedural information is best presented during practice. The just-in-time information presentation model forms the basis for the studies carried out in Chapters 3, 4, and 6.

Chapter 3 describes a study, in which the 'supportive before, procedural during' information presentation format is compared to three other formats using learning tasks in the domain of statistics (i.e., theory and application of Chi square tests). The assumed superiority of the 'supportive before, procedural during' format was not confirmed. In the domain of statistics it is hard to define strictly limited practice tasks because every topic in statistics elaborates on other topics and this may have influenced the results in this research. Therefore, the study in Chapter 4 is carried out in a domain that allows for well-rounded learning tasks.

In Chapter 4 the same four information presentation formats are compared using practice problems in the domain of physics (i.e., troubleshooting electrical circuits). No differences were found in effectiveness and efficiency between the four formats but, based on search behavior of the learners, information presentation according to the 'supportive before, procedural during' format appeared to be just-in-time. It was hypothesized that the necessity of mentally integrating a text (i.e., the procedural information) and a diagram (i.e., the electrical circuit) interfered with learning. The study in Chapter 5 was set up to find out if these mental integration processes did influence the learning processes.

The study in Chapter 5 compared two information presentation formats in the domain of physics. One in which the procedural information was integrated in the circuit diagram and one in which the procedural information was presented next to the circuit diagram. In both formats the supportive information was presented before practice. This study revealed that presenting the procedural information integrated in the circuit led to better transfer test performance than presenting this information next to the circuit. It was concluded that the necessity of mentally integrating a text and a diagram to some extend hampered learning and should be avoided in future research.

In Chapter 6 a replication of the study in Chapter 4 is described, except that the procedural information was presented integrated in the electrical circuit during practice. In this study the superiority of the 'just-in-time' format over the formats that presented both information types simultaneously before or during practice was supported. Learners who received supportive information before practice and procedural during practice obtained higher transfer test scores and higher efficiency scores than learners in the simultaneous formats.

Finally, in Chapter 7, a review is given of the results presented in the Chapters 3 to 6, some concluding remarks are made on the information content and the learning tasks or practice problems that were used and the timing of the information. Based on these remarks directions for future research are formulated.

Chapter 2 - Just-in-time information presentation and the acquisition of complex cognitive skills[1]

Abstract

This chapter describes a model for just-in-time information presentation. Learners receive the information needed to carry out a task precisely at the time it is needed. The model is twofold: *Supportive* information is best presented before practicing task classes while *procedural* information is best presented during practice on learning tasks. Just-in-time supportive information presentation promotes schema construction through meaningful learning or elaboration. Just-in-time procedural information presentation promotes schema automation through proceduralization or restricted encoding. This leads to a reduction in extraneous cognitive load because temporal split attention is avoided. This frees up cognitive capacity for learning the non-recurrent aspects of a complex cognitive skill and so enhances transfer performance.

Introduction

In the late 1970s and early 1980s a new concept in inventory management revolutionized Japanese and American manufacturing companies. The traditional just-in-case inventory systems based on long production runs, stockpiled inventories and uninterrupted production needed to be replaced by more flexible systems in order to meet new competitive and economic challenges. A just in time inventory system was introduced to replace the traditional just-in-case inventory systems (Hoyt, 1996). Just in time inventory management is a result of demand-pull production. This concept "involves the use of demand for a given product to signal when production should occur. The use of demand-pull allows a company to produce only what is required in the appropriate quantity and at the right time" (Cheng & Podolsky, 1993, pp. 9-10). In this way, the application of demand-pull can prevent unnecessary inventory, which would otherwise stockpile following the traditional just-in-case approach to manufacturing.

Hoyt (1996) argues that a lot of similarities can be found between production systems and educational systems. He draws perfect matching parallels between the traditional just-in-case inventory systems and business education. For example, business education is characterized by a slow response to customer needs, just as just-in-case inventory systems. There is often a time lag between the skills or knowledge a business requires and the education provided. Regularly, graduate students find that newly learned skills do not meet the demands of the workplace. Hoyt (1996) proposes to apply just in time inventory system principles to business education in order to solve this problem. In a just in time educational system, specific

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business courses should be provided just before students need the skills at work. Applying the earlier definition of demand-pull to educational systems, the demand for given knowledge and skills is used to signal when training should occur. The use of demand-pull allows a student to learn what is required in an appropriate course and at the right time. Just in time education principles are regularly applied in on-the-job training settings. On the Internet numerous just in time training packages can be found. Unfortunately, little can be said about the effectiveness of those just in time courses because of a lack of appropriate research.

In this chapter just in time inventory management principles, the demand-pull principle specifically, are applied to the instructional design of learning tasks that aim at mastering a complex cognitive skill. Within instructional design the demand for given information is used to signal when presentation of that information should occur. The use of demand-pull in instructional design allows a student to have required information available in an appropriate learning task, at the right time. In the Four-Component Instructional Design model (4C/ID model; Van Merriënboer, 1997), guidelines are given for just-in-time information presentation in training programs for complex cognitive skills. In this chapter these guidelines are outlined in more detail in a just-in-time information presentation model.

In the following sections the just-in-time information presentation model is described. Demand pull implications are different for the supportive and the procedural information a task requires. Therefore, the difference between supportive and procedural information is explained first. Second, the consequences of this difference with regard to just-in-time presentation are discussed. Finally, implications for research are discussed.

Just-in-time information presentation model

The just-in-time information presentation model presented here is a specification of the 4C/ID model. This specification concerns the instructional design of information related to whole-task practice and is twofold: *Supportive* information is best presented *before* practicing task classes (i.e., categories of learning tasks) and *procedural* information is best presented *during* practice on learning tasks. In Figure 1, a schematized overview is given of just in case information presentation (Figure 1a), just-in-time supportive information presentation (Figure 1b), and complete just-in-time information presentation (Figure 1c).

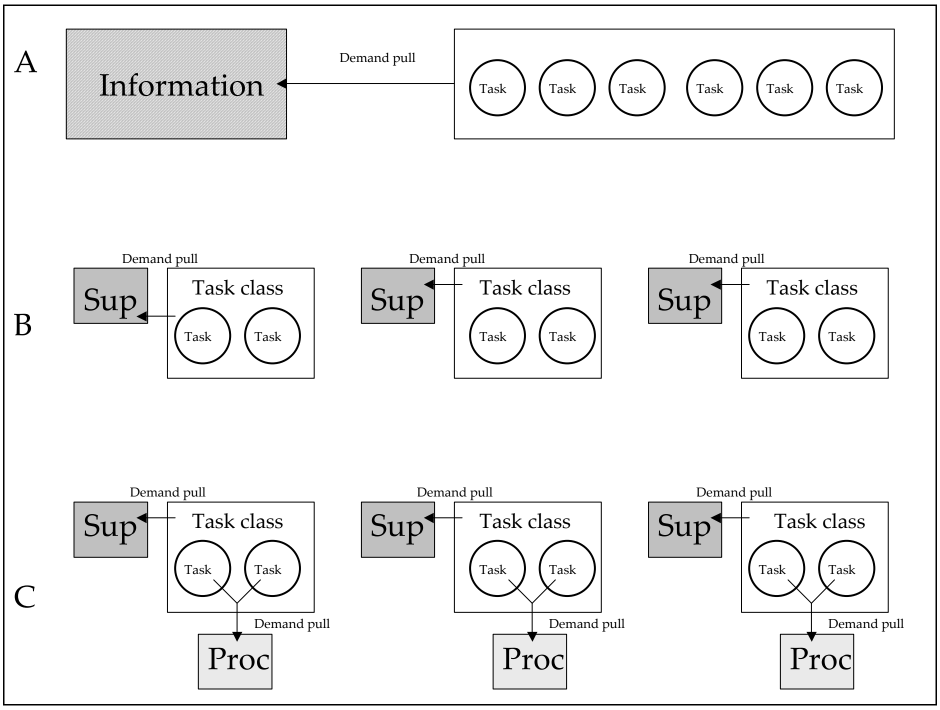


Figure 1: Three models for information presentation: Traditional just in case information presentation (A), just-in-time supportive information (Sup) presentation in an elaborative sequence (B), and full, just-in-time supportive and procedural information (Proc) presentation (C).

Procedural vs. supportive knowledge

A complex cognitive skill consists of a number of highly interrelated constituent skills that show qualitative differences in performance; at least some of the constituent skills require conscious processing and they all exhibit goal-directed behaviors. With regard to desired exit behavior, a difference can be made between non-recurrent and recurrent constituent skills (see Figure 2). The application of non-recurrent constituent skills varies from task to task while recurrent constituent skills can be applied in the same manner in different tasks. For example, for the complex cognitive skill 'troubleshooting in a alcohol-water distillery', skills related to reasoning about alcohol-water distillery using the principles underlying this functioning are considered non-recurrent skills. Recurrent skills, for instance, concern the procedures for operating the system and safety procedures. Mastering non-recurrent skills requires the construction of complex cognitive schemata that may guide subsequent problem solving behavior. Schema construction is a process of mindful abstractions from concrete experiences. Mastering recurrent skills requires the automation of schemata that is, highly domain-specific rules or procedures. Schema automation is mainly a function of the amount and quality of practice.

In order to design high quality instruction, non-recurrent and recurrent aspects of the complex cognitive skill have to be identified and analyzed. Moreover, an analysis has to be made regarding the information that is *supportive* to the performance of the non-recurrent aspects of the complex skill (e.g., causal and conceptual models) and information that is *procedural* to carry out the recurrent aspects of the skill (e.g., facts, concepts etc.). In the example, information about the working of a valve or about the consequences of temperature fluctuations for the system is considered supportive while information about the names of the different components of the system or about specific operations like switching the alarm off is considered procedural. Once the constituent skills and the appropriate knowledge have been identified, the skills are practiced in learning tasks that promote schema construction for non-recurrent aspects, and schema automation for recurrent aspects. Learning tasks typically provide whole-task practice, which means, most or all of the constituent skills are trained simultaneously. Whole-task practice can be seen as a sequence of simple-to-complex task classes in which concrete learning tasks include all aspects of the complex cognitive skill. The twofold purpose of whole-task practice is the construction of schemata that allow learners to perform unfamiliar task aspects (schema-based behavior) and the automation of schemata that allow learners to effortlessly perform familiar task aspects (rule-based behavior, see Figure 2).

In order to make assumptions about the effectiveness of just-in-time supportive and procedural information presentation, a measurement of desired outcome behavior has to be made. For the mix of schema-based and rule-based behaviors, effectiveness can be measured by the ability to solve transfer tasks. Two mechanisms to explain transfer are distinguished. The first mechanism is schema-based transfer in which the *same* declarative knowledge is used in a *different* way in solving transfer tasks. The second mechanism is rule-based transfer in which the *same* schemata, automated during practice, are used in the *same* way in solving transfer tasks. To elaborate on this, a continuum exists from near transfer tasks at the one end to far transfer tasks at the other end. Near transfer tasks are highly similar to the trained tasks while far transfer tasks are more and more different from the trained tasks. Both mechanisms are used simultaneously in solving transfer tasks. At the near transfer end of the continuum performance relies more on rule-based transfer than on schema-based transfer and at the far transfer end it is the other way round.

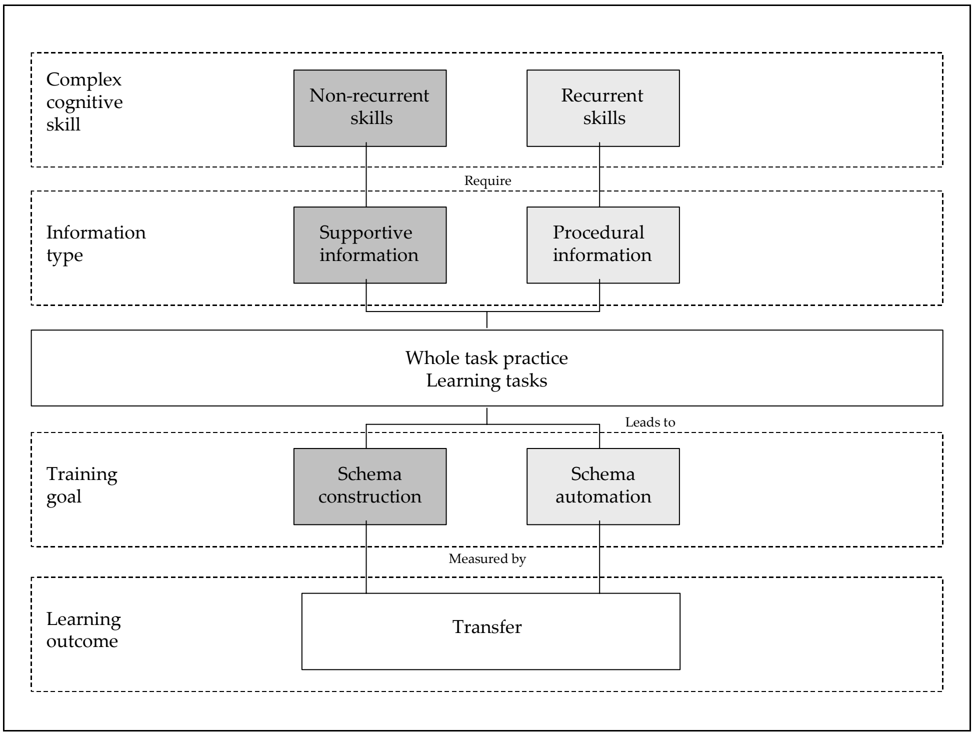


Figure 2: The distinction between supportive and procedural information in the just-in-time information presentation model.

Just-in-time supportive information presentation

In our model supportive information is sequentially coupled to a range of task classes (see Figure 1b). First, the training program for the complex cognitive skill is divided in task classes in which simple-to-complex categories of learning tasks are identified. Second, for each task class concrete learning tasks are formulated. Before each task class appropriate supportive information is given in order to promote meaningful learning or elaboration that is, learning processes in which the learner connects new information to already existing, relevant cognitive structures. This elaborated supportive information is helpful in performing the non-recurrent aspects of the learning tasks in this particular class. The new information becomes embedded in these structures and because of this anchoring the new information no longer depends on working memory for its existence (Ausubel, 1963). The use of *simple-to-complex sequences* for supportive information and task classes enhances the elaboration process that leads to better schema construction. The idea that the use of simple-to-complex sequences of task classes and related information has enhancing effects on learning stems from theories about prose learning which originated in the 1960s. Three of the most relevant theories in this respect are, the Subsumption Theory (Ausubel, 1963), the Assimilation Encoding Theory (Mayer, 1979) and the Elaboration Theory (Reigeluth & Stein, 1983) which are discussed here.

According to Ausubel's Subsumption Theory (1963), our cognitive architecture is hierarchically organized in terms of representations of past experiences. These representations are arranged from greater to lesser inclusiveness; every higher step in the hierarchy is linked to the former through a process of subsumption. Subsumption means the hierarchical incorporation of new material into an existing cognitive structure. Subsumption Theory thus assumes that meaningful learning only occurs when new material can be appropriately subsumed under a relevant, existing concept. The new material is 'anchored' and becomes more stable by subsuming it under existing cognitive structures (Ausubel, 1963). In order to facilitate the subsumption process, advance organizers can be applied in instructional design. These organizers are introduced in advance of the learning material and distinguish themselves from summaries and overviews by a higher level of abstraction, generality, and inclusiveness. Moreover, because the content of a given organizer or series of organizers (cf. the proposed elaborative sequence of supportive information and task classes) is selected on the basis of their suitability for explaining, integrating, and interrelating the material they precede, the organizational strength of the cognitive structure is enhanced. These organizers provide advance ideational scaffolding, that is, when the learner is confronted with unfamiliar material a cognitive structure is available for incorporating the new concepts (Ausubel, 1963; Jonassen, 1982).

However, studies concerning the effectiveness of advance organizers show inconsistent results (Jonassen, 1982). Mayer (1979) blamed this on the basic assumptions of the Subsumption Theory itself and therefore proposed a different theory, the Assimilation Encoding Theory (AET). The latter assumes that human cognitive structure is heterarchically organized and not hierarchically as Ausubel posits. AET distinguishes three stages of encoding: reception (the receipt of information in working memory), availability (the accessibility of anchoring knowledge in long term memory), and activation (the appropriate transfer of anchoring knowledge from long term memory to working memory so that it can be actively integrated with the received information and transferred back again to long term memory). Meaningful learning will take place only when these three stages are passed through. Advance organizers only contribute to the learning process when they help the learner to complete all three stages. They have no effect when anchoring knowledge is already available in and appropriately activated by either the learner or the material presented. Moreover, when the material is badly structured and consists of isolated facts, an advance organizer cannot even be constructed. Mayer found in a number of studies that the predictions made by the AET regarding advance organizers were fairly supported. In a meta-analysis of 132 studies advance organizers appeared to facilitate learning and retrieval (Jonassen, 1982; Mayer, 1979).

Elaboration Theory (ET; (Reigeluth & Stein, 1983) provides us with another example of simple-to-complex sequences in instructional design, the elaborative sequence. Such a sequence starts with an epitome, which entails the most inclusive and most general principles of a learning task, and gradually progresses to less inclusive, more detailed and more precise principles. The ET is explained by an analogy with a zoom lens that operates in steps. A person starts with a wide-angle view of a picture and sees the major parts and the relationships between those parts, but no detail. By zooming in the person sees more about a certain subpart (in our model, a task class and related supportive information) and learns more about its interrelationships. After viewing all the relevant features of a certain subpart the person can zoom out to the wide-angle view again to review the other subparts (i.e., the next task class and related supportive information) of the whole picture and the context of the subpart in the whole picture. This process of zooming in and zooming out can continue until all subparts are viewed in detail. Similarly, the ET prescribes that the epitome needs to be reviewed, thereby showing relationships between the most recent ideas and the ideas presented earlier. This pattern of elaboration followed by summary and synthesis is continued until the desired level of complexity is reached for all the aspects of the epitome (Reigeluth & Stein, 1983).

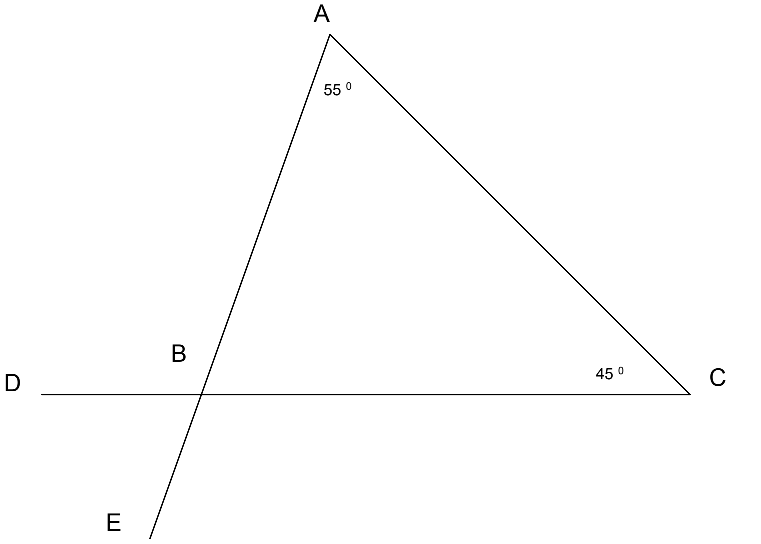
The three theories discussed above all expect beneficial effects from sequencing instructional tasks and related information in a simple-to complex order. However, the effectiveness of sequencing depends on two major factors: The strength of the relationship between task classes and the amount of time involved in mastering the whole complex cognitive skill. Sequencing becomes more important when the relationship between the constituent skills is stronger and when mastering a complex cognitive skill takes more than a couple of hours. When a cognitive skill is mastered in less time the learner can compensate for weaknesses in sequence (Reigeluth, 1999). These two basic rules should be kept in mind while designing instruction according to the just-in-time information presentation model.

Just-in-time procedural information presentation

While supportive information is best presented before a new task class, procedural information is best presented during practice on the learning tasks (see Figure 1c). By just-in-time procedural information presentation, the proceduralization process associated with this information is facilitated because the proper information is active in working memory when the skill is practiced. Because the procedural information is directly available during practice, it may be embedded in the automated schemata or rules that constitute the recurrent skill. Moreover, by establishing schema automation for recurrent aspects of whole-task practice, more working memory capacity becomes available which can be allocated to learning the non-recurrent aspects of the complex cognitive skill. Thus, just-in-time information presentation aimed at schema automation is also beneficial to schema construction.

The temporal aspects of information presentation in instructional design, especially those regarding procedural information, have consequences for cognitive load. Cognitive Load Theory (Chandler & Sweller, 1991; Sweller, 1988; Sweller, Van Merriënboer & Paas, 1998) generates guidelines for the development of instructional material, starting from the assumption that working memory is severely limited. Cognitive load theory distinguishes three forms of cognitive load that, together, determine the total cognitive load: Intrinsic cognitive load, extraneous cognitive load and germane cognitive load. Intrinsic cognitive load is determined by the task being learned and the expertise of the learner (e.g., it is high for tasks with high element interactivity and/or learners with low expertise). Extraneous cognitive load is caused by the instructional material itself and refers to all the processes a learner engages in during a task which are not beneficial to learning (e.g., searching for relevant information sources, combining information sources). Germane cognitive load is a result of the processes directly relevant for learning and therefore appropriate within a learning context (e.g., conscious, mindful abstraction of generalized knowledge). With a given intrinsic cognitive load, the extraneous cognitive load should be minimized and the germane cognitive load should be optimized by instructional design (Cooper, 1998; Sweller et al., 1998). Of course, the total cognitive load should always remain within the boundaries of working memory capacity.

From the perspective of cognitive load theory, just-in-time procedural information presentation can be considered as a means to avoid *temporal split attention*. Split attention arises when multiple sources of information, separated in space or time, have to be mentally integrated in order to understand the complete picture. For instance, in geometry a diagram is often explained by accompanying text. In order to understand the diagram the text has to be mentally integrated with the diagram. This causes an increase in extraneous cognitive load because of visual search activities. In trying to understand different parts of the picture, the learner continuously has to search for the matching written information. This phenomenon is called the split attention effect (Chandler & Sweller, 1991; Sweller, 1994). Integrating the multiple conditional sources of information, either in space or time, reduces extraneous cognitive load (see Figure 3 for example in which both spatial and temporal spilt attention are avoided). By integrating the multiple sources of information the need to search for relevant referents and mentally integrating them is diminished, resulting in a decrease of extraneous cognitive load and higher transfer test performance.



In the above Figure, find a value for Angle DBE.

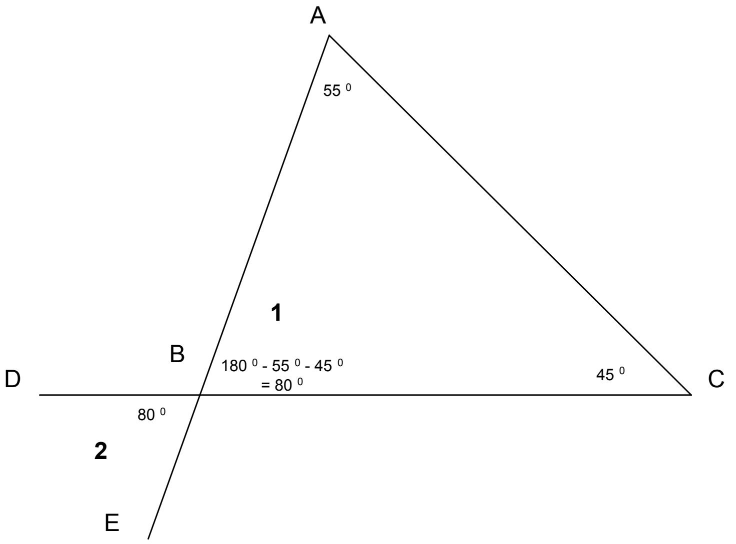
Solution: Angle ABC = 180^0 - *Angle BAC - Angle BCA (Internal angles of a triangle sum to* 180^0*)*

= $180^0 - 55^0 - 45^0$

= 80^0

Angle DBE = *Angle ABC (vertically opposite angles are equal)*

= 80^0 (1)



(2)

Figure 3: Example demonstrating split attention (1), integrated example with no split attention (2) (Sweller, J., Van Merriënboer, J., & Paas, F., 1998).

Avoidance of temporal split attention in instruction by just-in-time procedural information presentation should also reduce extraneous cognitive load. Analogous to integrating pictures and text, information separated in time is now integrated resulting in a lower extraneous cognitive load because the learners do not have to 'search-and-match' and mentally integrate the information presented. Mayer carried out several experiments which provide a demonstration of the temporal split attention effect (Mayer & Anderson, 1991; Mayer & Anderson, 1992; Mayer & Sims, 1994).

In the first two experiments considered here, in an instructive animation on the working of a bicycle tire pump or an automobile braking system, integrated narration and animation was compared to successive presentation of narration and animation, narration only, animation only and no instruction at all. It was found that integrated instruction led to better performances on relevant creative problem solving tests (Mayer & Anderson, 1991; Mayer & Anderson, 1992). Similar results were found in a third experiment were an instructive animation was given on the working of a bicycle tire pump or the human respiratory system. Integrated narration and animation was compared to successive presentation of narration and animation or no instruction at all. It appeared that learners in the integrated condition performed better on the problem solving test than the learners in the other conditions (Mayer & Sims, 1994). According to these results, eliminating temporal split attention leads to more effective learning. From the perspective of cognitive load theory, the reduction of extraneous cognitive load by just-in-time procedural information presentation (i.e., avoidance of temporal split attention) facilitates the mastering of recurrent constituent skills. This, in turn, further decreases extraneous cognitive load in the acquisition of non-recurrent skills, thereby facilitating schema construction.

Discussion

This chapter described a model for just-in-time information presentation. In a task analysis, the task itself is used to distinct which information is necessary for skill acquisition. The task is analyzed step-by-step to reveal the information that is necessary to understand and carry out the task. The constituent sub skills (i.e., non-recurrent and recurrent skills) and the desired exit behavior (i.e., schema construction or schema automation) are used to distinguish which information is treated as supportive and which is treated as procedural. When a firmer basis for the just-in-time information presentation model is established, we can elaborate our model further by trying to form hypotheses about the manner in which the information presentation takes place. Until now our model is about the 'What?', supportive and procedural information, and the 'When?', before or during practicing task classes. But another set of questions relates to the 'How?'.

Four relevant approaches regarding the 'How?' of information presentation can be distinguished: deductive vs. inductive approaches and expository vs. inquisitory approaches. First, the deductive and inductive approaches are based on deductive and inductive reasoning respectively. In deductive reasoning the learner uses given generalities to come to conclusions (instances) that can be proven correct. In contrast, in inductive reasoning, learning is viewed as inducing generalities from limited instances and testing them. As long as new information can be predicted by the generality, it is retained. Only when the learner encounters incompatible information are new generalities generated (Mayer, 1983). When a deductive information presentation approach is used, generalities are presented before instances (e.g., illustrative examples). Using the inductive approach to information presentation, the instances are presented prior to the generalities. According to Evans, Homme and Glaser (1962) a generality-instance format is best applied when the concept to be learned can be understood in abstract form while an instance-generality format is best used when this concept is difficult or too abstract for the learner (Fleming & Levie, 1979).

Second, the expository approach is characterized by the explicit presentation of relationships between pieces of information, while in the inquisitory approach the learners are asked to produce these relationships themselves. The inquisitory approach allows the learner to connect the new information to what is already known and leaves ample room for elaboration, the opposite is true for the expository approach. The latter should only be used when the available instruction time is severely limited. These four approaches are combined to four information presentation strategies: a deductive-expository strategy, a deductive-inquisitory strategy, an inductive-expository strategy and an inductive-inquisitory strategy. The 4C/ID model proposes that procedural information presentation should preferably be presented according to a deductive-expository strategy, in other words, the procedural information should contain explicit, rules and facts. But this is not true for all situations. The strategy best used to present the supportive information depends on availability of instructional time, relevant experience of the learner and required level of understanding. In general, an inductive-expository strategy is proposed. But when instructional time is severely limited, the learner has enough relevant experience and deep understanding is not necessary, the deductive-expository strategy is recommended. The inductive-inquisitory strategy is suggested when there is ample instructional time and the learners are inexperienced and a deep level of understanding is required.

To conclude this chapter, future research will be aimed at establishing a firm basis for the use of the demand pull principle in the instructional design of learning tasks that aim at mastering a complex cognitive skill. An attempt has to be made to find support for the assumptions that supportive information is best presented before practicing task classes and procedural information is best presented during task practice. When firm support is found for these assumptions, the manner in which the supportive or procedural information is presented can be further studied.

Chapter 3 - Timing of information presentation in learning statistics[1]

Abstract

In this chapter the just-in-time information presentation model is tested in the domain of statistics. Four information presentation formats are compared in a 2x2 factorial design: timing of supportive information (before *or* during task practice) x timing of procedural information (before *or* during task practice). Seventy-two psychology and education students (7 male and 65 female; mean age 18.5 years, $SD = 2.85$) participated. The effectiveness of the learning material was measured by test performance and the instructional efficiency by a combination of mental effort during practice and test performance. ANOVA showed a main effect for timing of supportive information: presentation *during* practice leads to more *efficient* learning than presentation *before* practice. Moreover, an interaction effect was found. Simultaneous presentation of procedural information before practice and supportive information *during* practice leads to the most *efficient* learning.

Introduction

In the 1960's and 1970's, *meaningfulness* came to be seen as a key factor in learning and remembering. According to Johnson (1975), "meaningfulness is potentially the most powerful variable for explaining the learning of complex verbal discourse" (pp. 425-426). Learning is meaningful if learners can relate new learning tasks to their existing cognitive structures (Novak, 1984; Novak & Gowin, 1984; Williams & Cavallo, 1995). In other words, the more that new learning can be associated with what is already known and with available cognitive schemata, the better it will be learned. This is accomplished by making sure that the new information is both deeply and richly processed, since superficial similarities are not likely to lead to proper encoding. This deliberate manipulation of the relevant aspects of cognitive structure for educational purposes is best accomplished by substantively preparing the learner for the learning tasks that are to come (e.g., with the aid of advance organizers (Ausubel, 1963; Ausubel & Robinson, 1969; Mayer, 1979). In other words, education should create a proper context within which the student can efficiently and effectively elaborate on already available cognitive structures. The success of this approach to learning depends on the availability of the information in long-term memory before the learner starts the practice tasks. A potential pitfall is the time-consumingness of this elaboration process. In practice, a trade-off between time effectiveness and level of elaboration often has to be made.

More recent theories of learning stress the importance of instruction situated in realistic knowledge-rich contexts, above all taking place in a highly interactive environment (Koschman Myers, Feltovich, & Barrows, 1994; Derry & Lesgold, 1996; Salomon & Perkins, 1999). Within these contexts, the learner receives or actively

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seeks the information necessary to carry out practice tasks at the moment the information is needed. This approach implies that what the learner needs should drive the delivery of information. Those who hold with this view often advocate learner-directed modes of instruction. They argue that integrated learning directed by students helps them to understand why, how, and when to use information and tools (Darling-Hammond, 1997; Ruopp et al., 1993). Accepted knowledge is seen as a stockpile of discrete ideas, concepts or tools that can be delivered as needed. In other words, information sources are functionally used. It assumes that ideas only have value in terms of their functional use in solving specified problems.

A consequence of this approach is that learners need to either actively seek or passively accept the information at the moment that it is needed. A potential problem is that the learner must simultaneously carry out a practice task and process the necessary information, which could prove too taxing to the processing capacity of working memory. The fact that human working memory is limited is well accepted (Baddeley, 1992; Miller, 1956). Once the limits are reached, performance deteriorates (Chandler & Sweller, 1991; Sweller, 1988; Sweller, van Merriënboer, & Paas, 1998). When task relevant information is presented simultaneously with the execution of the practice tasks, the risk of overloading working memory is present. The success of this approach, thus, depends on the optimal taxation of the information-processing capacity of working memory. In this study, an attempt is made to develop learning material with an optimal balance between the time-effectiveness of the elaboration process and the level of working memory load by presenting the *right* information at the *right* time.

To acquire a complex cognitive skill, the learner needs to practice a series of (sub) skills, which are often different in nature. The performance of some skills is consistent across problem or task situations (i.e., recurrent skills) while the performance of other skills is highly variable over task situations (i.e., non-recurrent skills). The different nature of these (sub) skills implies a difference in information necessary to master them.

In a process of skill decomposition, task analysis, and knowledge analysis a distinction can be made between two types of information (Fisk & Gallini, 1989). When statistics is considered, the domain of this study, a distinction can be made between skills concerned with the application of formulas (recurrent skills) and skills concerned with *when* to apply *which* formulas (non-recurrent skills). To master the correct application of formulas, *procedural* information about the exact form of the formula and definitions of the elements in the formula is needed. For example, this study uses Chi-square tests and to calculate Chi-square the following formula is needed: $\chi^2 = \Sigma(o - e)^2 / e$ in which χ^2 stands for Chi-square, o for observed frequency, and e for expected frequency. To master the skills that allow students to make the right choice as to whether the Chi-square test can be used, *supportive* information is needed about statistical testing in general and circumstances under which a Chi-square test is called for.

Mastering non-recurrent skills requires constructing schemata in long term memory, which can be used in different task situations. This construction involves a process of mindful abstractions from concrete experiences, that is, elaboration (Proctor & Reeve, 1988). Mastering recurrent skills requires, after construction, the *automation* of those schemata used in similar task situations and is accomplished through *proceduralization* (Anderson, 1993, 1996). For proceduralization to occur, relevant information has to be active in working memory when the skill is practiced. The underlying cognitive processes of the non-recurrent skills and recurrent skills imply that both information types require different optimal moments of presentation.

To facilitate the elaboration process, supportive information should be presented before practice, so that the learner has the opportunity to embed new information in already available cognitive structures. Procedural information, on the contrary, should be presented during practice in order for proceduralization to occur (Kester, Kirschner, van Merriënboer, & Bäumer, 2001).

This view is supported by instructional guidelines based on Cognitive Load Theory (Sweller, 1988), which concentrates predominantly on the limitations of working memory. According to Cognitive Load Theory, different types of cognitive load are imposed on the learner by the learning material, under which, intrinsic load (i.e., the load associated with the content of the learning material) and extraneous load (i.e., the load associated with the instructional features of the learning material).

Intrinsic cognitive load is inherent to the learning material itself and is determined by the element interactivity in the material and the expertise of the learner (e.g., it is high for learning material with high element interactivity and/or learners with low expertise). Learning material with high element interactivity demands simultaneous processing of several elements in working memory while material with low element interactivity allows for serial processing of several elements (Sweller et al., 1998). For example, the supportive information in this study has a high element interactivity because in order to decide which statistical test is appropriate under specific circumstances, the learner has to *simultaneously* process and evaluate features of different statistical tests in working memory so as to make the right decision. The procedural information, on the contrary, has a low element interactivity because in order to apply the formula of a Chi-square test for one sample, the learner has to *serially* process several mathematical operations in working memory. This especially has implications for the timing of supportive information during the acquisition of a complex skill. The intrinsic load associated with supportive information is higher than the intrinsic load associated with procedural information. Therefore, it should be better to present supportive information apart from procedural information, so that, all working memory capacity can be allocated to processing the supportive information, at that point in time.

Extraneous cognitive load is caused by the instructional features of the learning material and refers to all the processes a learner engages in during a task which are not beneficial to learning (e.g., searching for relevant information sources). Extensive research (Cerpa, Chandler, & Sweller, 1996; Chandler & Sweller, 1991; Chandler &

Sweller, 1992; Chandler & Sweller, 1996; Kalyuga, Chandler, & Sweller, 1999; Mayer & Anderson, 1992; Mayer & Moreno, 1998; Mayer & Sims, 1994; Sweller & Candler, 1994) has shown that an effective way to minimize extraneous cognitive load is to avoid split attention which arises when a learner has to mentally integrate several sources of *mutually referring* information (e.g., a picture and its explanatory text) in order to understand the learning material. By integrating the different sources of information spatially or temporally, split attention is prevented and learning is facilitated. In this study, the procedural information (e.g., the calculation procedure of expected frequencies for one sample) and the practice tasks (e.g., calculation of expected frequencies for one sample) are mutually referring. The procedural information could be applied to the practice tasks while the practice tasks rely upon the procedural information. Therefore, procedural information should be presented during practice in order to avoid *temporal* split attention (Van Merriënboer, Kirschner, & Kester, 2003). In general, with a given intrinsic cognitive load, the extraneous cognitive load should be minimized by instructional design (Sweller, van Merriënboer, & Paas, 1998). When this is accomplished, all cognitive capacity can be allocated to relevant learning processes, which will facilitate the mastering of non-recurrent skills (or schema construction) and recurrent skills (or schema automation).

In this chapter an attempt was made to shed some light on the issue of timing of information presentation. Four information presentation formats were distinguished. One in which both supportive and procedural information were presented *before* practice. In this format no steps were taken to manage intrinsic load or to avoid temporal split attention. A second format in which both supportive and procedural information were presented *during* practice. In this format no steps were taken to manage intrinsic load but temporal split attention was avoided. In a third format supportive information was presented *before* practice and procedural *during*. In this format steps were taken to manage intrinsic load and to avoid split attention. A final format presented supportive information *during* practice and procedural *before*. In this format steps were taken to manage intrinsic load but split attention was not avoided.

The effectiveness and efficiency of all four information presentation formats was studied in the domain of statistics. The effectiveness of the information presentation formats was measured by test performance. Test tasks that were equivalent to the practice tasks were used to measure if the learner mastered the recurrent skills, that is, was capable of using the *same* schemata the *same* way in solving equivalent test tasks. Test tasks that were very different from the practice tasks were used to measure if the learner mastered the non-recurrent skills, that is, was capable of using the *same* schemata in a *different* way in solving transfer test tasks. The method of Paas and van Merriënboer (1993) was used to calculate format efficiency scores for mental effort and test performance.

It was hypothesized that the formats in which the intrinsic cognitive load is properly managed would lead to more effective (i.e., higher test performance scores, especially for the transfer test tasks) and efficient learning because the risk of overloading working memory was seriously reduced by this measure. Moreover, the format in which intrinsic load was managed and split attention was avoided (i.e., the presentation of supportive information before practice and procedural during) would lead to the most effective and efficient learning because this format optimally allowed for elaboration and proceduralization, optimally made use of the available cognitive resources and, therefore, optimally facilitated schema construction and schema automation.

Method

Participants

Seventy-two freshman psychology and education students at the University of Gent, Belgium (7 male and 65 female; mean age 18.5 years, $SD = 2.85$) participated in this study. All of the participants spoke Dutch as first language, the language in which the instruction was given. They voluntarily signed up for an introductory two-day statistics course to get acquainted with this subject. Only students who had four hours or less mathematics a week in secondary education could sign up for this course. In Belgian secondary schools, students who choose for the social sciences typically have four hours or less mathematics a week. Students choosing engineering or natural sciences typically have seven hours or more. Secondary mathematics education in Belgium does not include any statistics and thus, all participants are novices in this domain. The first day of the course was meant to freshen up mathematics knowledge and skills, while the second day was an introduction to statistics. The statistics part of the course was used for the experiment.

Materials

Statistics course.

The statistics course was developed and presented in Mercator®, an electronic development and instruction environment. Mercator® was also used for the math course on the first day allowing the participants to get used to navigation in this program.

Aim of the statistics course was to learn the participants, step-by step, how and when to use a Chi-square test for one sample and how and when to use a Chi-square test for two or more samples. The participants received 24 practice tasks divided over six topics (i.e., 4 per topic), namely, frequency tables, expected frequencies for one sample, Chi-square test for one sample, cross tables, expected frequencies for two or more samples, and Chi-square test for two or more samples.

Each topic is composed of, supportive information, procedural information, general information that was used to 'glue' the course together and four practice tasks. Each topic was build up of two subsequent screens and each screen was divided in a left half and a right half. For every topic goes that both screens contained supportive information and/or procedural information (depending on the condition) presented on the left. On screen one, this information was combined with general information presented on the right and on screen two; it was combined with four practice tasks presented on the right. The practice tasks were administered to the participants in the form of conventional tasks and no feedback was given to participants about their performance. For a schematic overview of a topic in the statistics course see Figure 1.

In cooperation with and thoroughly checked by an expert in the field of statistics, a task analysis was carried out to determine which information of the practice tasks, was supportive information and which was procedural. For example, the description of the research question and examples of other research questions is considered supportive information and setting up a frequency table is considered procedural information (see Appendix 1 for a detailed description of the information).

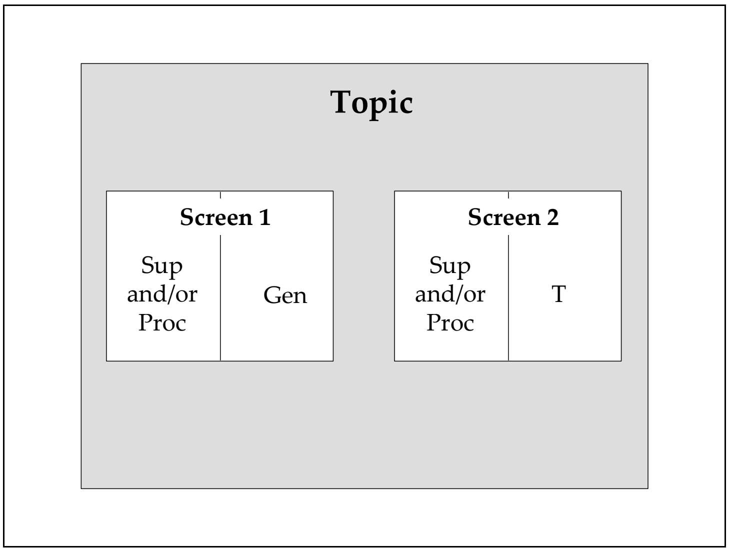

Figure 1: A schematic overview of the statistics course. Sup = Supportive information, Proc = Procedural information, Gen = General information, and T = Task practice.

Information presentation.

The participants were randomly assigned to one of the four formats. In the SupB-ProcB format, both supportive (Sup) and procedural (Proc) information were presented *before* (B) the participants carried out the practice tasks (n = 16). The participants assigned to the SupD-ProcD format received both information types *during* (D) carrying out the practice tasks (n = 17). In the SupB-ProcD format, supportive information was presented *before* practice and procedural information was presented *during* practice (n = 19). In the SupD-ProcB format the supportive information was presented *during* practice while the procedural information was presented *before* the participants carried out the practice tasks (n = 20). Figure 2 shows an overview of these four information presentation formats.

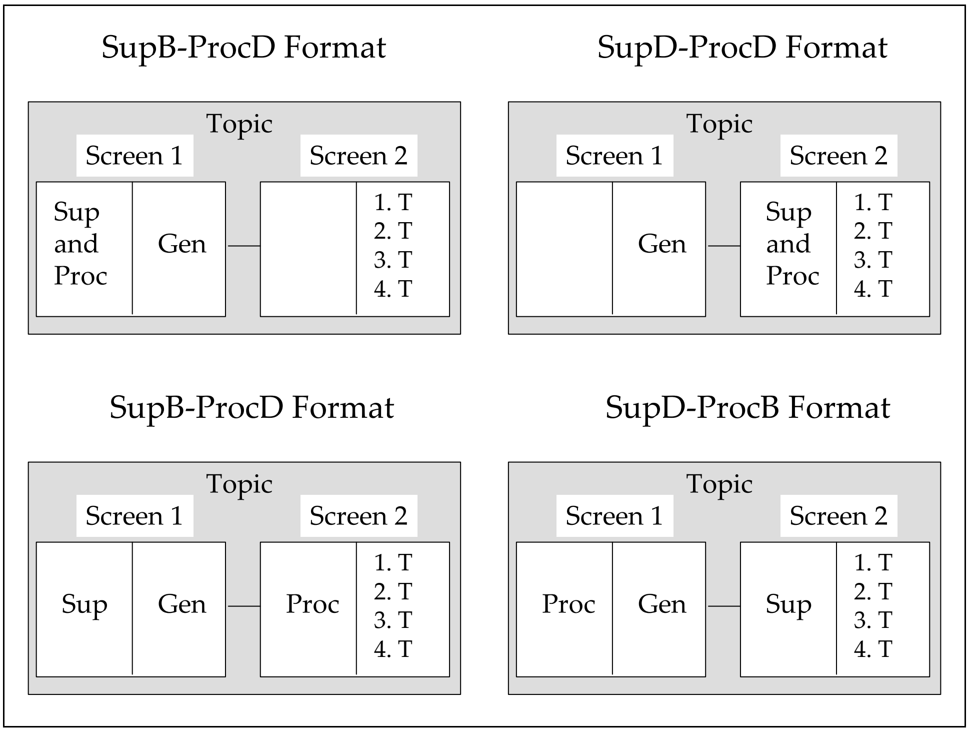

Figure 2: Overview of the four information presentation formats. Sup = Supportive information, Proc = Procedural information, Gen = General information, and T = Task practice

Test tasks.

After completing the electronic statistics course, the participants had to carry out a paper and pencil test with equivalent and transfer tasks. The equivalent test tasks (12 items, that is, 6 topics x 2 items per topic) were very similar to the practice tasks. They tested whether the participants were able to independently perform the learned procedures (i.e., had mastered the recurrent skills). Open questions were administered in order to give the participants optimal opportunity to show they know how to carry out the learned procedures. For example:

> Make a frequency table for the variable multiple choice question when we know that 3 participants chose answer A, 11 participants chose answer B, 27 answer C and 9 chose answer D. Calculate the percentages and enter them in the table.

The maximum score on the equivalent test tasks was 36 points, one point for each item about expected frequencies (four points in total) and four points each for the other items (32 points in total). Two raters carried out the scoring of the equivalent test tasks. The interrater reliability of the two raters was .93 (Intraclass Correlation Coefficient, SPSS). The internal consistency of the equivalent test tasks was .73 (Cronbach's alpha).

The transfer test was used to measure the participant's ability to recognize situations in which a Chi-square test is called for (i.e., had mastered the non-recurrent skills). The transfer tasks (16 items) were very dissimilar to the practice tasks. Multiple-choice (MC) questions were administered to test if participants had been able to form a good mental model of Chi-square testing. These MC questions all represented tasks for which a different statistical test could be used. The participants were asked to determine whether the specific problem called for using a Chi-square test or not. For example:

Problem: A manufacturer of a particular drug claims that the drug is effective in 90% of all cases. In a sample of 200, the drug wasn't effective in 40 cases. Is the claim valid?

Is the Chi-square test the right test to use to support the claim?

- o Yes
- o No
- o I don't know.

Both the wrong answer and the answer "I don't know" were considered to proof that the transfer had not taken place. The maximum score on the transfer test was 16 points and the test has a reliability of .65 (Cronbach's alpha). A closed format was chosen because it enabled the participants to compare and distinguish between problems that required different statistical tests and to identify the proper test without having to perform these tests. After all, the participants had no prior statistical knowledge and therefore did not know how to perform any statistical test other than the Chi-square test. The sequence of the test tasks was random.

Mental effort measurement.

Mental effort was measured during practice with a nine-point rating-scale for measuring the participants' perceived mental effort (Paas, 1992; Paas, van Merriënboer, & Adams, 1994). The mental effort measures ranged from very, very low mental effort to very, very high mental effort. The rating-scale was administered at fixed points during practice, namely, at the end of every topic. Participants were asked to note how much mental effort it cost them to understand the learning material and, in a second question, how much mental effort it cost them to carry out each practice task. This resulted in a total of twelve mental effort measurements. The internal consistency of these mental effort measures (Cronbach's alpha) was .91.

Log tool.

A log tool was used to measure the time the participants spent on the electronic statistics course.

Procedure

The experiment was divided into two sessions. The morning session involved the electronic statistics course and the afternoon session the paper and pencil test. Before starting the experiment, participants received instructions about the general procedure of the experimental task. They were told that the statistics course was being used for research purposes and that they:

- had to work independently,
- were not allowed to take notes,
- had to go through the statistics course in the prescribed order,

- were not allowed to make any adjustments within Mercator® (during the math course the participants learned about certain personal adjustments that can be made in the program but these may not be used during the experiment), and
- were not allowed to bring anything to the PC-classroom except for a pen and a calculator.

It was made clear that they had to hand in their answer sheets when finished. Participants were allowed to ask questions before and during the experiment, but this was not encouraged. All questions about operating the electronic statistics course were answered. Questions about the content of the statistics course were not answered. In this case, participants were referred back to the information given in the course. Participants went through the electronic course at their own pace. It was possible for the participants to move back and forth both within topics and between topics.

In the afternoon session the participants were told that they had to practice what they had learned in the morning session. In fact, they received the test. It was stressed not to guess while answering the multiple-choice questions and to work independently.

Results

Test performance

Equivalent tasks.

First, the scores participants obtained on the equivalent test tasks were considered. In this study, an alpha level of .05 was used for all statistical tests. ANOVA revealed no statistically significant main effects or interaction effects. Equivalent test task scores are presented in Table 1.

Transfer tasks.

ANOVA revealed no statistically significant main effects for the transfer test either. The results on the transfer test are summarized in Table 1.

Table 1: Summary of the test data.

	Supportive information			
	Before		During	
Procedural information	*M*	*SD*	*M*	*SD*
Equivalent test tasks (max. = 36)				
Before	18.56	6.44	20.63	5.09
During	20.39	5.90	19.47	4.08
Transfer test tasks (max. = 16)				
Before	6.37	2.00	8.45	1.32
During	6.84	2.69	6.88	2.87

Mental effort measures.
The mean of the 12 mental effort measures was considered. ANOVA revealed no statistically significant main effects, or interaction effects regarding the mean mental effort. For an overview of these results see Table 2.

Table 2: Summary of the mean mental effort data[a]

	Supportive information			
	Before		During	
Procedural information	*M*	*SD*	*M*	*SD*
Before	4.74	1.13	3.86	1.35
During	4.11	1.00	4.13	.96

[a]*Max = 9*

Instructional efficiency.
Instructional efficiency (*E*) scores were calculated for mental effort and test performance (Paas & van Merriënboer, 1993). First, the mental effort measures and the performance measures per participant were transformed to *z*-scores. The grand mean is used for calculation, through which the mean *z*-score for every condition can be determined. These mean condition *z*-scores can be represented in a Cartesian coordinate system with *P*erformance *z*-scores on the horizontal axis and *M*ental effort *z*-scores on the vertical axis. The line $P = M$ through the origin of the axes indicates an efficiency of zero (slope = 45^0). The relative condition efficiency is calculated as the perpendicular distance from a data point in the coordinate system to the line $P = M$ (Paas & van Merriënboer, 1993). Calculation of *E* is done, per participant, with the following formula:

$$E = \frac{\textit{P}\text{erformance - }\textit{M}\text{ental Effort}}{\sqrt{2}}$$

Equal performance (*P*) and mental effort (*M*) scores yield an instructional efficiency of zero, a neutral score. When $P > M$, the instructional material is efficient because the mental effort is lower than might be expected on the basis of observed performance. When $P < M$, the material is *not* efficient because the mental effort is higher than might be expected on the basis of the observed performance.

Efficiency measures were calculated on the basis of the equivalent test task scores and the transfer test scores (see Table 3). For the efficiency based on the equivalent test tasks, ANOVA revealed no statistically significant effects. For the efficiency based on the transfer test tasks ANOVA revealed a statistically significant main effect for the timing of supportive information (F (1, 68) = 6.07, MSE = .99, $p < .05$; $\eta^2 = 0.082$) and a statistically significant interaction between the timing of supportive and procedural information (F (1, 68) = 6.05, MSE = .99, $p < .05$; $\eta^2 = 0.082$). Post hoc tests, using Tukey's HSD, indicated that only the SupB-ProcB format and the

SupD-ProcB format differed significantly ($p < 0.05$). Participants who had received supportive information during practice (*M* = .28, *SD* = .94) had higher efficiency scores than participants who had received supportive information before practice (*M* = -.30, *SD* = 1.10). When procedural information is presented before practice, presentation of supportive information during practice yields much higher efficiency scores (*M* = .57, *SD* = .77) than the simultaneous presentation before practice (*M* = -.59, *SD* = 1.19). When procedural information is presented during practice, there is no difference between the presentation of supportive information during practice (*M* = -.06, *SD* = 1.03) and before practice (*M* = -.09, *SD* = .99).

Table 3: Summary of the mean efficiency measures.

	Sup Before				Sup During			
	Proc Before		Proc During		Proc Before		Proc During	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Transfer test tasks	-.59	1.19	-.09	.77	.57	.99	-.06	1.03
Equivalent test tasks	-.51	1.25	.12	.30	.30	1.05	-.01	1.04

Sup = Supportive information; Proc = Procedural information

Time-on-task

ANOVA revealed no statistically significant main effects or interaction effects regarding the total time spent on the statistics course. For an overview of the results see Table 4.

Table 4: Mean total time (min) spent on the statistics course

	Supportive information			
	Before		During	
Procedural information	*M*	*SD*	*M*	*SD*
Before	141.27	19.77	140.92	17.15
During	139.13	26.68	146.57	17.02

Discussion

In this study, at least partial evidence is found for the hypothesis that information presentation formats that properly manage intrinsic load (i.e., the 'supportive before, procedural during' format and the 'supportive during, procedural before' format) lead to better results than information presentation formats that do not. However, contrary to what was predicted, not the 'supportive before, procedural during' format but rather the 'supportive during, procedural before' format yields better results than the other formats. The presentation of *supportive* information *during* practice in combination with the presentation of *procedural* information *before* practice yields the highest efficiency measure based on invested mental effort and the transfer test scores. Apparently, the 'supportive during, procedural before' information presentation format effectively prepares the learner for the practice tasks that are about to come by presenting procedural information before practice. This leads to better appreciation of the meaningful context (i.e., availability of supportive information) during practice. Research by Carlson, Sullivan and Schneider (1989) and Carlson, Khoo, and Elliott (1990) emphasizes the beneficial influence of a meaningful context during practice of earlier presented procedural information. They found that transfer test scores increased when learners were able to practice the procedural information in meaningful contexts.

Presentation of supportive information during practice is superior to the presentation of this information before practice. Participants who had the supportive information available during practice exhibited a higher efficiency based on invested mental effort and transfer test scores than participants who had received supportive information before practice. These results imply that the presentation of supportive information *during* practice provided learners with a meaningful, knowledge rich context in which they received or could actively seek information they needed to carry out the tasks at hand. In this specific statistics course, the supportive information was not necessary to carry out the practice tasks, but it was necessary for a better understanding of these tasks. Apparently, when this information was presented while carrying out the practice tasks, its relevance for these practice tasks was clearer than when it was presented before the practice tasks. Presentation of supportive information during practice seemed to provide a meaningful, knowledge rich context that enabled the learners to judge this information on its own merit. They related this information to the practice tasks better and therefore became more aware that they needed this information to fully understand the practice tasks, leading to more efficient learning.

Before a final conclusion is reached, a few comments should be given. The predicted beneficial effects of the 'supportive before, procedural during' format failed to occur. This format aimed at properly managing intrinsic cognitive load and avoiding split attention, so that, the learners could devote all their cognitive capacity to relevant learning processes. However, when the mental effort results are considered, low mental effort scores for all formats were found. In every format, the mean mental effort scores never exceeded the rating 'not low, not high'. Since there is no indication that the statistics course exceeded working memory capacity, managing intrinsic load and prevention of split attention will not have facilitating effects on the learning process. Therefore, superiority of one of the formats over the others is not to be expected. This was true for the effectiveness of the learning material (i.e., test performance), but not for the efficiency of the learning material (i.e., the combination of mental effort during practice and transfer test performance).

It was shown that the 'supportive during, procedural before' format yielded the best results for this measure due to the significant difference between this format and the 'supportive before, procedural before' format. If matters of cognitive load and working memory capacity did not play a role in the study then it is strange that the 'supportive during, procedural before' format still was more successful with regard to the efficiency measure on the transfer test. This result can be explained by the fact that the supportive information was decisive to do well on this test. And because it appears that supportive information is better appreciated during practice, it follows that the 'supportive during, procedural before' format is superior to the 'supportive before, procedural before' format.

Further research is needed to find out under which circumstances and in which domains the different information presentation formats are successful. In statistics for example, it was rather difficult to describe the task in terms of independent pieces of knowledge. It is probably better to choose a task in which that is not such a problem. In this study, an attempt was made to present a well rounded statistical practice task, but every topic in statistics elaborates on other topics and therefore it is very difficult to find strictly limited practice tasks. Moreover, in hindsight, because of the obvious interdependence of the practice tasks and the procedural information, the learners may have gotten the false notion that the supportive information was not of much relevance for the task while in fact it was meant as input for a deeper understanding of the learning material. This may have interfered with the learning process in general. Limited, well-rounded, practice tasks in which both the importance of supportive information and procedural information is clear might be better found in technical domains, such as engineering or mechanics, or scientific domains, such as physics.

Bearing this study in mind, it can be concluded that the 'supportive during, procedural before' information presentation format yields more efficient instructional material than the other information presentation formats. Presenting all information at the same time is a sub optimal option. However, more research is needed to determine the exact mechanisms affecting learning behind the information presentation formats.

Chapter 4 - The optimal timing of information presentation during mastering a complex skill in science[1]

Abstract

The study in this chapter is carried out in the domain of physics. Well rounded problems were formulated to teach students to troubleshoot electrical circuits. Special care is taken to design practice problems in which the supportive and procedural information are equally important. Four information presentation formats are compared in a factorial design with the factors timing of supportive information (before *or* during problem practice) and timing of procedural information (before *or* during problem practice). An optimal information presentation format is proposed: *supportive* information is presented *before* practicing a skill and *procedural* information is presented *during* practice. Optimal timing of information presentation facilitates learning and enhances test performance. Eighty-eight third year high school students (37 male, 51 female; mean age = 14 years, *SD* = 0.52) participated in the experiment. Information search behavior and transfer test performance were studied. The information search behavior confirmed the hypothesis. Findings on the transfer test were less clear due to a bottom effect.

Introduction

Since the industrial revolution, Western society focused on improvement. A lot of money, time and effort has been spent on the optimalization and innovation of technologies and production processes in industry, medicine, education, and so forth. In the seventies, this drive for increasing effectiveness and efficiency led to a revolution in inventory management. A new concept was introduced which radically changed the way Japanese and, later, American manufacturers handled their stock. Instead of the traditional just-in-case inventory systems based on long production runs, stockpiled inventories and uninterrupted production, a just in time inventory system was introduced (Hoyt, 1996). The key concept behind this kind of inventory management is *demand-pull production*; the demand for a certain product determines when production should occur. This allows a manufacturer to produce only what is needed, in the appropriate quantity and at the right time. In this way, the stockpiling of unnecessary inventory is prevented because only inventory that is required by the demand-pull is held in stock (Cheng and Podolsky, 1993).

It is not only the business production processes that are put under pressure by the urge to improve, but also, the performance levels of new recruits and existing staff are a continuing concern (Fuchsberg, 1990). Rapidly changing technologies and market conditions require life-long, continuous learning by employees. In order to make this continuous learning process more effective and efficient traditional

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classroom approaches are being abandoned in favor of learning on demand or 'just in time learning'. In this type of learning the demand-pull principle used to improve the production process is applied to business education. By applying this principle, the time lag that often exists between the complex skills or knowledge that a business requires and the education that must be provided for its acquisition, is reduced (Hoyt, 1996). The business' demand for complex skills and knowledge is used to signal when employee training should occur. Specific business courses are provided just before employees need the complex skills or knowledge at work. Next to specialized training agencies, higher education institutions are becoming more involved in delivering this post-secondary education and training. Curricula are modularized and developed for non-traditional, work-based subject matter while improvements in technology make virtual delivery of course material possible and allow for increased flexibility, convenience, interactivity and customization of this material (Gallagher, 2001).

Improving the training content itself can further enhance effectiveness and efficiency of education in life-long learning, which starts in nursery school. Not only should the training be *just in time*, but also, to optimize the learning process within the training, the necessary information to acquire the complex skill or knowledge should be presented at the right time within the training itself. Again, the demand-pull principle is applied outside its original context. The demand for specific information, resulting from problem requirements, is used to signal when this information should be presented during the training. It is argued that the learning of a complex skill requires different types of information and that, for increasing the effectiveness and efficiency of the training, each type has to be presented at different times during the training. Advances in technology make it possible to develop computer-based learning environments in which it is possible to easily vary the timing of information presentation (e.g., on-line help systems, pop-up balloons, use of hyperlinks, and so forth). These technological advances are of special importance in science education.

Practicals play a prominent and costly role- both in terms of time and money- in science education. According to Kirschner and Huisman (1998), non-laboratory practicals ('dry labs') such as computer-based simulations are well suited to help students acquire specific cognitive skills (such as analysis, synthesis and evaluation) needed to practice science and to carry out scientific inquiry. The principal sub-skills for independent scientific work that can be developed through practical work are: discrimination, observation, measurement, estimation, manipulation, planning, execution and interpretation. In order to gain these skills, extensive practice in dealing with problems and frequent feedback as to whether the approaches used and solutions determined are successful are essential. Due to the technological advances it is no longer necessary for students to learn from costly, laboratory practicals, instead, they can learn from computer-based simulations in an effective, efficient and safe way. Troubleshooting simulations, the vehicle used within this study to help students acquire complex cognitive skills, are especially well suited to this because they allow students to develop and follow (often poor) solutions and designs and then to discover, modify and eliminate their inadequacies quickly and safely.

Woolnough (1983) goes so far as to call this use of practicals 'investigations' since natural scientists are investigators and problem-solvers. Their method of working entails a cyclical process involving:

- studying a situation and acknowledging that there is actually a problem to be solved
- defining the problem to be solved
- seeking alternative solutions/solution strategies for the problem
- evaluating the alternative solutions/solution strategies
- specifying or choosing the 'best' solution strategy
- solving the problem
- evaluating the solution and determining whether a new problem need be acknowledged, in which case the cycle begins again

Common sense tells us that, in order to acquire a complex skill, traditional (expository) substantive information is a procedural for this. Before one can do something with this information (act upon it, act with it), one first has to internalize it. Each step in the process above presupposes the possession of information, including knowledge of methods and techniques, knowledge of one's own domain (theories, principles, concepts and facts) and of related domains. In simple terms, one must acquire a broad critical knowledge of the subject matter, the learning of basic competencies, prior to successful, productive and useful scientific enquiry. Subsequently, one can learn to synthesize concepts rationally, enquire scientifically and solve problems via unrestrained inductive thinking (Kyle, 1980).

After having internalized the necessary substantive information, students need to be placed in situations where they have to make use of that information in carrying out the tasks associated with scientific inquiry. Practicals provide an opportunity to develop complex skills, such as, investigating and problem solving. This is especially the case for science simulations where quick, easy, and safe repetition of experiments (in our case malfunctioning electrical circuits) is possible. In other words, it assists them in refining their understanding of: problem identification; experimental design; assembling, testing and calibrating equipment; data collection; analysis; interpretation; and reporting of results. The major problem is how to design such computer-based practicals so that the necessary substantive information is presented just in time in order to help the students to acquire the necessary complex cognitive skills optimally effective and efficient.

Real learning is based upon a network of interrelated, often heterarchically organized competencies (here troubleshooting of electrical circuits). These competencies subsume, in turn, nested networks of knowledge (e.g., what a short circuit is), skills (e.g., how an ammeter is attached), and attitude (e.g., that there can be more than one right answer). These knowledge, skills and attitudes require learning settings in which the knowledge can be gained and the skills and attitudes can be acquired in authentic, realistic contexts. These modern curricula make use of design principles based upon constructivism to achieve this (Kirschner, 2000). *Constructivism* is neither an approach to nor a model for instructional design. It is a philosophy of learning based on the idea that learners construct knowledge – and eventually 'the one(s) who know(s)' - based on their mental and social activity. Learners are active in seeking meaning. Consistent with this view, learning must be situated in a rich context (Brown, Collins & Duguid, 1988), reflective of real world contexts, for this constructive process to occur and for transfer to environments beyond the school to be possible. The problems must be authentic and are best learnt through cognitive apprenticeship (Collins, 1988) on the part of the learner in a rich environment. Finally, all of this is best (and possibly only) achieved when learning takes place via poorly or in ill-structured problems (Spiro, Coulson, Feltovich & Anderson, 1988).

And, when should the substantive necessary information within the domain be presented? In other words, when is it just in time? Is there a difference between more general information needed for troubleshooting a problem and more task-specific, procedural information? If the information necessary to solve the troubleshooting problem is not presented at the right time so that there is a distinct coupling between the perception of the necessary information and the actions taken (Gibson, 1977), the expected benefits might not be achieved.

Complex skills contain two types of constituent skills or sub skills, which are different in nature, namely, non-recurrent constituent skills and consistent constituent skills (Fisk and Gallini, 1989; van Merriënboer, 1997). Non-recurrent skills are steered by the interpretation of cognitive schemata and their performance varies from problem situation to problem situation (i.e., other use of the same, general knowledge); recurrent skills are directly driven by the application of cognitive rules or automated schemata and their performance is virtually the same in every problem situation (i.e., same use of the same, situation-specific knowledge). For example, a computer programmer not only has to master a programming language (e.g., recurrent skills such as writing an IF-THEN statement in computer code) but also the skill of making a technical design for an application (e.g., non-recurrent skills such as drawing a Nassi-Shneidermann diagram for a specific computer program). The usage of an IF-THEN statement in a specific computer program is always the same and always leads to the same result, but, although the technique of drawing a Nassi-Shneidermann is always the same, its application depends on the specifications of a computer program and always leads to other results. The same occurs in the subject of this study, namely troubleshooting electrical circuits. In order to find the problems in a malfunctioning electrical circuit and to repair them, a task performer not only has to be able to properly insert the specific elements (e.g., recurrent skills such as inserting a voltmeter in parallel because current cannot flow through this meter), but also has to be able to understand conditions that influence current and current intensity (e.g., non-recurrent skills such as the difference between a series connection and a parallel connection and their influence on the circuit). The usage of a voltmeter is always the same and always leads to the same result (i.e., measurement of voltage through the circuit), but, although the principles of series and parallel connections are always the same, the features of specific series or parallel connections determine their influence on current and current intensity in the circuit and therefore the results are always different. The exit-behavior that has to be achieved by mastering non-recurrent and consistent constituent skills is also different in nature, just as the processes that lead to this achievement. Mastering non-recurrent skills requires the deliberate construction of general, abstract schemata in long-term memory while mastering recurrent skills requires the automation of schemata through repetitive practice.

Schema construction is mainly achieved by elaboration, that is, the gradual integration and anchoring of new information in already existing cognitive structures in long-term memory (Mayer, 1980). *Schema automation* is mainly accomplished by proceduralization (Anderson, 1982; Anderson, 1996), in which factual information is embedded in so-called productions (i.e., primitive rules that drive cognitive action). Proceduralization only occurs when all necessary information to solve the practice problem is available in working memory during practice. Different types of information are needed for schema construction and automation to occur. The information associated with schema construction is called supportive information and consists of conceptual models of how a learning domain is organized, for example, knowledge about the structure of electrical circuits, the working of series connections and differences between series connections and parallel connections. The information needed to achieve schema automation is called procedural information and consists of task-specific rules that specify actions to achieve particular goals and the facts, principles and concepts that are needed to correctly apply the task-specific rule (e.g., an ammeter has to be connected in series (the task-specific rule) because this meter has no resistance (the underlying principle); more examples of these information types can be found in Appendix 2 which gives an impression of the supportive and procedural information used in this study). Coming back to the demand-pull principle, Kester, Kirschner, van Merriënboer, and Bäumer (2001) argue that the mastery of a complex skill requires *supportive* information *before* practice to allow for the construction of schemata and elaboration of mental models, in combination with *procedural* information *during* practice to allow for the automation of schemata and proceduralization of task-specific rules. This assumption is supported by guidelines for effective and efficient development of instructional material generated by cognitive load theory (Chandler and Sweller, 1991; Sweller, 1988; Sweller, van Merriënboer and Paas, 1998).

A major pillar of cognitive load theory is the assumption that working memory is severely limited (Baddeley, 1992; Miller, 1956). Since, the acquisition of a complex skill puts a considerable burden on working memory, it is important to attend to the effective management of cognitive load during the acquisition process. One of the most important design principles pertains to the reduction of so-called *extraneous* cognitive load. Extraneous cognitive load refers to the load that is caused by the instructional material itself and involves all the processes a learner engages in during problem solving but which are *not* directly beneficial to learning (e.g., searching for relevant information sources, combining different information sources, weak-method problem solving etc.). To this end, extensive research has been carried out concerning the split attention effect (for an overview see Sweller, van Merriënboer and Paas, 1998), whereby that extraneous load is significantly reduced by integrating two mutually referring information sources instead of presenting them separately in either space or time. By physically integrating the necessary information sources in the instructional material, learners do not longer have to mentally integrate the sources themselves, and therefore, extraneous cognitive load is reduced. In this study, the focus is on avoiding *temporal* split attention. Strictly speaking, to avoid temporal split attention all necessary information to solve a problem (i.e., supportive as well as procedural information) should be presented during practice, but, simultaneously processing all the necessary information and solving problems can produce cognitive overload if the problem itself is already causing a high so-called *intrinsic* cognitive load (Marcus, Cooper and Sweller, 1996).

This intrinsic cognitive load is determined by the degree of element interactivity of the problem (Sweller, van Merriënboer and Paas, 1998). High element interactivity requires the learner to process several elements and their relationships simultaneously in working memory in order to solve the problem. A *low* element interactivity allows the learner to serially process few elements at a time. Learning supportive information is, in general, a task with high element interactivity because to-be-constructed mental models contain many interrelated elements. For example in this study, the learner has to simultaneously process features of electrical circuits and features of a central heating system to understand the flow of current in an electrical circuit. On the other hand, learning procedural information is, in general, a task with low element interactivity because task-specific rules only contain few related elements. For example, the learner can easily process each symbol that must be used to denote a particular element in an electrical circuit. Based on the idea of avoiding temporal split attention and managing intrinsic cognitive load it is advocated that supportive information (i.e., information with a high element interactivity that can easily lead to cognitive overload when presented during practice) is best presented *before* the learner starts relevant problem practice while procedural information (i.e., information with a low element interactivity) is best presented *during* relevant problem practice (van Merriënboer, Kirschner and Kester, 2003).

The research presented here attempts to find evidence for an optimal information presentation format based on the demand-pull principle and guidelines from cognitive load theory. The presumed optimal format, that is, supportive information before practice in combination with procedural information during practice, is compared with three alternative formats, namely (1) all information before practice, (2) all information during practice, and (3) procedural information before practice combined with supportive information during practice. The effectiveness of all four information presentation formats, measured by information search behavior, practice performance, transfer test performance, time-on-task and invested mental effort, is studied in the domain of physics. It is predicted that learners who receive supportive information before problem practice combined with procedural information during problem practice will show substantially less information search behavior than the other learners. Moreover, for this group a higher performance during practice and during a transfer test and lower invested mental effort is expected than for the other groups.

Method

The purpose of this study was to test the hypothesis that the presentation of supportive information before practice, in combination with the presentation of procedural information during practice, reduces search behavior and yields higher learning outcomes for students in computer-based physics practicals. All information was presented to the learners on the computer screen of a troubleshooting problem in electrical circuits, a typical part of the high school physics curriculum in the Netherlands. A factorial design was used with the factors timing of supportive information (either before or during practice) and timing of procedural information (also either before or during practice).

Participants

Eighty-eight third year high school students at Sintermeertencollege in Heerlen, the Netherlands (37 male, 51 female; mean age = 14 years, *SD* = .52) participated in this study. All of the participants spoke Dutch as their first language, the language in which the instruction was given. They were required by their teacher to participate in a physics lesson on electrical circuits as part of their regular physics curriculum. No specific grade was given for this course. In the Netherlands, all students in the academic stream in high school receive physics education in their third year. The content used in the physics lesson was new for all participants. They received 9 euro (approximately 9 dollars) for their participation.

Materials

Physics lesson.

Crocodile Physics®, a simulation program for secondary school science classes, was used to develop the physics lesson for this experiment. The course contained an introduction and ten practice troubleshooting problems for faulty electrical circuits and was followed by ten test problems. In the introduction the participants received information on:

- what to expect, e.g., the number of problems, available time and how to switch the circuit on and off;
- how to navigate within the application, e.g., left and right arrows were used to go back or forth in the course, by clicking on different icons participants could jump to an information block, a practice problem or a test problem; and
- the experimental rules, e.g., changing the circuit itself (e.g., removing a lamp or rewiring the circuit), taking notes or changing the computers configuration (e.g.,

change the full screen presentation to part screen, making changes in the menu of Crocodile Physics®) was not allowed, and that the work had to be done individually and independently.

The troubleshooting problems, consisting of malfunctioning electrical circuits, were accompanied by information blocks presented either before practice, during practice or before and during practice. Every problem was presented in a split screen with on the left, if applicable, an information block and on the right the malfunctioning circuit (see figure 1). Inherent to a malfunctioning circuit is that elements (e.g., lamps) become irreversibly damaged after one try (i.e., it explodes). So, to allow the participants a good look at what happens in a circuit when certain actions are performed each circuit was presented twice. Participants had to explain what the problem was and how this problem could be solved. The circuits in the practice problems made use of a maximum of six elements: a toggle switch, a lamp, a battery, a resistor, a voltmeter and an ammeter. The problems differed in the number of elements used and the number of *different* elements used.

In cooperation with a subject matter expert, a task analysis was carried out to determine which information needed for the troubleshooting problems was supportive and which was procedural. Information that either aimed at schema construction, had a high element interactivity and was not referring directly to the circuits in the troubleshooting problems was labeled as supportive. An example of this is the explanation of how current flows through a closed electrical circuit using a central heating system as an analogy. Information that aimed at schema automation, had a low element interactivity and referred directly to the circuits in the troubleshooting problems was labeled as procedural. An example of this is the text "This is a voltmeter and electrical potential is measured by a voltmeter" next to the symbol for a voltmeter. An impression of the supportive and procedural information used in this study is given in Appendix 2.

Information presentation.

Four information presentation formats were distinguished. The participants were randomly assigned to one of these formats. In the SupB-ProcB format, both supportive (Sup) and procedural (Proc) information were presented *before* (B) the participants practiced the troubleshooting problems (n = 22). The participants assigned to the SupD-ProcD format received both information types *during* (D) the troubleshooting of the practice circuits (n = 22). In the SupB-ProcD format, predicted to be optimal, supportive information was presented *before* problem practice and procedural information was presented *during* problem practice (n = 23). In the SupD-ProcB format the supportive information was presented *during* problem practice while the procedural information was presented *before* the participants practiced the troubleshooting problems (n = 21).

Log tool.

A logging program was especially developed for the experiment. This program kept track of the time-on-task and of the navigation of the participants through the physics lesson. A screen dump was made and saved every time the participants opened a new window. Each collection of screen prints shows the route that the participants followed through the course.

Practice problems.

During practice, the participants could obtain a maximum of 49 points by diagnosing and finding solutions to the malfunctioning circuits in ten practice problems. For every correct statement made, they received one point. For example, the situation in figure 1 is that, when the switch is closed, the lamp explodes. In this problem the following statements were rewarded with one point: the lamp explodes, the power supply (i.e., the battery) is too strong, insert a weaker battery, insert an extra lamp or insert a resistor. The maximum number of points the participants could receive for the practice problems ranged from four to eight. In the given example it is five, the problem statement (i.e., the lamp explodes), the reason for the problem (i.e., the power supply is too strong) and three possible solutions (i.e., insert a weaker battery, an extra lamp or a resistor). The practice performance scores of ten participants were determined by two raters. The interrater reliability for practice performance of the two raters was 0.96 (Intraclass Correlation Coefficient, SPSS) and the internal consistency is 0.72 (Cronbach's alpha).

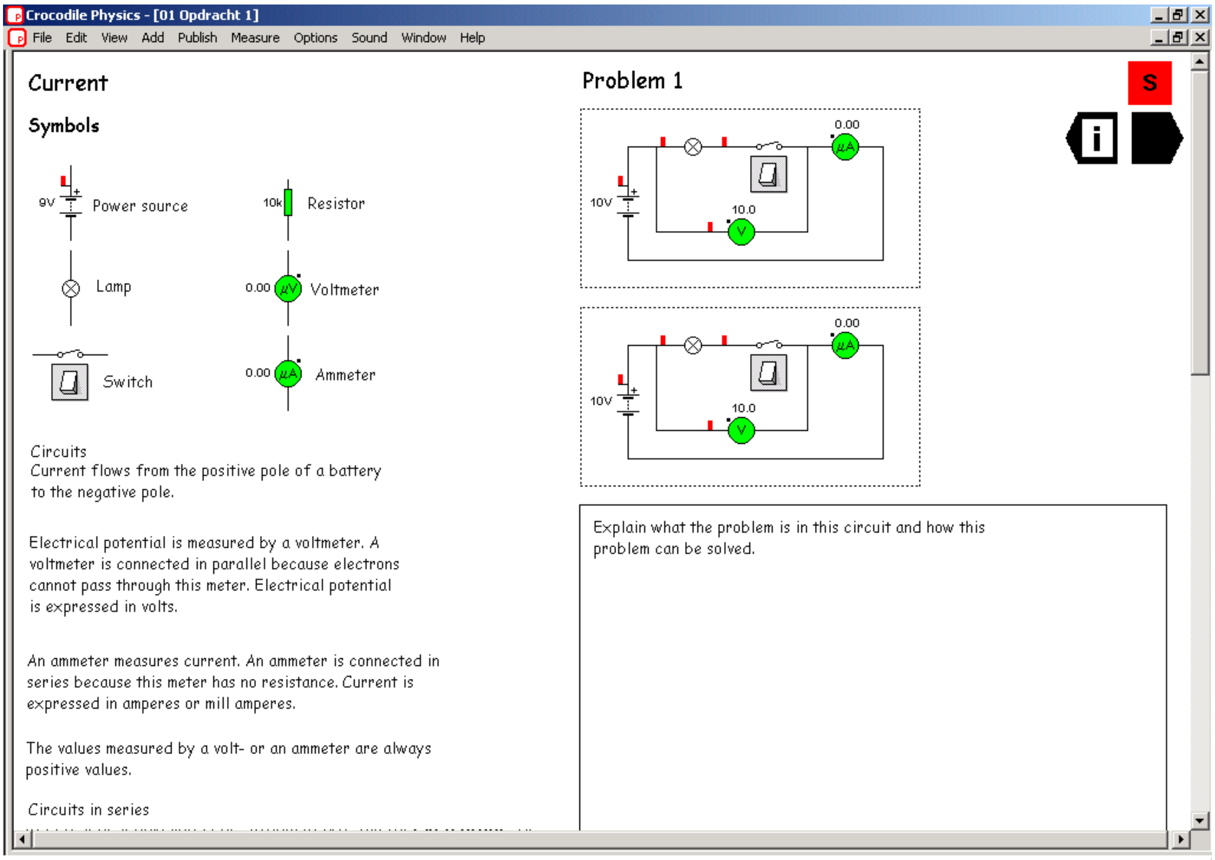

Figure 1: Screenshot of a practice problem.

Transfer test.

After the ten troubleshooting practice problems the participants solved ten troubleshooting *test* problems. The test problems also consisted of malfunctioning electrical circuits designed in Crocodile Physics® but without the accompanying information blocks. Five of the test problems were equivalent to the practice problems and five contained new elements (i.e., a variable resistor, a fuse, a push switch, a buzzer, a LED, or a motor and gears). Participants again had to explain what the problem was and how it could be solved. The transfer test was meant to determine whether the participants could perform the learned procedures and whether they were capable of applying these procedures to new situations (i.e., to circuits in which new elements were used). The participants could obtain a maximum of 36 points. As was the case in practice, they received one point for each correct statement, either a diagnosis or a solution. The maximum number of points the participants could receive for the test problems ranged from one to six. These scores depended on the number of possible solutions that could be given to stop the circuit from malfunctioning. The test performance scores of ten participants were determined by two raters. The interrater reliability for test performance of the two raters was 0.85 (Intraclass Correlation Coefficient, SPSS) and the internal consistency of the transfer test was 0.69 (Cronbach's alpha).

Mental effort measurement.

Mental effort was measured both during practice and during the test with a 9-point rating-scale (Paas, 1992; Paas, Van Merriënboer and Adam, 1994), which asked the participant to rate their invested mental effort. The mental effort measures ranged from very, very low mental effort to very, very high mental effort. The aim of this mental effort measurement was to get insight in the mental load perceived by the participants while working on the troubleshooting problems. The rating-scale was administered during practice and during the test directly after each troubleshooting problem. Participants were asked: How much mental effort did you invest to repair the former circuit? No additional information was provided to explain the term 'mental effort'. This resulted in a total of twenty mental effort measurements, ten during practice and ten during the test. The internal consistency of the mental effort measures was 0.85 (Cronbach's alpha) for the practice problems and 0.89 for the test problems.

Procedure

Participants received an oral instruction, which stressed that they had to work independently, mind the time limit, work seriously and not ask questions during the experiment. They were told that the aim of the experiment was to find out if it is useful to integrate this kind of simulation software in regular education and, if this is the case, how this should be done.

All participants had two hours to complete the course with the practice problems and the test problems. Within these two hours the participants could go through the course and the test at their own pace. Participants could not go back to the practice problems after they had started the test problems. During each part, the search behavior (in particular, revisiting earlier presented information blocks) and the time spent on each problem was logged.

Results

Information search behavior

The information search behavior of the participants was represented by the number of times a participant consulted the 'before' information block during practice. The SupD-ProcD format is omitted because participants in this group received all of the information during practice, i.e., there was no 'before' information block that could be consulted during practice. Per information presentation format and per practice problem the mean number of times a participant consulted the 'before' information block was calculated. Results are shown in figure 2.

An overall mean score was calculated for the number of times the participants consulted the 'before' information block during all practice problems (see table 1).

Table 1: Summary of the mean revisiting behavior data.

	Supportive information					
	Before			During		
Procedural information	*M*	*SD*	*n*	*M*	*SD*	*n*
Before	5.86	4.64	22	7.62	6.06	21
During	1.61	2.48	23	--	--	--

A Kruskal-Wallis test was used to compare the SupB- ProcB, the SupB- ProcD and the SupD- ProcB format. In this study, an alpha level of 0.05 was used for all statistical tests. A significant difference was found between the information presentation formats, H (2) = 17.82, $p < 0.001$. Figure 2 illustrates that participants in the SupB- ProcD format showed, as predicted, substantially less search behavior than the participants in the SupB- ProcB and SupD- ProcB format. They consulted the 'before' information block substantially less frequently than the other participants who did not differ in search behavior.

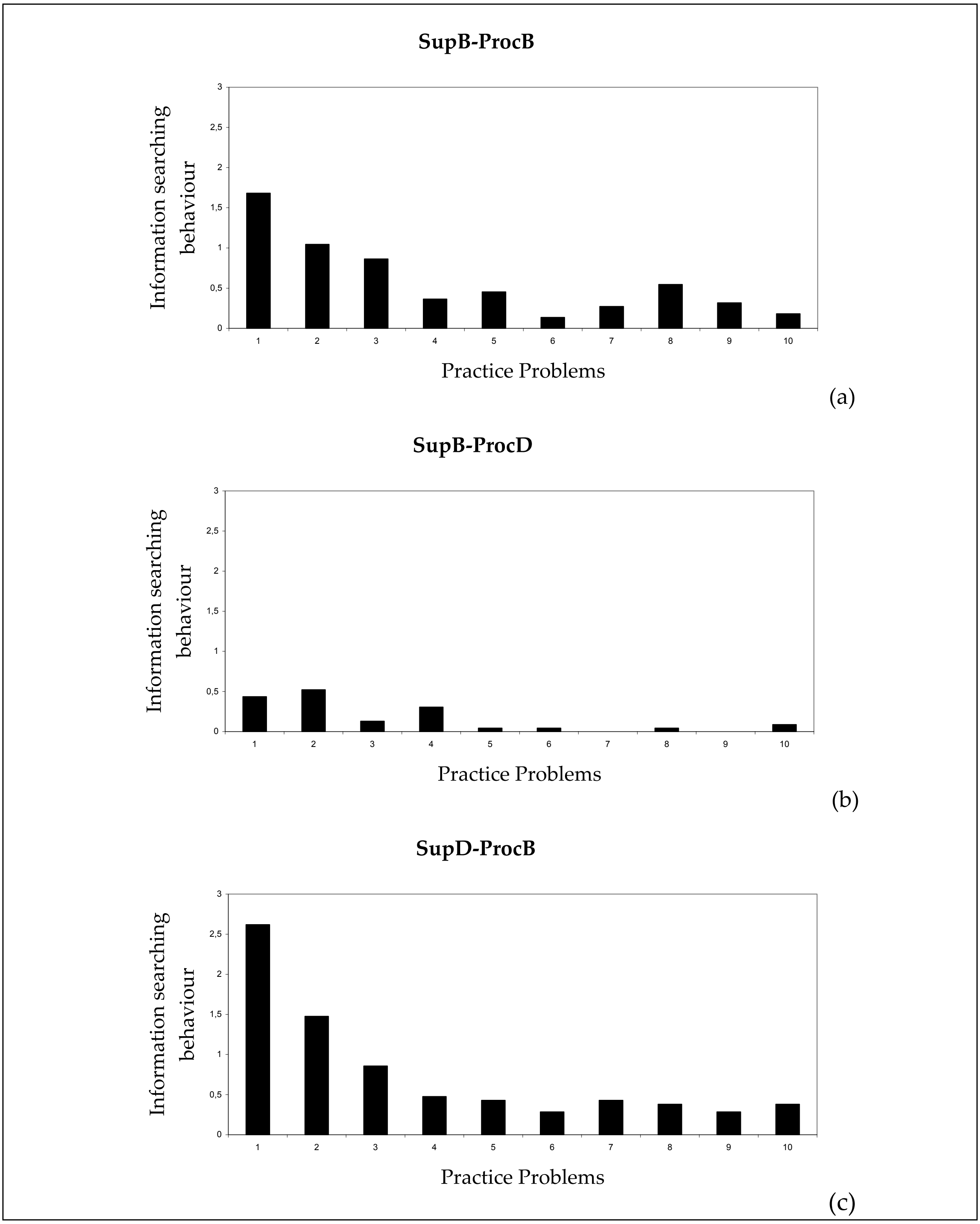

Figure 2: Mean information search behavior per information presentation format and per practice problem. Sup = supportive, Proc = procedural and B = before and D = during.

Time-on-task

In this study it is assumed that the information presentation formats have different effects on time-on-task, therefore, the time-on-task during practice (including the 'before' information block) is considered. There is a main effect for the timing of procedural information on time-on-task during practice, F (1, 81) = 4.17, MSE = 220.30, $p < 0.05$; $\eta^2 = 0.049$. Participants receiving procedural information before practice spent less time on the practice problems (M = 45.46, SD = 14.52) than participants receiving this information during practice (M = 52.46, SD = 15.98).

Also, a significant interaction between the timing of supportive and procedural information was found, F (1, 81) = 6.39, MSE = 220.30, $p < 0.05$; $\eta^2 = 0.073$. In post hoc tests, using Tukey's HSD, it was found that only the SupB-ProcB group (M = 40.21, SD = 10.61) and the SupB-ProcD group significantly differed (M = 54.95, SD = 17.91; $p < 0.01$). For an overview of the results see table 2.

Table 2: Mean total time (min) spent on the practice problems and the 'before' information block

	Supportive information					
	Before			During		
Procedural information	*M*	*SD*	*n*	*M*	*SD*	*n*
Before	40.21	10.61	22	51.53	16.28	19
During	54.95	17.91	22	49.96	13.75	22

Practice scores

First, it should be noted that the scores are very low for all conditions. ANOVA revealed neither statistical significant main effects nor interaction effects. Nevertheless, the mean scores are highest for the SupB-ProcD condition and thus point into the predicted direction. Practice scores are presented in table 3.

Table 3: Summary of the practice performance data[a]

	Supportive information					
	Before			During		
Procedural information	*M*	*SD*	*n*	*M*	*SD*	*n*
Before	7.50	3.42	22	7.10	4.62	21
During	8.52	5.07	23	7.32	5.19	22

aMax = 49

Transfer test

ANOVA revealed neither statistical significant main effects nor interaction effects. Overall, transfer test scores are very low and presented in table 4.

Table 4: Summary of the transfer test data[a]

	Supportive information					
	Before			During		
Procedural information	*M*	*SD*	*n*	*M*	*SD*	*n*
Before	7.14	3.82	22	6.43	3.63	21
During	6.04	4.51	23	5.77	3.87	22

aMax = 36

Mental effort

Not all participants filled in all mental effort scales. Only the data of participants who filled in more than 60% of the mental effort measures during practice (i.e., six items or more; $n = 78$) or during the test (i.e., six items or more; $n = 77$) were used in the mental effort analysis. The Expectation Maximization (EM) approach, available in SPSS Missing Values Analysis, was used to replace the missing values with expected values.

A main effect for procedural information on the mean mental effort during the *practice* problems (i.e., ten measures) was found, F (1, 78) = 4.51, $MSE = 5.48$, $p < 0.05$; $\eta^2 = 0.06$. Participants receiving procedural information before practice reported less invested mental effort ($M = 5.92$, $SD = 1.02$) than participants receiving this information during practice ($M = 6.47$, $SD = 1.20$). In post hoc tests, using Tukey's HSD, it was found that only the SupB-ProcB group and the SupB-ProcD group ($p < 0.05$) differed significantly. An ANOVA of the mean mental effort during the *test* (i.e., ten measures) yielded neither main effects nor interaction effects. For an overview of these results see table 5.

Table 5: Summary of the mean mental effort data during practice and transfer test[a]

	Supportive information					
	Before			During		
Procedural information	*M*	*SD*	*n*	*M*	*SD*	*n*
Practice						
Before	5.63	1.02	21	6.26	0.95	18
During	6.63	1.12	19	6.32	1.29	20
Transfer test						
Before	5.35	1.11	21	5.44	0.99	17
During	5.82	1.73	19	5.86	1.44	20

aMax = 9

Discussion

The ability to solve problems, interpret experimental data, and use knowledge and skills in unfamiliar situations are far and away the most important general objectives for science students to achieve via practicals (Kirschner & Meester, 1993). The major question that this study attempted to answer is: How can practicals best be designed in particular with regard to information presentation so as to help students achieve these objectives. In this study, evidence is found for the hypothesis that, due to problem requirements, learners predominantly need *supportive* information *before* problem practice and *procedural* information *during* problem practice. The information search behavior of the participants who received supportive information before practice and procedural during practice was substantially lower than that of the participants who received all information before practice and those who received procedural information before practice and supportive during practice. This means that the participants who received the right information at the right time consulted earlier given information substantially less often during practice than the participants in the two other relevant formats. Hereby can be concluded that the presumed optimal information presentation format (i.e., supportive information presentation before and procedural information during practice) indeed was optimal compared to the format in which all information was presented before practice and the format in which procedural information was presented before and supportive during practice. A final remark has to be made concerning the format in which all information was presented during practice. Participants in this format were prohibited to show any search behavior because no 'before' information block was available in this format. In this study it remains unclear if participants would have shown any search behavior if a 'dummy' information block was available to them before practice. Therefore, no conclusions can be drawn with regard to the search behavior of participants in the 'all during' format.

In spite of the apparent optimal information presentation in our preferred format (supportive before, procedural during), no significant effects for this format were found on the effectiveness of the instruction. The performance scores during practice were slightly in favor of the preferred condition but also extremely low, indicating that during the acquisition phase of the complex skill (i.e., troubleshooting electrical circuits) not much was learned. Obviously, this also has its impact on the performance on the test. For transfer test performance no differences were found. In retrospect, the given information and the practice problems seemed to be too difficult for the participants, so, a bottoming effect appeared for the test results. Apparently, the amount of practice offered was not sufficient for acquiring the complex skill of troubleshooting.

With regard to time-on-task and mental effort, it appeared to be more effective to present procedural information before practice, the effect of which is intensified when supportive information is also presented before practice. Thus, time-on-task and invested mental effort was lowest when all information was presented before practice. At first sight, these results seem to contradict the assumptions regarding the effectiveness of the instructional material. But the term effective is misleading in this context, because the lower mental effort and shorter time-on-task are not accompanied by a higher performance during practice or the test. For example, it is well possible that participants who received the procedural information before practice, in comparison to those who received this information during practice, found it more difficult to fully grasp the relevancy of this information, became confused and discouraged by this presentation mode and therefore invested less time and mental effort in the practice problems. In short, given the low overall performance, it is impossible to make a value judgment regarding the time-on-task and mental effort results.

Nevertheless, another alternative explanation has to be given for the mental effort results. After each malfunctioning circuit the following question was posed: How much mental effort did you invest to repair the former circuit? With this question it was intended to measure the mental effort the participants invested in diagnosing and repairing the malfunctioning circuit aided by the presented information. In the format with the lowest mean mental effort score (i.e., all information before), this question only follows the malfunctioning circuit because all the necessary information had already been presented before practice. However, in the other three formats this question directly follows the malfunctioning circuit *in combination with* an information block. Therefore, it is well possible that the participants in the 'all before' condition failed to take the necessary information into account while giving a mental effort score for diagnosing and repairing the circuit. This could have had an unjust decreasing effect on the mental effort scores for these participants.

Regardless of the bottom effect, the preferred information presentation format, based on the problem demand-pull principle, avoiding temporal split attention and managing intrinsic cognitive load, did not fully succeed in optimally equipping the learners for the problem at hand. So, why did these facilitating effects fail to occur? It is possible that the avoidance of temporal split attention by presenting procedural information during problem practice is of no use when the instructional material still allows for *spatial* split attention, as was the case in our study. In the presented materials the learners still had to mentally integrate the presented information with the malfunctioning circuit in order to understand what the problem was. This mental integration process could have interfered with the skill acquisition process and vice versa. The beneficial effects of the presentation of supportive information before problem practice to manage intrinsic cognitive load may not have surfaced because the introduction did not prepare the learners for the problems that were about to come and therefore the learners could have missed the relevance of this supportive information completely. Moreover, the presentation of procedural information during problem practice could have prevented that the learners consulted the supportive information presented before problem practice because, strictly speaking, the procedural information is in nature enough to solve the problem, but not nearly enough to reach deeper understanding and schema construction. Although the right information was presented at the right time, simultaneously manipulating the circuit, mentally integrating the necessary information and judging every piece of information on its own merit may have been too challenging for the learners.

Future research is needed to find out which cognitive load managing measures are useful to apply to the timing of information presentation. For example, it seems to be the case that only the avoidance of temporal split attention is no guarantee for a favorable learning outcome. It may be necessary to take temporal and spatial split attention effects into account at the same time. Furthermore, the results of our current study are especially colored by the low practice and test performance scores; in the future, such an effect should be avoided by simplification of the instructional materials and taking the learners' entry levels more carefully into account. Finally, when different information presentation formats are compared, each format should allow for the same searching activities, there are two possibilities:

the usage of 'dummy' information blocks were necessary or prohibition of consulting former information blocks in all formats.

To conclude, the results from this study indicate that it is possible to determine optimal information presentation moments for these types of simulation practicals in science curricula based on problem requirements. The distinction between supportive information and procedural information proved to be useful to distinguish between different optimal moments for presentation. When the learners are allowed to search during problem practice, they have to search less for necessary information when it is presented according to problem demand-pull principles, that is, supportive information just before it is needed for practice and procedural information directly during practice. Unfortunately, performance scores did not yet corroborate this result, which is probably due to a bottom effect.

Chapter 5 - The split attention effect in computer simulated troubleshooting of electrical circuits[1]

Abstract

In this chapter a study is presented that explores the hypothesis that the existence of split-source elements in the learning material prevents the occurrence of beneficial effects on learning of just-in-time information presentation. The effects of two information presentation formats on learning to solve problems in electrical circuits were compared. In both formats the supportive information was presented before practice and the procedural information during practice. In one format (split-source format) the procedural information was *not integrated* in the circuit diagram while in the other format (integrated format) the procedural information was *integrated* in the circuit diagram. Twenty-five high school students (16 male, 9 female; mean age = 16.2 years, *SD* = .72) participated. To avoid a bottom-effect on performance fourth-year students, instead of third-year students, participated. It was hypothesized that learners in the integrated format would achieve better test results than learners in the split-source format. Equivalent test problem and transfer- test problem performance were studied. Transfer test scores confirmed the hypothesis, no differences were found on the equivalent test scores.

Introduction

Since the late eighties many of instructional design guidelines have been generated from Cognitive Load Theory (Sweller, 1988). One of the major pillars of this theory is that working memory is limited (Baddeley, 1992; Miller, 1956). Effective and efficient instructional material avoids overloading working memory so as not to hamper the learning process. Cognitive Load Theory distinguishes three types of cognitive load: intrinsic, extraneous and germane load. According to Sweller, Van Merriënboer and Paas (1998), the intrinsic cognitive load is inherent to the practice problem itself and "... cannot be directly influenced by instructional designers..." (p. 262). The extraneous and germane load refer to the cognitive load that arises when learners interact with the instructional material and can be influenced by instructional designers. Extraneous cognitive load includes all cognitive load associated with the processes a learner engages in while interacting with the instructional material that are *not beneficial* for learning. Examples of activities, which induce extraneous cognitive load, are, mentally integrating different sources of information (e.g., separate information in a figure and a text) or searching for relevant information in order to understand the subject matter. Germane cognitive load includes all cognitive load associated with processes a learner engages in while interacting with the instructional material that are *beneficial* for learning. For example, variability of practice problems may stimulate learners to construct better cognitive schemata

[1] *A version of this chapter is submitted as: Kester, L. Kirschner, P. A., & Van Merriënboer, J. J. G. (2003). The split attention effect in computer simulated troubleshooting of electrical circuits.*

(Spiro, Coulson, Feltovich, & Anderson, 1988; Sweller, Van Merriënboer & Paas, 1998).

The focus of the study reported here is on decreasing the extraneous cognitive load of the instructional material by avoiding split attention, which arises when a learner has to mentally integrate two sources of information in order to understand the learning material, for example a picture and its explanatory text. Chandler and Sweller (1992) called this the split attention effect. The notion of the split attention effect originates from research on worked examples, also an effective way to reduce extraneous cognitive load. For novice learners, studying worked examples facilitates learning as compared to solving conventional problems (Cooper & Sweller, 1987; Sweller & Cooper, 1985; Atkinson, Derry, Renkl, & Wortham, 2000). According to Tarmizi and Sweller (1988), conventional problems necessitate a means-ends search, which is a weak problem solving activity with a considerable claim on cognitive resources while worked examples enable the learner to concentrate on the problem states and their solution steps leading to better schema acquisition. In their research on worked examples, they were the first to show that in some cases the beneficial effects of worked examples on schema acquisition failed to occur. A closer examination of these worked examples showed that they all contained separate sources of information that needed to be mentally integrated in order to understand the worked example (e.g., a geometry worked example made use of a diagram and its explanatory text). It was hypothesized that the mental integration of these separate sources of information (i.e., the diagram and the explanatory text) used up available cognitive resources at a cost to the learning process and that the integrated presentation of these separate sources of information would enlarge the cognitive resources available for learning and would thus be beneficial for schema acquisition. Tarmizi and Sweller (1988), Ward and Sweller (1990), and Sweller, Chandler, Tierney and Cooper (1990) all showed that worked examples *without* split-source information led to better learning results than split-source worked examples and conventional problems.

The findings from worked example research resulted in extensive research that concentrated on this split attention effect (Cerpa, Chandler & Sweller, 1996; Chandler & Sweller, 1991; Chandler & Sweller, 1992; Chandler & Sweller, 1996; Kalyuga, Chandler & Sweller, 1999; Mayer & Anderson, 1992; Mayer & Moreno, 1998; Mayer & Sims, 1994; Sweller & Chandler, 1994). In this research, the focus shifted from split-source information in worked examples to split-source information in more general learning material such as pictures and text in an instructional textbook. In several domains, for instance, electrical training programs (Chandler & Sweller, 1991), and computer or machine programming (Cerpa, Chandler & Sweller, 1996; Chandler & Sweller, 1992; Chandler & Sweller, 1996; Sweller & Chandler, 1994), conventional learning material was compared to integrated learning material. Both learning materials contained identical information. In the conventional material, mutually referring sources of information were presented separately (e.g., diagrams and explanatory text were presented separately) while in the integrated material all mutually referring sources of information were integrated (e.g., diagrams and explanatory text were integrated). After studying the learning material the participants received both theoretical questions and a practical test. The test results favored the integrated learning material provided that the mutually referring information sources were unintelligible without mental integration. Instead of integrating two sources of visual material some researchers choose to integrate animation and narration (Mayer & Anderson, 1992; Mayer & Moreno, 1998; Mayer & Sims, 1994) or auditory information and diagrams (Kalyuga, Chandler & Sweller, 1999) to avoid the split attention effect. This dual-mode of presenting mutually referring material also resulted in enhanced test performance.

In the study presented here, a new context was chosen to examine the split attention effect. The learning period in this study did not consist of studying worked examples alternated by practicing conventional problems, or, studying learning material, but of a series of conventional practice problems preceded by supportive information and accompanied by procedural information. During the learning period learners had to solve a number of problems in a series of computer-simulated malfunctioning electrical circuits. The *supportive information* presented before practice was useful, explanatory information. For example, before practice information was presented explaining what an electrical circuit was and how electrons flow through a circuit using a central heating system as a metaphor. The *procedural informatio*n enabled the learners to recognize elements and to perform actions and was directly referring to the circuit. For example, "This is a voltmeter" (next to the symbol of a voltmeter) or "a voltmeter has to be connected in parallel because current cannot flow through this meter". Although this information was intelligible by itself, the malfunctioning circuit was not. The procedural information contained the information that the learners needed for solving the problems without being explicit about the solution, as is the case in worked examples. Prior research showed that the presentation of supportive information before practice and procedural information during practice was beneficial for learning because the learner did not have to search for information during practice (Kester, Kirschner and Van Merriënboer, in press). This research examined whether the instructional material could be further improved by integrating the procedural information in the malfunctioning circuits so that the learner's necessity to mentally integrate split-source material is reduced.

The effectiveness of the learning material is measured by test performance. Two types of test problems can be distinguished. *Equivalent* test problems in which the *same* information learned during practice is used in the *same* way during the test and *transfer* test problems in which the *same* information is used in a *different* way (e.g., a motor is used instead of a lamp to draw power) during the test. A continuum exists from equivalent test problems at the one end to transfer test problems at the other end. Equivalent test problems are similar to the practice problems while transfer test problems are more and more different from the practice problems. It is assumed that transfer test problem solving requires more sophisticated cognitive schemata than equivalent test problem solving.

In this study, two information presentation formats are compared. In both formats the supportive information is presented before practice and the procedural information during practice, but in the split-source format the procedural information is *not integrated* in the malfunctioning circuit while in the integrated format the procedural information is *integrated* in the circuit. It is hypothesized that learners in the integrated format achieve higher test scores, especially for the transfer test problems, than learners in the split-source format because the split attention effect is avoided in the integrated format. As a result, in the integrated format more cognitive capacity is available for learning processes, which leads to the acquisition of better and richer schemata than in the split-source format.

Method

Participants

Twenty-five fourth-year high school students at Sintermeerten College in Heerlen, the Netherlands (16 male, 9 female; mean age = 16.2 years, *SD* = .72) participated in this study. All of the participants spoke Dutch as their first language, the language in which the instruction was given. They voluntarily participated in a physics lesson on electrical circuits. No specific grade was given for participation. All participants followed the same physics curriculum beginning in their third year. They were all equally familiar with the topic of the physics lesson because they had all received the theory a year before. They received 10 Euro (approximately 10 US dollars) for their participation.

Materials

Physics simulation.

Crocodile Physics®, a simulation program for secondary school science classes, was used to develop the physics lesson for this experiment. The computer-based simulation contained an introduction and nine practice troubleshooting problems for faulty electrical circuits and was followed by ten test problems. In the introduction the participants received information on:

- what to expect: the number of problems, available time and how to switch the circuit on and off;
- how to navigate within the simulation: left and right arrows were used to go back or forth in the simulation, by clicking on different icons participants could jump to a practice problem or a test problem; and
- the experimental rules: taking notes or changing the computer's configuration (e.g., change the full screen presentation to part screen, making changes in the menu of Crocodile Physics®) was not allowed, and the work had to be done individually and independently.

The troubleshooting problems consisted of malfunctioning electrical circuits. These problems were preceded by supportive information on the working of electrical circuits and accompanied by procedural information. Inherent to a malfunctioning circuit is that elements (e.g., lamps) become irreversibly damaged after one try (i.e., they explode). To allow the participants a good look at what happens in a circuit when the switch is turned on, a 'repeat-button' was available to allow the participants to review the events in the circuit after turning the switch on. The use of the 'repeat-button' was unlimited. After manipulating the malfunctioning circuit the participants had to provide a *description* of the problem, a diagnosis of the *cause* of the problem, and a *solution* for the problem. The circuits in the practice problems made use of six different elements: a toggle switch, a lamp, a battery, a resistor, a voltmeter and an ammeter. All practice circuits contained, one or more of each of these six elements.

Information presentation.

Two information presentation formats were distinguished. The participants were randomly assigned to one of the two formats. In both formats the participants received the supportive information before practice and the procedural information during practice. In the split-source format (n = 13) the procedural information was *not integrated* in the malfunctioning circuit. The circuit was presented on the left side of the screen and the procedural information on the right side (see Figure 1a). In the integrated format (n = 12) the procedural information was *integrated* in the circuit (see Figure 1b). The total information was equivalent.

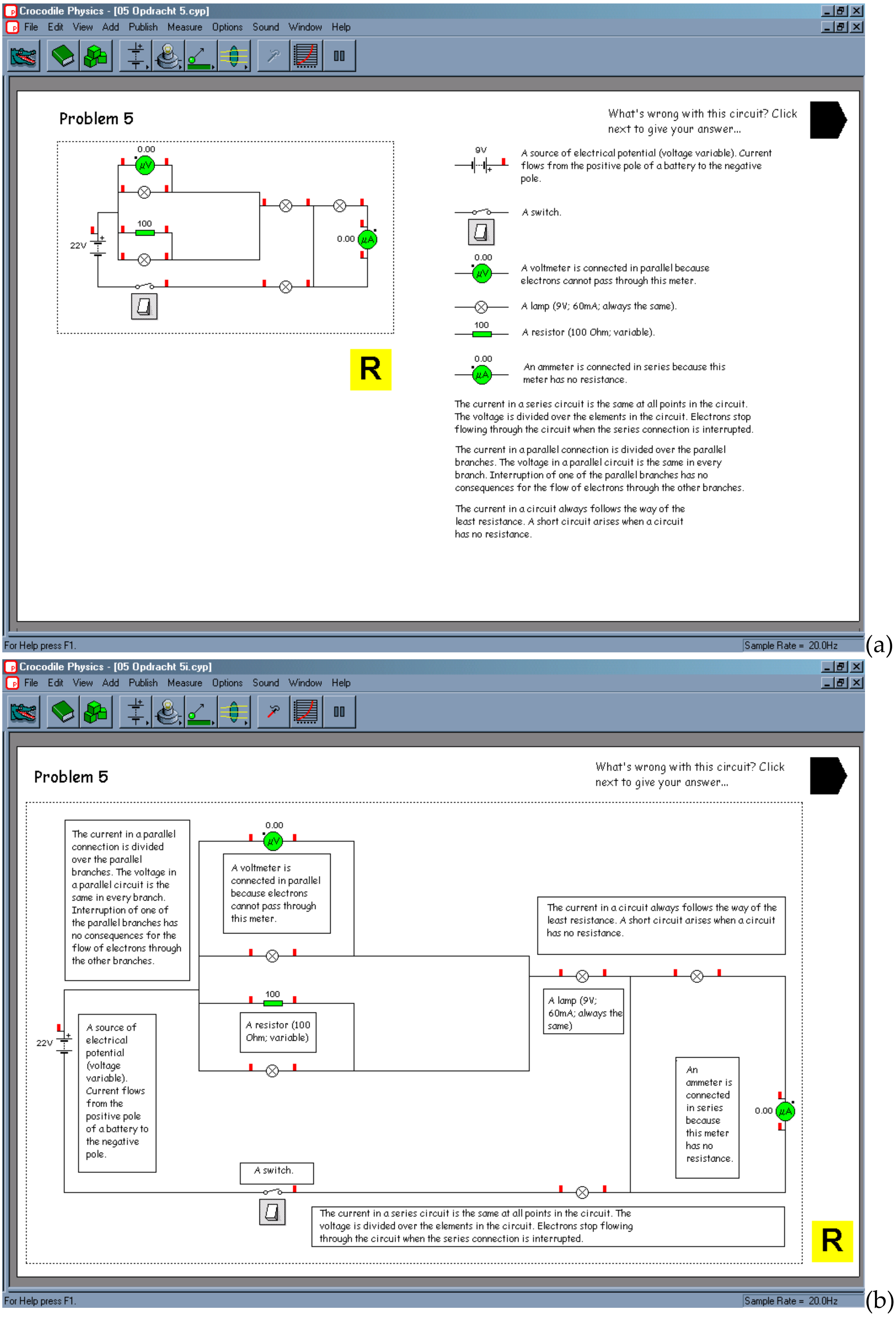

Figure 1: An example of a practice problem in the split-source (a) and the integrated format (b).

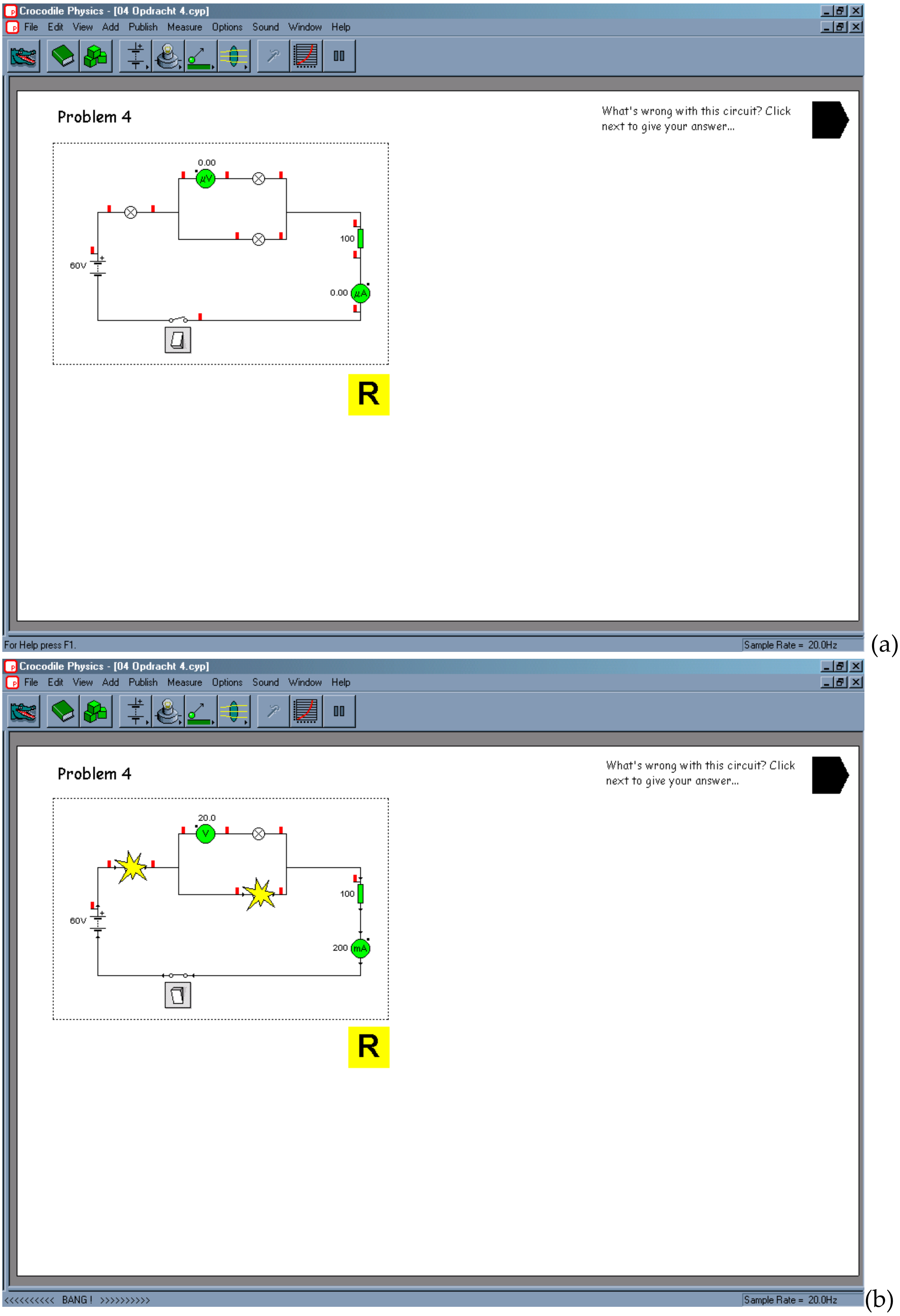

Figure 2: An example of a practice problem before (a) and after (b) closing the toggle switch.

Practice problems.

Nine practice problems were administered to the participants. During practice, the participants could obtain a maximum of 27 points by giving a problem description, a problem cause, and a problem solution for the malfunctioning circuits. Participants received one point for a correct problem description, one point for a correct diagnosis of the problem cause, and one point for a correct problem solution. For example, in one of the practice problems (see Figure 2a) the inserted battery is too powerful for the elements in the circuit *and* a voltmeter is incorrectly connected. In this problem the following correct responses could be made:

- Problem description: the lamp in series and the bottom lamp in parallel explode (= ½ point), the top lamp in parallel does not work at all (= ½ point; see Figure 2b).
- Problem cause: the power supply (i.e., the battery) is too strong for both the lamp in series and for the bottom lamp in parallel (= ½ point), the top lamp in parallel does not work because the voltmeter is connected in series to this lamp (= ½ point).
- Problem solution: insert a weaker battery or add elements in series (= ½ point; note that equivalent answers do not yield extra points), connect the voltmeter in parallel (= ½ point).

The practice performance scores of ten participants were determined by two raters. The interrater reliability for practice performance was .74 (Intraclass Correlation Coefficient, SPSS). The internal consistency of the practice items was .78 (Cronbach's alpha).

Test problems.

After the nine troubleshooting practice problems ten troubleshooting *test* problems were administered to the participants. The test problems also consisted of malfunctioning electrical circuits designed in Crocodile Physics®, but without the accompanying information. Five of the ten test problems were novel but equivalent to the practice problems and five contained a new element (i.e., a variable resistor, a fuse, a LED, or a motor and gears).

Again the participants had to give a problem description, a problem cause and a problem solution for each test problem. The equivalent test problems were meant to determine whether the participants could perform the learned procedures. The problems that contained a new element (i.e., transfer test problems) were meant to measure whether the participants were capable of applying the learned procedures to new situations. The participants could obtain a maximum of 15 points for the five equivalent problems and 15 points for the five transfer problems. The scoring procedure was equivalent to the practice problems. The total test performance scores of ten participants were determined by two raters. The interrater reliability for the total test performance was .86 (Intraclass Correlation Coefficient, SPSS). The internal consistencies of the equivalent problems and the transfer problems were considered separately and were .72 and .70 (Cronbach's alpha) respectively.

Mental effort measurement.
Mental effort was measured both during practice and during the test with a 9-point rating-scale (Paas, 1992; Paas, Van Merriënboer & Adam, 1994), which asked the participant to rate their invested mental effort. The mental effort measures ranged from very, very low to very, very high mental effort. The rating-scale was administered during practice and during the test directly after each problem. After each practice and test troubleshooting problem the following question was posed to the participants: How much mental effort did it cost you to solve the problem(s) in the preceding circuit? Moreover, after the nine practice problems a separate mental effort measurement was taken with regard to the subject matter. The participants had to answer the question: How much mental effort did it cost you to understand all subject matter? The internal consistency of the mental effort measures was .71 (Cronbach's alpha) for the nine practice problems, .70 for the five equivalent test problems, and .76 for the five transfer test problems.

Log tool.
A logging program was developed especially for this experiment to keep track of the time-on-task and of the navigation of the participants through the physics simulation. This program generates a text file with a list of window headers coupled to a timestamp. The route the participants followed through the simulation and the time it took them to complete it could be determined.

Procedure
Participants received an oral instruction, which stressed that they had to work independently, adhere to the time limit, work seriously, carefully study the supportive information on the working of electrical circuits and not ask questions during the experiment. It was emphasized that they were not allowed to skip any part of the answer (problem description, cause or solution) even if they did not know the answer. In that case they were required to give the answer "no answer" or "do not know". It was made clear that, after finishing the physics simulation, their responses would be checked with respect to omissions. They were told that the aim of the experiment was to find out if it is useful to integrate this kind of simulation software in the curriculum and, if this is the case, how this should be done. Before the participants could actually start with the physics lesson they were 'walked through' an example of the troubleshooting problems they were about to receive in class by the experimenter. During this example they could ask questions. This 'walk through' functioned to assure that the whole procedure was clear to all of the participants before the actual experiment started.

All participants had two hours to work through the introduction in class and complete the simulation with the supportive information, the practice problems and the test problems. After the plenary introduction the participants went through the supportive information, the practice and the test at their own pace but in fixed order. Participants could not go back to the supportive information once they started the practice problems and could not go back to the practice problems once they started the test problems. They could move around unrestrictedly within the screens containing the supportive information, the practice problems or the test problems. During the physics lesson the behavior of the participants on the computer and the time spent on each problem was logged.

Results

Practice problems

For an overview of the practice results see Table 1.

Table 1: Overview of the mean practice results.

	Information presentation format					
Variable	Split-source			Integrated		
	M	*SD*	*N*	*M*	*SD*	*N*
	Practice scores (max. = 30)					
Practice problems	12.35	3.98	13	12.63	2.53	12
	Mental effort					
Practice problems	4.97	.93	13	4.94	0.83	12
Subject-matter	5.00	1.22	13	4.58	1.38	12
	Time-on-task (min)					
Supportive information	7.42*	4.81	13	4.19*	1.47	12
Practice problems	30.67	11.66	13	31.34	7.51	12
	Repeats					
Practice problems	36.69	11.97	13	28.5	14.54	12

$p < .05$

Practice scores.

An alpha level of .05 was used for all statistical tests. A *t*-test showed no significant differences between the split-source and integrated format on practice performance.

Mental effort.

The mean mental effort during practice and the mental effort considering subject matter were considered separately. *T*-tests showed no significant differences between the experimental groups on these two measures.

Time-on-task.

Two time measures were analyzed: time spent on the supportive information on the working of electrical circuits and time spent on practice. A *t*-test showed a significant difference between groups on time spent on the supportive information ($t(14.39) = 2.31$; $p < .05$). The participants in the integrated format ($M = 4.19$ min; $SD = 1.47$) spent less time on the supportive information than participants in the split-source format ($M = 7.42$ min; $SD = 4.81$).

Repeats.
The number of times the participants used the repeat button was counted. A *t*-test showed no significant differences between the experimental groups on use of the repeat button during practice.

Test problems
For an overview of the test results see Table 2.

Table 2: Overview of the mean test results.

	Information presentation format					
Variable	Split-source			Integrated		
	M	*SD*	*N*	*M*	*SD*	*N*
	Test scores (max. = 15)					
Equivalent test problems	5.91	3.19	13	6.10	1.95	12
Transfer test problems	4.19*	1.81	13	5.96*	2.64	12
	Mental effort					
Equivalent test problems	5.25	1.08	13	4.72	.99	12
Transfer test problems	4.91	1.17	13	5.32	1.34	12
	Time-on-task (min)					
Equivalent test problems	8.64	2.36	13	10.91	2.89	12
Transfer test problems	9.61*	2.76	13	11.46*	5.54	12
	Repeats					
Equivalent test problems	14.46	4.03	13	12.92	5.13	12
Transfer test problems	12.09	2.39	11	11.33	5.16	12

*p < .05

Test scores.
The equivalent test problems and the transfer test problems were considered separately. A *t*-test showed a statistical significant difference between the experimental groups on the performance on the transfer test problems, t (19.65) = -1.94; $p < .05$. Participants in the integrated format (M = 5.96; SD = 2.64) performed better on these test problems than participants in the split-source format (M = 4.19; SD = 1.81). No statistical difference was found for the performance on the equivalent test problems.

Mental effort.
A *t*-test showed no significant differences between the experimental groups on mental effort on the equivalent test problems or on the transfer test problems.

Time-on-task.
A *t*-test revealed a significant difference between the experimental groups on the time the participants spent on the transfer test problems, $t(21.29) = -2.15$; $p < .05$. The participants in the split-source format (M = 9.61 min; SD = 2.76) spent less time on solving these test problems than the participants in the integrated format (M = 11.46

min; *SD* = 5.54). No significant differences were found between the experimental groups on the time the participants spent on the equivalent test problems.

Repeats.
The number of times the participants used the repeat button was counted. A *t*-test showed no significant differences for the equivalent and the transfer test problems between the experimental groups on use of the repeat button.

Discussion

The hypothesis that learning material presented in an integrated way leads to better transfer test results than split-source presented learning material was supported in this study. Participants receiving the procedural information integrated in the malfunctioning electrical circuit performed better on the transfer problems (i.e., problems that contained a new element) than the participants who received the procedural information not integrated in the electrical circuit.

No differences were found between the experimental groups on the equivalent test problems . The relative decrease between equivalent test scores and transfer test scores for the split-source group (29%) is much larger than this decrease for the integrated group (2%). The split source group performed worse on the transfer test while the integrated group performed almost equally well on both tests. Both groups apply what they have learned equally well on familiar test problems while participants in the integrated group are more able to transfer their knowledge to new situations. This supports the hypothesis that, although participants in both groups acquired a schema of electrical circuits, the schemas of participants in the integrated format are richer because, due to avoidance of the split attention effect, they had more cognitive capacity available when this schema was formed.

The mental effort results are in line with this hypothesis. First, the mean mental effort reported by the participants never exceeded the rating 'not low, not high', which indicated that both groups had enough cognitive capacity to acquire a basic schema of electrical circuits with which they could complete the equivalent test problems. Second, based on the transfer test results, the invested mental effort seemed to be used differently by both groups. It appears that participants in the split-source format had to divide their cognitive capacity over learning processes and mental integration processes (i.e., text and diagram) while participants in the integrated format could allocate it all to learning processes, which led to better transfer test scores (i.e., richer schema acquisition). So, although both groups invested the same amount of mental effort the participants in the integrated format had the opportunity to invest it more adequately.

The participants in the integrated group spent less time on reading the supportive information and more time on solving the transfer test problems than the participants in the split-source group. It remains unclear why the participants in the integrated group spent less time on studying the supportive information because at that point in the experiment no manipulation had yet taken place. The supportive information for both groups is exactly the same and is presented exactly at the same point in the simulation. However, although participants in the integrated group spent less time on the supportive information presented before practice this had no influence on practice performance and equivalent test problem performance; both groups performed equally well on these measures. Moreover, participants in the integrated format performed better on the transfer test problems than the other participants.

The difference in time-on-task spent on the transfer test problems can be easily explained by the fact that it takes more time to fill in the answers for the problems presented instead of simply stating "no answer" or "do not know". However, when this point is left aside and the relative increase in time of the integrated group is compared to the relative increase in transfer test performance of this group, it is seen that a small increase in time investment leads to a large increase in performance. In other words, it is unlikely that the participants in the integrated group performed better on the transfer test than the other participants only because they invested more time during the transfer test.

Based on the results of this study it seems that generalization of the split attention effect to the context of conventional problem solving in computer-simulations is possible. Beneficial effects on learning, comparable to those shown in earlier split attention research (Cerpa, Chandler & Sweller, 1996; Chandler & Sweller, 1991; Chandler & Sweller, 1992; Chandler & Sweller, 1996; Kalyuga, Chandler & Sweller, 1999; Mayer & Anderson, 1992; Mayer & Moreno, 1998; Mayer & Sims, 1994; Sweller & Chandler, 1994), are also found in this study. This study emphasizes the importance of integrating referring material, even in a context other than worked examples.

In conclusion, this study shows that, in the context of conventional problem solving, the integration of procedural information sources leads to better transfer test performance and, thus, is beneficial for schema acquisition. Seeing as how multimedia gaming and simulation is gaining in importance and use in present day education, future research should further study how to optimize this effect to help design and develop more effective and efficient multimedia practicals. Specific attention should be paid to the combination of split attention and modality effects.

Chapter 6 - Just-in-time information presentation: Improving transfer performance and learning efficiency of a complex troubleshooting skill[1]

Abstract

The study in this last Chapter is a replication of the study described in Chapter 4. The same four information presentation formats are studied with the only difference that the procedural information is integrated in the circuit diagram when possible. It is hypothesized that for learning complex cognitive skills such as troubleshooting, supportive information is best presented before practice and procedural information during practice. This is expected to optimize cognitive load and yield highest transfer-test performance and learning efficiency, defined as higher transfer performance in combination with lower load during practice. Eighty-five students (49 male, 36 female; M = 15.2 years, SD = .59) participated in a 2x2 factorial experiment with the factors timing of supportive information and timing of procedural information, both with the levels *before* and *during* practice. Transfer test and learning efficiency scores support the hypotheses.

Introduction

Practical educational approaches, such as project-based education, the case method, problem-based learning, and competency-based learning usually focus on more or less realistic and authentic whole tasks or meaningful problems (Merrill, 2002; Reigeluth, 1999; van Merriënboer & Kirschner, 2001). Such tasks and problems are considered to help learners (1) master complex skills that require integration of the knowledge, skills and attitudes necessary for effective performance, (2) learn to coordinate constituent skills that make up complex performance, and, eventually, (3) transfer what is learned in school to their daily life or work settings.

A potential pitfall of using meaningful problems is that, because of their complexity, they demand too much of the novice learners' cognitive system. Working memory capacity is limited and exceeding this capacity hampers learning (Baddeley, 1992; Miller, 1956; Sweller, 1988). This cognitive load on working memory can be influenced in several ways. First, working on meaningful problems can be scaffolded by sequencing problems during practice from simple to complex (Reigeluth, 1983; 1999) or by using low-load problem formats, such as worked-out examples (Paas & van Merriënboer, 1994; van Gerven, Paas, van Merriënboer, & Schmidt, 2002) or completion problems (van Merriënboer, Schuurman, de Croock, & Paas, 2002; van Merriënboer & de Croock, 1992). Second, information necessary to solve the meaningful problems can be presented just-in-time; in other words, precisely when the learner needs it for practice (van Merriënboer, Kirschner, & Kester, 2003; Kester, Kirschner, & van

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Merriënboer, in press). This chapter focuses on just-in-time information presentation as a method of managing the cognitive load on working memory while solving meaningful problems.

The cognitive load that a learner experiences during practice is caused by the complexity of the problem and the design of the instructional material. Solving the problem itself yields *intrinsic* cognitive load which is determined by the degree of element interactivity. High element interactivity is associated with a high intrinsic cognitive load because it requires the learner to process several elements and their relationships in working memory simultaneously in order to solve the problem. In this study, the learner has to simultaneously process features of electrical circuits and features of a central heating system which is used as an explanatory analogy for the flow of current in an electrical circuit. Low element interactivity is associated with low intrinsic cognitive load because it allows the learner to serially process a small number of elements at a time (Sweller, van Merriënboer, & Paas, 1998). The learner can, for example, easily process each symbol used to denote a particular element in an electrical circuit.

The design of the instructional material yields either *extraneous* cognitive load or *germane* cognitive load. Extraneous cognitive load is caused by the processes that a learner engages in which are *not* directly *beneficial* to learning, for instance, searching for relevant information sources, combining different information sources in order to understand the learning material, or weak-method problem solving. Extraneous cognitive load uses up cognitive resources at the cost to learning processes. Germane cognitive load includes all cognitive load associated with processes that a learner engages in that are *beneficial* for learning, for instance, attending to important features of the problem (van Merriënboer, Schuurman, de Croock, & Paas, 2002), or abstracting from a variety of practice problems so as to construct more general cognitive schemata (Spiro, Coulson, Feltovich, & Anderson, 1988; Sweller et al., 1998). With a given intrinsic cognitive load, well-designed learning material minimizes extraneous cognitive load and optimizes germane cognitive load within the thresholds of totally available cognitive resources. Different strategies are available to manage the various forms of cognitive load (Chandler & Sweller, 1991; Sweller, 1988; Sweller et al., 1998). The present study zooms in on strategies for managing cognitive load that can be used to optimize the timing of information presented with meaningful problems for acquiring troubleshooting skills.

Complex skills, such as troubleshooting electrical circuits or designing a computer program, are made up of constituent skills that differ in nature (Fisk & Gallini, 1989; van Merriënboer, 1997; van Merriënboer et al., 2003). *Non-recurrent* constituent skills require interpretation of cognitive schemata, and their performance varies from problem situation to problem situation, that is, situation specific use of the same, general knowledge. In the present study, an example of a non-recurrent skill is being able to reason about the differences between various series and parallel connections and solving the problems caused by their influence on the circuit. *Recurrent* constituent skills require applying cognitive rules or automated schemata and their performance is the same in every problem situation, that is, they entail situation independent use of the same, situation-specific knowledge. An example of a recurrent skill in this study is properly inserting a voltmeter in parallel because current cannot flow through this meter. Non-recurrent and recurrent skills constitute the complex skill that allows learners to solve the troubleshooting problems.

In order to master the non-recurrent constituent skills, *supportive* information such as a conceptual model of how a learning domain is organized, is necessary. Learning supportive information is, in general, a problem with *high element interactivity* because to-be-constructed mental models contain many interrelated elements. This has consequences for the proper management of cognitive load during practice (van Merriënboer et al., 2003). It seems advisable to present supportive information before the practice problems since simultaneously solving the practice problems and processing the highly interactive supportive information is likely to increase the risk of overloading working memory. When supportive information is presented before practice, all cognitive capacity is available to process this information, which allows learners to construct rich and adequate cognitive schemata. As a result, cognitive schemata that can easily be activated in working memory during the solution of practice problems will be available in long-term memory. Mastery of recurrent constituent skills requires the availability of *procedural* information, that is task-specific rules along with the facts, principles, or concepts needed to correctly apply these rules. Learning procedural information is, in general, a problem with *low element interactivity* because task-specific rules always contain a limited number of related elements (i.e., some conditions and one action). Presenting procedural information during practice is not advised against. The risk of overloading working memory when simultaneously processing procedural information and solving practice problems is low due to the low element interactivity of the procedural information. Simultaneous presentation of procedural information and practice problems helps learners to automate schemata that they apply to familiar aspects of novel problem situations, because the necessary procedural information is made directly available in working memory during practice and so facilitates a process known as proceduralization (Anderson, 1996), by which the relevant knowledge is embedded in automated schemata. To minimize the extraneous cognitive load in the instructional material it seems advisable to present procedural information *precisely* when learners need it during practice, so that they do not need to keep this information active in working memory over time (Kester, Kirschner, van Merriënboer, & Bäumer, 2001; van Merriënboer et al., 2003). Extensive research has also been carried out on the question *how* the procedural information should be presented (for an overview see Sweller et al. 1998; for a study in the same domain see Kester, Kirschner, & van Merriënboer, submitted), indicating that extraneous load is significantly reduced by integrating explanatory text in a diagram, instead of, separating them spatially. Integration of text and diagram in time and space frees learners from mentally integrating the different information sources themselves which lowers the extraneous load. Therefore, it seems advisable to present procedural information *during* practice and *integrated* in the circuit diagram.

In summary, supportive information presented *before* practice and procedural information presented in an integrated way *during* practice is optimal with regard to the management of cognitive load (i.e., preventing cognitive overload en decreasing extraneous load) and best allows learners to construct cognitive schemata, a process which is associated with germane cognitive load. To investigate these assumptions, this research compares the presentation of supportive information *before* practice and procedural information *during* practice, with three other formats. One format presents both supportive and procedural information *before* practice; a second format presents both supportive and procedural information *during* practice with procedural information integrated in the circuit diagram, and a final format presents supportive information *during* practice and procedural information *before* practice.

The effectiveness and learning efficiency of the information presentation formats are studied. The effectiveness of the formats is measured by performance on two types of test problems. *Equivalent* test problems are analogous to the practice problems and, therefore, have a high level of familiarity. They make use of the same elements of a circuit that were used during learning. *Transfer* test problems use different elements than the practice problems and thus, have a lower level of familiarity. A motor, for example, is used instead of a lamp to draw current in a circuit. Transfer test problems, therefore, require cognitive schemata of a higher abstraction level than equivalent test problems; the learners need to use 'system principles' to reason about how a correctly functioning circuit should work to recognize and solve the problems in the malfunctioning circuit (Kieras & Bovair, 1984). The learning efficiency of the formats is calculated on the basis of transfer test performance and cognitive load during practice (Paas & van Merriënboer, 1993). High learning efficiency denotes high transfer test performance in combination with low cognitive load during practice and low learning efficiency denotes low transfer test performance in combination with high cognitive load during practice.

It is hypothesized that presenting *supportive information before* practice and *procedural information during* practice will yield higher transfer test performance than the other formats, since, the better the management of cognitive load during learning, the better the acquisition of general and abstract schemata that are necessary for transfer to occur. Furthermore, learning will be more efficient when supportive information is presented before practice and procedural information is presented during practice, that is, higher transfer test performance will be obtained with relatively low cognitive load during practice. Optimal management of cognitive load enables learners to use all of their cognitive capacity for processes relevant for learning because no cognitive load is caused by activities irrelevant to learning. The predicted superiority in transfer test performance and learning efficiency will manifest itself as an interaction effect between the factors timing of supportive information and timing of procedural information.

Method

Participants

Eighty-five tenth grade students at Bernardinus College in Heerlen, the Netherlands (49 male, 36 female; mean age = 15.2 years, *SD* = .59) participated in this study. All participants spoke Dutch as their first language, the language in which the instruction was given. They voluntarily participated in a physics lesson on electrical circuits, using a computer-based simulation. No specific grade was given for this lesson. All participants followed the same physics education, which started in ninth grade. They were all equally familiar with the topic of the lesson because they all received the theory the previous academic year. They received a music compact disc of their own choice as compensation for their participation.

Materials

Physics lesson.

Crocodile Physics 1.5®, a simulation program for secondary school science classes, was used to develop the physics lesson for this experiment. The computer-based lesson contained an introduction, ten practice-troubleshooting problems and ten test-troubleshooting problems. In the introduction the participants received information on:

- what to expect: the number of problems, available time and how to switch the circuit on and off;
- how to navigate within the application: left and right arrows were used to go back or forth in the lesson, participants could jump to a practice problem or a test problem by clicking on different icons; and
- the experimental rules: taking notes or changing the computer's configuration, for instance, change the full screen presentation to part screen, making changes in the menu of Crocodile Physics® was not allowed, and the work had to be done individually.

Inherent to a malfunctioning circuit is that the elements become irreversibly damaged after the switch is turned on, for example a lamp explodes after turning the switch on. To allow the participants to observe this more than once, a *repeat* button was implemented which allowed participants unlimited observations of the events in the circuit after turning the switch on. After troubleshooting the malfunctioning circuit participants had to give a *description* of the problem, diagnose the *cause* of the problem and give a *solution* to the problem. The circuits in the practice problems made use of six elements; namely a toggle switch, a lamp, a battery, a resistor, a voltmeter and an ammeter. During practice all circuits contained all six elements.

Information presentation.

The troubleshooting problems, consisting of malfunctioning electrical circuits, were accompanied by information blocks presented either before practice, during practice or before *and* during practice. Four information presentation formats were distinguished in a 2 x 2 factorial design with the factors timing of supportive (Sup) information presentation, before (B) or during (D) practice and timing of procedural (Proc) information presentation, before or during practice. The participants were randomly assigned to one of the four formats. In the SupB-ProcB format *both* supportive information and procedural information were presented simultaneously *before* practice. The participants assigned to the SupD-ProcD format received *both* supportive and procedural information simultaneously *during* practice. In the SupB-ProcD format the supportive information was presented *before* practice while the procedural information was presented *during* practice. Finally, in the SupD-ProcB format the supportive information was presented *during* practice while the procedural information was presented *before* practice. For an example of a practice problem seen Figure 1.

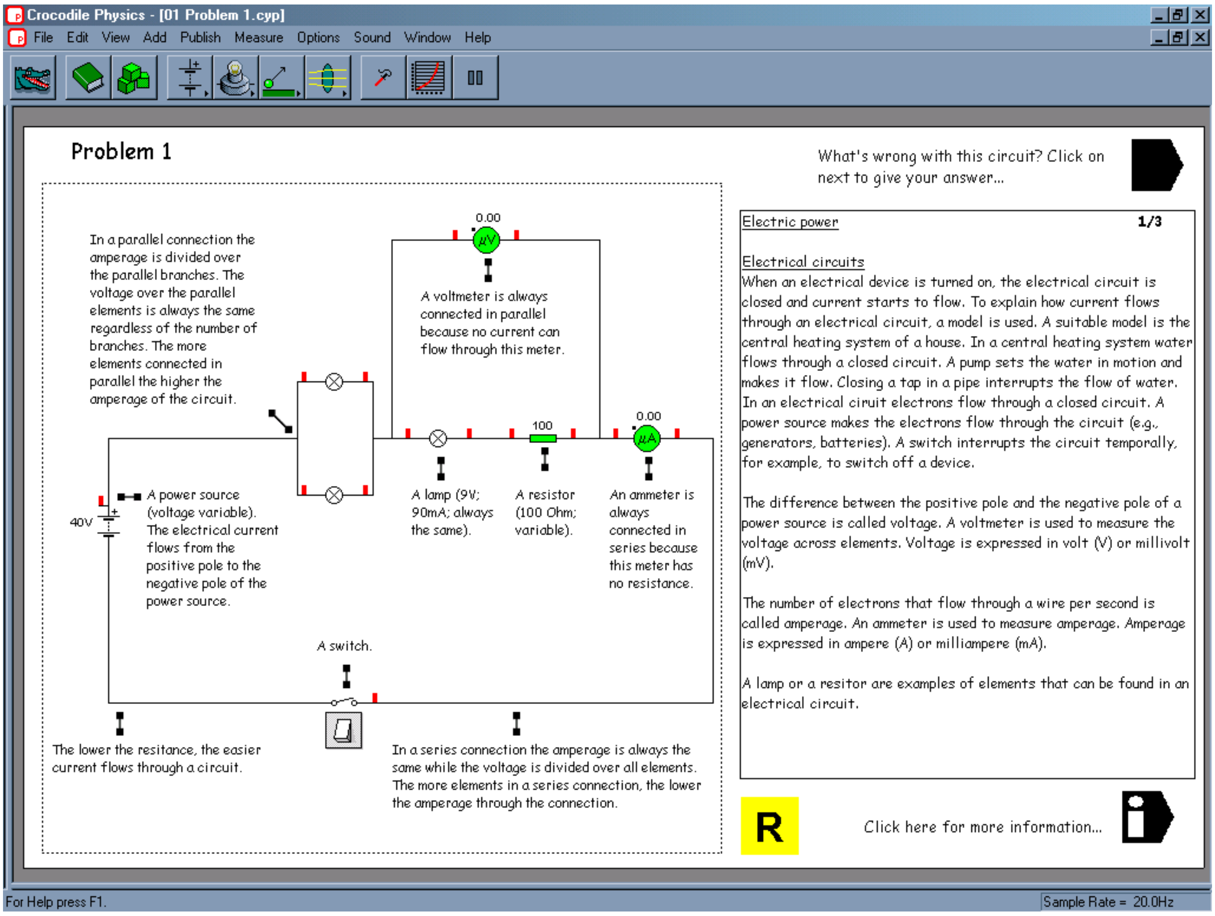

Figure 1: An example of a practice problem in the supportive-during/procedural-during (SupD-ProcD) format. The supportive information is presented in the right-hand frame and the procedural information is integrated in the circuit diagram.

Practice problems.

Participants received ten practice problems. Every practice problem consisted of three parts. The participants could obtain a maximum of 30 points by giving a problem *description* (1 point), a problem *cause* (1 point) and a problem *solution* (1 point) for the malfunctioning circuits in these ten practice problems. For example, in one of the practice problems the inserted battery is too strong for the elements in the circuit. In this problem the following correct responses could be made:

- Problem description: the lamp explodes (= 1 point)
- Problem cause: the power supply, for instance, the battery, is too strong for the lamp (= 1 point)
- Problem solution: insert a weaker battery *or* add more lamps in series (= 1 point)

The practice performance scores of eight participants were determined by two raters. The interrater reliability for practice performance of the two raters was .87 (Intraclass Correlation Coefficient, SPSS). The internal consistency of the practice items was .82 (Cronbach's alpha).

Test problems.

After the ten practice problems participants received ten *test* problems. The test problems also consisted of malfunctioning electrical circuits designed in Crocodile Physics®, but without the accompanying information. Five of the ten test problems were equivalent to the practice problems, that is, they contained the same elements, and five contained a new element, that is, a variable resistor, a fuse, a LED, or a motor and gears.

The test problems consisted of the same parts as the practice problems. The *equivalent test problems* were meant to determine whether the participants could perform the learned procedures. The test problems that contained a new element, the *transfer test problems,* were meant to measure whether the participants were able to apply the procedures to new situations. The participants could obtain a maximum of 15 points for the five equivalent problems and another 15 points for the five transfer problems. As was the case in practice, they received one point for each correct response, either a description, a cause or a solution. The total test performance scores of eight participants were determined by two raters. The interrater reliability for the test performance on the equivalent problems of the two raters was .87 (Intraclass Correlation Coefficient, SPSS) and for the transfer problems it was .92. The internal consistencies of the equivalent problems and the transfer problems were .64 and .63 (Cronbach's alpha) respectively.

Mental effort measurement.

Mental effort was used as an index of cognitive load. It refers to the amount of cognitive capacity that is allocated to problem solving. Mental effort was measured both during practice and during the test with a 9-point rating-scale (Paas, 1992; Paas, Van Merriënboer & Adam, 1994). The mental effort measures ranged from very, very low mental effort to very, very high mental effort. The rating-scale was administered during practice and during the test directly after each troubleshooting problem. After each practice and test problem the participants were asked: How much mental effort did it cost you to find a solution for the problem(s) in the preceding circuit? Moreover, after the ten practice problems a separate mental effort measure was taken with regard to the subject matter. The participants were then asked: How much mental effort did it cost you to understand all subject matter? The internal consistency of the mental effort measures was .83 (Cronbach's alpha) for the ten practice problems, .69 for the five equivalent test problems and .68 for the five transfer test problems.

Log tool.
A logging program was used in the experiment. This program kept track of the time-on-task and of the navigation of the participants through the physics lesson. This program generates a text file with a list of window headers coupled to a timestamp, so, the route the participants followed through the lesson and the time it took them to complete it could be determined.

Procedure
Participants received an oral instruction which stressed that they had to work independently, observe the time limit, work seriously, carefully study the general information on the working of electrical circuits and not ask questions during the experiment. It was emphasized that they were not allowed to skip any part of the answer (problem description, cause or solution) even if they did not know the answer. In the latter case they were advised to give the answer "no answer " or "do not know ". It was made clear that all of the responses would be checked after the session to determine whether there were omissions regarding the answers on the troubleshooting problems and the mental effort measures. They were told that the aim of the experiment was to find out if it is useful to integrate this kind of simulation-software into regular education and, if this is the case, how this should be done. Before the participants could actually start with the physics lesson they were 'walked through' an example of the troubleshooting problems they were about to receive in class by the experimenter. During this example they could ask questions only about the simulation and about the procedure. All efforts were made to ensure that the whole procedure was clear to all of the participants before the actual experiment started.

All participants had 1 hour and 40 minutes available to work through the introduction and complete the lesson. After the introduction, the participants could go through the practice and the test at their own pace, but in a fixed order. Participants could not go back to the information presented before practice once they started the practice problems and they could not go back to the practice problems once they started the test problems. Within each part of the lesson, that is the 'before' information part, the practice part and the test part, the participants could move around freely. During the physics lesson the participant behavior on the computer and the time spent on each problem was logged.

Results

Practice problems
See Table 1 for an overview of the results for the practice problems.

Table 1: Overview of the practice results

	Information Presentation Format[a]							
	SupB-ProcD		SupB-ProcB		SupD-ProcD		SupD-ProcB	
	M	SD	M	SD	M	SD	M	SD
Practice performance* (Max. = 30)	16.00	4.13	15.07	5.29	17.28	3.76	18.02	5.54
Mental effort during practice* (1-9)	4.44	1.16	4.88	1.33	4.80	.89	4.13	1.46
Mental effort for subject matter (1-9)	4.29	1.49	3.93	1.91	5.56	2.06	4.08	2.25
TOT[b] study, troubleshooting and formulating answers (mins.)	22.82	5.05	19.67	5.81	23.14	6.03	24.12	7.54
# Repeats	20.92	6.16	28.62	11.06	27.67	10.08	28.15	10.21

* $p < .05$ *for timing of supportive information on practice performance, and for the interaction of supportive information x procedural information on mental effort during practice.*

[a]*Sup = supportive information; Proc = procedural information; B = before, and D = during.* [b]*TOT = Time-on-task*

Practice performance.
An alpha level of .05 was used for all statistical tests. ANOVA revealed a main effect for timing of supportive information presentation on practice performance, F (1, 85) = 4.26; MSE = 95.04; $p < .05$. Participants receiving supportive information during practice (M = 17.64; SD = 4.65) performed better than participants receiving supportive information before practice (M = 15.52; SD = 4.72).

Mental effort.
Perceived mental effort during practice and for understanding the subject matter were considered separately. ANOVA yielded an interaction between the timing of supportive and procedural information on mental effort during practice, F (1,85) = 4.26; MSE = 6.36; $p < .05$. If supportive information is presented *before* practice, the participants report less mental effort to solve the problems when procedural information is presented during practice (M = 4.4; SD = 1.16) than when procedural information is also presented before practice (M = 4.9; SD = 1.33). If supportive information is presented *during* practice, the participants report less mental effort to solve the problems when procedural information is presented before practice (M = 4.1; SD = 1.46) than when procedural information is also presented during practice (M = 4.8; SD = .9). No differences between the conditions were found for the mental effort reported for understanding the subject matter.

Time-on-task.
Participants with missing values due to failure of the log tool (n = 33) were excluded from the time-on-task analyses. No significant differences were found for the time the participants spent on studying and troubleshooting the practice problems and formulating answers.

Number of repeats.
Participants with missing values due to failure of the log tool (n = 31) were excluded from the analysis of the use of the repeat button. ANOVA revealed no differences between experimental groups for the use of the repeat button during practice.

Test problems
See Table 2 for an overview of the results for the test problems.

Table 2: Overview of Results for the Test Problems.

	Information Presentation Format[a]							
	SupB-ProcD		SupB-ProcB		SupD-ProcD		SupD-ProcB	
	M	SD	M	SD	M	SD	M	SD
	Transfer test problems							
Transfer test performance* (Max.=15)	6.90	2.00	5.57	2.68	5.24	2.59	6.31	2.83
Mental effort (1-9)	5.61	1.35	5.88	1.19	5.46	1.44	5.18	1.87
Learning efficiency**	.32	.83	-.29	1.13	-.33	.98	.34	1.20
Performance efficiency*	.21	.87	-.28	1.05	-.17	.98	.26	1.22
TOT[b] troubleshooting and formulating answers (mins.)	7.98	1.82	7.66	2.80	7.75	2.17	8.22	2.78
# Repeats	10.62	4.07	9.85	3.02	9.20	4.00	9.08	2.40
	Equivalent test problems							
Equivalent test performance (Max.= 5)	7.00	2.60	7.64	2.83	7.78	2.35	6.98	2.66
Mental effort (1-9)	4.71	1.27	5.08	1.52	4.88	1.27	4.81	2.01
Learning efficiency	-.03	.18	-.09	1.34	-.02	.90	.14	1.29
Performance efficiency	-.03	.98	-.02	1.27	.11	.99	-.08	1.35
TOT troubleshooting and formulating answers (mins.)	8.17	1.85	7.12	2.07	7.93	1.99	8.63	2.74
# Repeats	10.31	4.82	9.54	2.99	8.00	1.93	10.46	8.32

*$p < .05$ *for the interaction of supportive information x procedural information on performance and performance efficiency of the transfer test.*

**$p < .01$ *for the interaction of supportive information x procedural information on learning efficiency of the transfer test.*

[a]*Sup = supportive information; Proc = procedural information; B = before, and D = during.* [b]*TOT = Time-on-task*

Test performance.
For *transfer* test performance, ANOVA revealed an interaction between the timing of supportive and the timing of procedural information in the expected direction, $F(1,85) = 4.68$; $MSE = 30.5$; $p < .05$ (see Figure 2). If supportive information is presented before practice, the presentation of procedural information during practice leads to higher transfer test performance ($M = 6.90$; $SD = 2.00$) than when procedural information is also presented before practice ($M = 5.57$; $SD = 2.68$). Reversely, if supportive information is presented during practice, the presentation of procedural information before practice leads to higher transfer test performance ($M = 6.31$; $SD = 2.83$) than when procedural information is also presented during practice ($M = 5.24$; $SD = 2.59$). No significant differences between conditions were found for equivalent test performance.

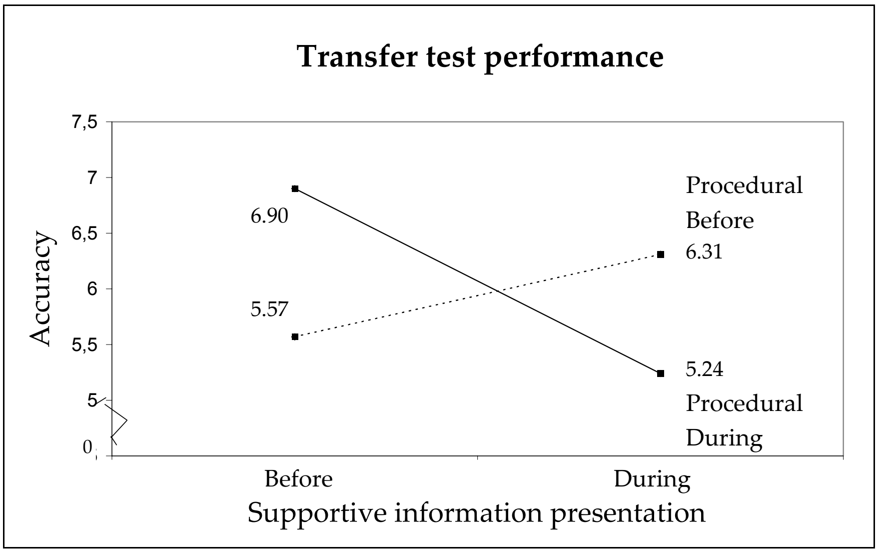

Figure 2: Interactions between the timing of supportive information and the timing of procedural information for the transfer test.

Mental effort.
No significant differences between conditions were found for reported mental effort for either the transfer test problems or the equivalent test problems.

Learning and performance efficiency.
The procedure of Paas and van Merriënboer (1993; see also Paas, Tuovinen, Tabbers, van Gerven, 2003) was used to calculate efficiency. First, for each participant the performance measures and the mental effort measures are transformed into *z*-scores, using the grand mean across conditions. Second, the mean *z*-scores for every condition can be represented in a Cartesian coordinate system with *M*ental effort *z*-scores on the horizontal axis and *P*erformance *z*-scores on the vertical axis. The line $P = M$ through the origin of the system is assumed to indicate an efficiency of zero (slope = 45^0). The efficiency, *E,* is calculated as the perpendicular distance from a data point in the coordinate system to the line $P = M$ (Paas & van Merriënboer, 1993). The formula for calculating this distance is:

$$E = \frac{P_{\text{erformance}} - M_{\text{ental Effort}}}{\sqrt{2}}$$

Equal performance (*P*) and mental effort (*M*) scores yield an instructional efficiency of zero, a neutral score. When $P > M$, the instructional material is more efficient, indicated by a positive value, because the performance is higher than might be expected on the basis of perceived mental effort. When $P < M$, the material is less efficient, indicated by a negative value, because the performance is lower than might be expected on the basis of perceived mental effort. *Learning* efficiency is calculated based on perceived mental effort during *practice* and test performance while the *performance* efficiency is calculated based on the perceived mental effort during the *test* and test performance. Thus, it directly indicates at which cognitive costs test performance is reached.

For the transfer test, ANOVA revealed an interaction that showed the expected pattern for learning efficiency, between the timing of supportive information and the timing of procedural information, $F(1,85) = 7.92$; $MSE = 8.7$; $p < .01$. If supportive information is presented before practice, it is indeed more efficient to present procedural information during practice ($M = .32$; $SD = .83$) than it is to present procedural information before practice ($M = -.29$; $SD = 1.13$). But if supportive information is presented during practice, it is more efficient to present procedural information before practice ($M = .34$; $SD = 1.2$) than it is to present procedural information during practice ($M = -.33$; $SD = .98$; see Figure 3a). For the performance efficiency of the transfer test, ANOVA also revealed an interaction between the timing of supportive information and the timing of procedural information, showing the same pattern as for learning efficiency, $F(1,85) = 4.20$; $MSE = 4.53$; $p < .05$. If supportive information is presented before practice, it is more efficient to present procedural information during practice ($M = .21$; $SD = .87$) than it is to present procedural information before practice ($M = -.28$; $SD = 1.05$). If supportive information is presented during practice, it is more efficient to present procedural information before practice ($M = .26$; $SD = 1.22$) than it is to present procedural information also during practice ($M = -.17$; $SD = .98$; see Figure 3b). For the equivalent test problems, no differences between conditions were found for either the learning efficiency or the performance efficiency.

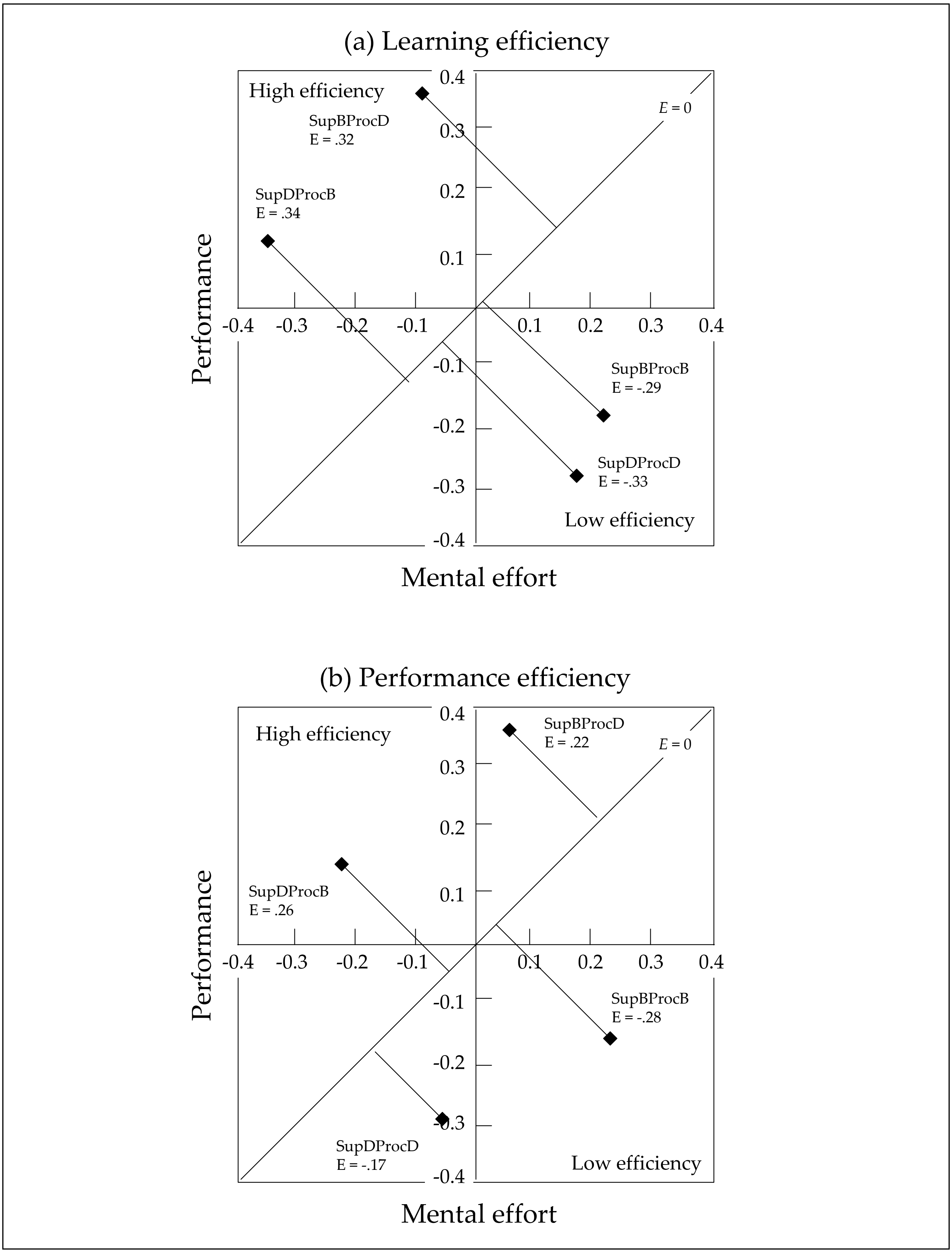

Figure 3: The mean learning efficiency scores (a) and the mean performance efficiency scores (b) drawn in a Cartesian coordinate system.

Time-on-task.
No differences between conditions were found for the time-on-task (i.e., troubleshooting and formulating answers) of the transfer test problems and for the time-on-task of the equivalent test problems.

Number of repeats.
ANOVA revealed no significant differences between conditions for the use of the repeat button during either the transfer test problems or the equivalent test problems.

Discussion

In this study, evidence is found for the hypothesis that the presentation of supportive information before practice and procedural information during practice leads to highest transfer-test scores. Learners in this 'just-in-time' information presentation format performed better on the transfer-test problems than learners in the formats that presented both information types simultaneously, either before or during practice. Moreover, the performance efficiency scores indicate that learners in the 'just-in-time' format not only show highest transfer-test performance, but also reach this performance with a proportionally low investment of mental effort in test problem solving.

With regard to practice problem solving, learners in the 'just-in-time' format reported lower mental effort ratings during practice than learners in the simultaneous formats. The combination of low investment of mental effort during practice and high transfer-test performance is reflected in a high learning efficiency. Thus, as hypothesized, learners in the 'just-in-time' format show higher learning efficiency scores than learners in the simultaneous formats.

Summarizing, the combination of results on mental effort and performance is straightforward. Learners in the 'just-in-time' format show a high transfer-test performance and high learning efficiency, because the transfer-test performance is reached with a proportionally lower investment of mental effort during practice. Moreover, they show high performance efficiency, because the transfer-test performance is also reached with a proportionally lower investment of mental effort during the test itself. The fact that these effects are found for the transfer-test problems, and not for the equivalent test problems, may well indicate that learners in the ‘just-in-time’ format are better able to use their available cognitive capacity for processes beneficial to learning and, in particular, for the construction of cognitive schemas. The availability of general, abstract schemas may well explain the better ability to solve transfer-test problems, because the general information in these schemas can be used to deal with the unfamiliar aspects of these problems. For equivalent test problems, there is no or little added value of the availability of general, abstract schemas because these problems only contain familiar aspects (see Sweller, van Merriënboer, & Paas, 1998).

An unexpected finding is that presenting supportive information *during* practice and procedural information *before* practice is almost as effective and efficient as presenting the supportive information *before* practice and the procedural information *during* practice. The transfer-test scores of learners in this 'reverse' format did not differ as much from the transfer-test scores of learners in the 'just-in-time' format as was expected. The same is true for the mental effort scores, as well as the learning efficiency and performance efficiency scores. A possible explanation for the success of the 'reverse' format is that the supportive information has a lower element interactivity than thought beforehand and the procedural information is apparently so compact, clear and orderly that learners are able to memorize it and have this information available in long-term memory before they start to work on the practice problems.

The finding that learners receiving supportive information during practice scored higher on the practice problems than those receiving supportive information before practice supports the idea that the element interactivity of the supportive information has been too low. Obviously, learners had little difficulty simultaneously processing the supportive information and carrying out the practice problems. Processing the supportive information during practice only seems to become problematic when the procedural information must *also* be processed during practice. Likewise, learners may have had little difficulty to memorize the small amount of procedural information that was presented before practice, but, only when the supportive information was *also* presented before practice, it yielded suboptimal results.

Future research should help to strengthen the theoretical explanations for the results of this study. First, it will be necessary to conduct experiments that use a larger amount of procedural information, which makes it impossible to memorize the information before practice, and at the same time use supportive information with a very high element interactivity, which makes it much more difficult to simultaneously process this information and solve the practice problems. If the given explanations are correct, a clear advantage of the 'supportive before, procedural during' format over the 'supportive during, procedural before' format should be found. Second, it is assumed that the quality of constructed cognitive schemata may explain why effects are found on transfer-test problems and not, or to a lesser degree, on equivalent test problems. In future studies, more direct measures of the quality of constructed schemas are necessary. For instance, an in-depth analysis of verbal protocols may yield more insight in learners' reasoning and underlying cognitive schemas. Finally, it is necessary to replicate the results of this study using other types of problems, such as design problems or categorization problems instead of troubleshooting problems, and in other learning domains than physics.

The practical implications of this study are pretty straightforward. In problem solving instruction, it is clearly not optimal to present all the information that is relevant to problem solving before learners start to work on the problems, and it is also not optimal to present all this information while learners are working on the problems. Instead, it is better to present part of the information before problem solving and part of the information during problem solving. While the results of the present study are not unequivocal, it seems advisable to present information with a high internal complexity or element interactivity before practice and all other information during practice (see Kester, Kirschner & van Merriënboer, 2001; van Merriënboer, Kirschner, & Kester, 2003).

To conclude, this study reveals a difference in effectiveness and efficiency for information presentation formats that present supportive information and procedural information *separately* before or during practice and information presentation formats that present both information types *simultaneously* before or during practice. Conform the hypotheses, the presentation of supportive information before practice and procedural information during practice leads to more effective and efficient learning. Unexpectedly, the presentation of supportive information during practice and procedural information before practice also leads to more effective and efficient learning. These findings are particularly important for the design of problem solving instruction because more and more educational approaches stress the importance of meaningful problem solving in realistic learning tasks. This study showed that the combination of information presentation and problem solving strongly affects the success of these instructional methods.

Chapter 7 – General discussion

Abstract

The main aim of this thesis was to test the theoretical assumptions on the optimal timing of information during complex skill acquisition, inherent in the just-in-time information presentation model. It was hypothesized that supportive information presented before practice and procedural information presented during practice would facilitate the skill acquisition process and, therefore, would lead to higher learning outcomes. Four experiments were carried out to shed some light on the issue of timing of information presentation during complex skill acquisition; one in the domain of statistics and three in the domain of physics. Experiments 1, 2, and 4 compared the just-in-time information presentation format, to three other information presentation formats to test its expected superiority. Experiment 3 tested whether the integrated presentation of procedural information in a circuit diagram was superior to non-integration with respect to learning outcomes. This chapter gives an overview of the results of these experiments, some concluding remarks and directions for future research.

Review of the results

The studies described in the Chapters 3, 4, and 6 tested whether supportive information presented before practice and procedural information presented during practice led to more effective and/or efficient learning than information presentation according to other information presentation formats. The effectiveness of the instructional material was measured by the performance on test tasks that differed in familiarity to the learning tasks. The higher the performance on test tasks with many unfamiliar aspects, the higher the effectiveness of the material. Learning efficiency was measured by invested mental effort during practice combined with test performance. Highly efficient instructional material is characterized by low invested mental effort during practice combined with high test performance.

In the first study (domain: statistics; Chapter 3) and the second study (domain: physics; Chapter 4), no differences were found between the information presentation formats on the effectiveness of the instructional material. With regard to efficiency, the statistics study revealed superiority of the 'supportive *during*, procedural *before*' format. This unexpected result was explained by the fact that it was difficult to design clear-cut, limited learning tasks in statistics, which complicated the determination and separation of necessary supportive and procedural information. Therefore, the second study was carried out in the domain of physics in which a clear-cut, troubleshooting problem was designed. Although, this study revealed no differences in effectiveness of the information presentation formats, evidence was found that, based on the search behavior of the learners, the presentation of supportive information before practice and procedural information during *was* just-in-time. This means that *temporal split attentio*n was avoided in the instructional material and could not have interfered with learning. It was concluded that avoiding temporal split attention in instructional material that still allowed for spatial split attention is, apparently, of no use. In a third experiment (Chapter 5) it was tested whether *spatial split attention* hampered learning in the instructional material used in the second experiment. It was found that integrating the procedural information in the circuit diagram to avoid spatial split attention led to more effective learning compared to presenting the procedural information separate from the circuit diagram. Finally, a replication of the second study was carried out (Chapter 6) in which, where applicable, the procedural information was integrated in the circuit diagram. This experiment revealed that the 'supportive *before*, procedural *during'* format was more effective and more efficient than the formats in which both information types were presented simultaneously before or during practice.

To conclude, after some 'fine-tuning', support is found for the hypothesis that supportive information is best presented before practice and procedural information is best presented during practice. Instructional material in which supportive information is presented before practice and procedural information during led to more effective and more efficient learning than material in which the information is presented simultaneously before or during practice, provided that, both the supportive information and the procedural information can be clearly described and spatial split attention is avoided.

Concluding remarks

Chapter 2 describes a just-in-time information presentation model anchored in the 4C/ID model. Both models are consistent with cognitive load theory, which provides instructional design guidelines that take the limitation of working memory into account.

The just-in-time information presentation model advocates that supportive information is best presented before practice. This allows the learner to connect new information to already existing, relevant cognitive structures (i.e., elaboration), which leads to the construction of general and abstract schemata useful for solving new problems containing unfamiliar elements (i.e., transfer). Procedural information is best presented during practice. This allows the learner to embed the information active in working memory in highly domain-specific representations (i.e., knowledge compilation) followed by strengthening it such that schemata become more and more automated each time they are successfully applied. These automated schemata are useful in dealing with familiar aspects of new problems. According to cognitive load theory, supportive information is best presented before practice because of its high element interactivity. The intrinsic cognitive load that arises from simultaneously processing supportive information and carrying out practice problems is likely to exceed working memory capacity. To avoid temporal and/or spatial split attention it is best to present procedural information during practice. Separation of the procedural information from the practice problems in time or space increases the extraneous cognitive load; as a result, valuable working memory capacity has to be allocated to processes irrelevant for learning such as mentally integrating different sources of information.

Although in several experiments (Chapter 4, Chapter 5 and Chapter 6) support is found for the assumptions from the just-in-time information presentation model and cognitive load theory, some unexpected results were found as well. In the first (Chapter 3) and the last (Chapter 6) experiments, the efficiency of the information presentation format where supportive information was presented *during* practice and procedural information before practice (i.e., the 'reversed' format), was unexpectedly high. Moreover, the last experiment (Chapter 6) revealed that the 'reversed' format did not differ much in effectiveness from the just-in-time format. These results are difficult to place in the theoretical framework. A few alternative explanations have already been given. In the statistics experiment (Chapter 3) it was difficult to determine and separate the supportive and procedural information necessary to carry out the task. In the last experiment (Chapter 6) the procedural information was so compact, clear and orderly that the learners could easily memorize this information before they started practice and, apparently, the supportive information had a lower element interactivity than thought. In the following section some other possible explanations are given.

Information types

In the studies described in this thesis support is found for the just-in-time information presentation format (Chapter 4 and Chapter 6) and the 'reversed' format (Chapter 3 and Chapter 6). It appears that it does not matter which information is presented when, as long as both information types are not presented simultaneously. None of the studies revealed, as was expected, beneficial effects of the formats that presented both information types simultaneously before or during practice, so these formats will not be discussed further.

In the area of psychology and linguistics there is little consensus on terminology and how to define supportive information and procedural information (for an overview see Ummelen, 1996). This illustrates how difficult it is to make a clear distinction between both information types. In this thesis, supportive information is defined as information associated with schema construction; conceptual models of how a learning domain is organized. Procedural information is defined as information needed to achieve schema automation; task-specific rules that specify actions to achieve particular goals and the facts, principles and concepts that are needed to correctly apply the task-specific rule. A distinction between these information types was based on the desired exit-behavior (Chapters 3, 4, 5, and 6), a task analysis (Chapters 3, 4, 5, and 6), and cognitive load theory (Chapters, 4, 5, and 6). First, it was decided which of the sub skills should (ideally) be automated at the end of practice. The information prerequisite to accomplish this is labeled procedural and the remaining information supportive. Second, this classification is fine-tuned by a step-by-step task analysis. This assures that the procedural information only consists of information necessary to solve the problem and that the supportive information only consists of information necessary to understand the problem. Finally, in the domain of physics it was made sure that the procedural information only contained information that referred to the electrical circuit diagram. This information analysis leads to a distinction between procedural information and supportive information on task level. Issues of information content on a text level are not handled which may have interfered with the intended learning processes.

All information, procedural and supportive, was presented to the learners in a *descriptive* way. This could have influenced the way learners perceived the information and therefore, the learning processes involved in learning from this information. A piece of the procedural information about a voltmeter, for example, was stated as follows "a voltmeter is connected in parallel because electrons cannot pass through this meter" instead of "connect a voltmeter in parallel because electrons cannot pass through this meter". The latter formulation implies action and is probably better recognizable as a task-specific rule than the same information presented in a descriptive formulation. As a result, learning processes other than those intended - in this example elaboration instead of knowledge compilation - could have been elicited in the learners while interacting with the learning material. It is possible that learners in the 'reversed' format elaborated the procedural information before practice and retrieved it from their long-term memory when they needed it during practice. This possibly enabled them to perform as well as learners in the just-in-time format on the transfer test.

Instructional approach

Two important issues have to be addressed with regard to timing. First, a problem-centered approach is taken to just-in-time information presentation, that is the timing of information presentation was determined by the problem requirements. Learners received the necessary information just when they needed it to meet the problem requirements. A problem-centered approach was chosen to develop universal instructional design guidelines for the timing of information presentation regardless of individual differences. Moreover, a problem-centered approach bypasses the problem that novice learners who encounter a new complex problem are not likely to make use of all available information because they know too little of the skill and the underlying information. Nevertheless, it seems a bit contradictory that just-in-time information presentation does not allow for an active role of the learner. In the first, second and last study (Chapters 3, 4, and 6) learners were to a certain extent active in information consultation. In the statistics study (Chapter 3) learners were allowed to browse back and forth through the learning material and therefore could consult the information not only when the problem required it but also when they required it. The results of this study indicated that learners who received procedural information before practice and who had the supportive information available during practice achieved higher learning efficiency scores than the other learners. In the second study (Chapter 4), learners also were allowed to browse back and forth through the learning material and it was revealed that just-in-time information presentation elicited less browsing behavior than the information presentation in other formats. Unfortunately, this result could not be coupled to learning effectiveness or efficiency because of a bottoming out effect in the performance scores. In the last study (Chapter 6), learners receiving supportive information *during* practice were free to browse through this information which was displayed on three consecutive screens. This left some room for learners to consult this information when they felt that they needed it. In the 'supportive during, procedural before' format, this led to more effective and more efficient learning than in the format that presented both information types during practice. Hence, on the one hand, active consultation of the supportive information during practice seems to facilitate learning when the procedural information is presented before practice (Chapter 3 and 6) while just-in-time information presentation according to the problem requirements indeed seems to be just-in-time also from the learner's perspective (Chapter 4). However, based on these results it is possible that more or less unrestricted consulting of information on the learner's initiative could influence learning.

Second, as stated in the discussion of Chapter 2, the deductive vs. inductive approaches to information presentation may also play a role here. With regard to the supportive information, the information presentation formats used can be interpreted to be deductive or inductive. The supportive information represents the generalities and the different practice problems represent the instances (note that instances usually pertain to (worked) examples but here, the concept is extended to problems). Presenting supportive information before practice can be seen as deductive because in such a format the generalities (i.e., supportive information) are followed by instances (i.e., practice problems). Presenting supportive information during practice can be seen as inductive because in such a format the instances are accompanied by generalities. A deductive approach is best applied when the concept can be understood in abstract form (Evans, Homme & Glaser, 1962) while an inductive approach is best used when the concept is too difficult or too abstract for the learner (Fleming & Levie, 1979). It is possible that the concepts explained in the supportive information of the statistics study (Chapter 3) and the physics studies (Chapter 4, 5 and 6) were too abstract for the novice learners. This could explain the beneficial effects on learning of the 'reversed' format in the statistics study (Chapter 3) and the last physics study (Chapter 6).

Learner conceptions

A few remarks have to be made concerning practice and the design of the practice problems. First, in the statistics experiment (Chapter 3), 3 hours were reserved for practice in the electronic learning environment Mercator© and in the physics experiments (Chapter 4, 5, and 6) maximally 2 hours were reserved for practice and the test in the computer-based simulation environment Crocodile©. In other words learners were briefly exposed to unfamiliar learning environments in which the learning tasks or practice problems are presented in an unfamiliar way and they were expected to study and learn from them. This might have been too ambitious.

The participants in the experiments have spent seven or more years (in the statistics experiment more than 12 years) in traditional educational systems which make use of primarily classical, frontal, in-class education in which 'the theory' most of the time is followed by practice. It takes time for the learner to adapt to novel instructional material in innovative learning environments and the fact that time was very limited in the experiments described here may have influenced the results found.

Second, it is hard to design relatively simple problems that appeal equally to the supportive information and the procedural information. Learners presented with a problem primarily want to solve it, not understand it. For this purpose they need procedural information more than they need supportive. Usually, they do not think or realize that understanding the problem helps solving it. If the time-on-task on supportive information of the split attention experiment (M = 5.87, SD = 3.91; Chapter 5) are representative for the rest of the experiments, it is likely that such goal-driven learners did not attend to the supportive information as they were supposed to. This also could be reflected in the results of the studies presented here.

To conclude, although a number of alternative explanations for the results found in the different experiments were ruled out in the last experiment. Enough issues remain to be attended to in future research.

Future research

First, problems should be selected that require more complex procedural and supportive information. This will probably enlarge the differences between the just-in-time information presentation format and the 'reversed' format. The procedural information is then too complex to memorize when it is presented before practice and the supportive information is more likely to interfere with learning because of its high element interactivity when it is presented during practice. To achieve this goal meaningful problems should be used that are as realistic and authentic as possible given the experience of the learner. Furthermore, more attention should be paid to the specification of procedural and supportive information. To elicit the intended learning processes it seems important that learners recognize the procedural and supportive information as such. To accomplish this, a multidisciplinary approach should be chosen in which insights from psychology are combined with insights from linguistics.

Second, more research is necessary to establish the circumstances under which a particular approach to timing is better; that is timing based on problem requirements or timing based on learner demand. A comparison of these two approaches to the timing of information presentation is only fruitful when the learner is made aware that the supportive information is both available and as important as procedural information during problem solving to master a complex cognitive skill. A possible solution to this twofold problem is to physically emphasize the leaning material that is linked to the relevant supportive information (e.g., add meaningful headers) and to create problems that require the application of the same general knowledge in different problem situations (i.e., variability in problem formats).

Moreover, to get a firmer grip on the effects of a deductive or inductive approach to information presentation the entry level of the learners should be better established. In this way it can be determined if the learner will benefit more from an deductive or an inductive approach.

Finally, modern technologies offer interesting possibilities for future research to enhance the timing as well as the presentation of information. Instead of presenting information based on problem requirements or learner demand as discussed earlier, a gaze-based interface (i.e., that makes use of eye-movement tracking) offers the opportunity to present information based on visual attention. A learner's gaze determines when necessary information is presented. Just by looking at a particular element of, for example a computer-based simulation for a certain amount of time, relevant information is presented. Another interesting modern technology, augmented reality, could enhance the presentation of information. This technology makes it possible to blend computer-based information with reality, for example, through wearable displays. Augmented reality seems very promising as a means to avoid split attention. All learners have to do to view the computer-based information is to accommodate their eyes. Learners can be supported by augmented reality techniques during training in real-life situations. Both techniques seem very promising but require careful examination of the cognitive processes behind perception, attention and working memory.

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Appendix 1

Summary of the supportive and procedural information used in the study described in Chapter 3.

Supportive information	Procedural information
Task class 1: Frequency tables	
Description of a research question (with several examples).	Definition of analysis units (with different examples).
Explanation of variable analysis units, operationalization of variables (with examples).	Definition of a variable, a measurement value and classes (with an example).
Description of a measurement instrument and the process of data collection.	Definition of raw data.
Introduction of the structioning technique, 'frequency table'.	Definition of a frequency table (with an example). Definition of relative frequencies and the calculation procedure of relative frequencies (with an example). Description of setting up a frequency table inclusive relative frequencies (with an example).
Task class 2: Expected frequencies for one sample	
Description of the assumptions a researcher can have regarding a research question (with an example).	Definition of expected frequencies and the calculation procedure of expected frequencies for one sample (with an example).
Task class 3: Chi square test for one sample	
Introduction in which the question is raised: "How to decide whether differences between observations and expectations are significant or not?" A description of statistical testing, differences between parametrical and non-parametrical tests and the Chi-square test for one sample (with examples).	Definition of the quantity Chi-square.
Description of the interpretation of the value of Chi-square.	Calculation procedure of Chi-square (with an example). Introduction Chi-square table and an explanation of how to use it (with an example). Definition of the calculation procedure of the degrees of freedom, the critical values and how to interpret them (with a example).

Supportive information	Procedural information
Task class 4: Cross tables	
Introduction of the structuring technique, cross tables (with an example).	Definition of a cross table.
Description of the relations that can exist between variables (with an example). Introduction of the relative frequency. Explanation of the relevance of relative frequencies (with an example).	Calculation procedure of the relative frequency. Definition independent and dependent variables.
Task class 5: Expected frequencies for two or more samples	
Connotation in which is stressed that the expected frequencies for two or more samples are no percentages.	Definition and calculation procedure of expected frequencies for two or more samples (with an example).
Task class 6: Chi-square test for two or more samples	
Introduction in which the question is raised: "How to decide whether two variables are related or not?". A description of the Chi-square test for two or more samples. An explanation of how to interpret the value of Chi-square.	The formula of Chi-square for two or more samples (with an example). Description of how to use the Chi-square table (with an example). Definition of the calculation procedure of the degrees of freedom, the critical values and how to interpret them (with an example).

Appendix 2

Impression of the supportive and procedural information used in the study described in Chapter 4.

Supportive information	Procedural information
Circuits	
The definition and explanation of an electrical circuit analogous to a central heating system.	
General purpose and examples of a source of electrical potential (e.g., a battery).	 [Symbol of a source of electrical potential] Current flows from the positive pole of a battery to the negative pole.
General purpose of a switch.	
Definition of electrical potential.	 [Symbol of a voltmeter] Electrical potential is measured by a voltmeter. A voltmeter is connected in parallel because electrons cannot pass through this meter. Electrical potential is expressed in volts.
Definition of current.	 - [Symbol of an ammeter] An ammeter measures current. An ammeter is connected in series because this meter has no resistance. Current is expressed in amperes or mill amperes. A voltmeter and ammeter should always display a positive value.
Series circuits	
Definition of a series circuit.	The current in a series circuit is the same at all points in the circuit. The voltage is divided over the elements in the circuit. Electrons stop flowing through the circuit when the series connection is interrupted.
Parallel circuits	
Definition parallel circuit.	The current in a parallel connection is divided over the parallel branches. The voltage in a parallel circuit is the same in every branch. Interruption of one of the parallel branches has no consequences for the flow of electrons through the other branches.

Supportive information	Procedural information
Resistance	
Definition and explanation of resistance analogous to a central heating system and with car lights as an example.	
	The higher the resistance in a wire the more difficulty electrons have flowing through that wire.
Resistance in series circuits	
	The more resistors connected in series, the higher the resistance in the circuit and the lower the current with a constant voltage.
Resistance in parallel circuits	
	The more resistors connected in parallel, the lower the total resistance and the more current the source of electrical potential delivers.

Summary

In this thesis a just-in-time information presentation model is described that is anchored in the 4C/ID model. Both models are consistent with cognitive load theory, which provides instructional design guidelines that take the limitation of working memory into account.

The just-in-time information presentation model, outlined in Chapter 2, advocates that supportive information is best presented before practice. This allows the learner to connect new information to already existing, relevant cognitive structures (i.e., elaboration), which leads to the construction of general and abstract schemata that are useful in solving unfamiliar aspects of new problems (i.e., transfer). Procedural information is best presented during practice. This allows the learner to embed the information that is active in working memory in highly domain-specific representations (i.e., knowledge compilation) followed by strengthening, whereby schemata become more and more automated each time they are successfully applied. These automated schemata are useful in solving familiar aspects of new problems. According to cognitive load theory supportive information is best presented before practice because of its high element interactivity. The intrinsic cognitive load that arises from simultaneously processing supportive information and carrying out practice tasks is likely to exceed working memory capacity. To avoid temporal and/or spatial split attention it is best to present procedural information during practice. Separation of the procedural information from the practice tasks in time or space increases the extraneous cognitive load; as a result, valuable working memory capacity has to be allocated to processes irrelevant for learning such as, mentally integrating different sources of information.

Chapter 3 describes a study, in which four information presentation formats were compared using practice problems in the domain of statistics (i.e., theory and application of Chi square tests) . The first format presented supportive information and procedural information simultaneously before practice. The second format, the just-in-time information presentation format, presented supportive information before practice and procedural information during practice. The third format presented supportive information and procedural information simultaneously during practice and, finally, the fourth format presented supportive information during practice and procedural information before practice. It was assumed that presenting supportive information before practice and procedural during practice would facilitate the construction and automation of adequate schemata. This should be manifested in more effective (i.e., high test performance) and efficient learning (i.e., low investment of mental effort and high test performance). This hypothesis was not confirmed. No differences in effectiveness of the information presentation formats were found. It was revealed that presentation of supportive information during practice and procedural before practice was more efficient than simultaneous presentation of supportive and procedural before practice. Apparently, learning was most efficient in a meaningful context, which was provided by the supportive

information presented during practice. This necessity of a meaningful context was explained by the fact that it was rather difficult to describe the task in terms of independent pieces of knowledge. It was attempted to present a well rounded statistical practice task, but every topic in statistics elaborates on other topics and therefore it was very difficult to design strictly limited practice tasks. Therefore, the study in Chapter 4 is carried out in a domain that allows for well rounded learning tasks.

In Chapter 4 the same four information presentation formats are compared using practice problems in the domain of physics (i.e., troubleshooting electrical circuits). Again it was assumed that presentation of supportive information before practice and procedural during practice would lead to more effective and more efficient learning. Although, no differences were found in effectiveness and efficiency between the four formats, the information search behavior of learners, who received supportive information before practice and procedural information during practice, revealed that these learners searched substantially less for relevant information than learners in the other formats. This indicates that information presentation according to this format indeed was just in time. Nevertheless, this did not influence the effectiveness or efficiency of the material. It was hypothesized that this was due to the necessity of mentally integrating a text (i.e., the procedural information) and a diagram (i.e., the electrical circuit) at cost of processes relevant for learning. The study in Chapter 5 was set up to find out if these mental integration processes did influence the learning processes.

The study in Chapter 5 compared two information presentation formats in the domain of physics. In both formats the supportive information was presented before practice and the procedural information during practice. However, in one of the formats the procedural information was presented next to the electrical circuit as explanatory text while in the other format this information was integrated in the circuit. It was assumed that integrating the procedural information in the circuit would spare the learners the mental integration of these information sources, which is expected to be, beneficial for learning (i.e., manifested in test performance). This study revealed that presenting the procedural information integrated in the circuit led to better transfer test performance than presenting this information next to the circuit. It was concluded that the necessity of mentally integrating a text and a diagram to some extend hampered learning and should be avoided in future research.

In Chapter 6 a replication of the study in Chapter 4 is described, except that the procedural information was presented integrated in the electrical circuit during practice. So, four information presentation formats (i.e., supportive information, before or during practice, combined with procedural information, before or (integrated) during practice) were compared. Again, superiority of the 'just-in-time' format over the other formats was expected which would be manifested in more effective (i.e., high test performance) and more efficient (i.e., low investment of mental effort and high test performance) learning. This hypothesis was supported in this study. Learners who received supportive information before practice and procedural during practice obtained higher transfer test and efficiency scores than the learners who received both information types simultaneously before or during practice.

To conclude, after some 'fine-tuning', support is found for the just-in-time information presentation model. Conform the hypotheses, the presentation of supportive information before practice and procedural information during practice leads to more effective and efficient learning. Unexpectedly, the presentation of supportive information during practice and procedural information before practice also leads to more effective and efficient learning.

A few alternative explanations were given to explain this unexpected findings which resulted in some directions for future research. With regard to the content of information, issues on text level might have influenced the learning processes involved in complex skill acquisition. All information, procedural and supportive, was presented to the learners in a descriptive way. This could have influenced the way learners perceived the procedural information and therefore, the learning processes involved in learning from this information. To elicit the intended learning processes it seems important that learners recognize the procedural and supportive information as such. To accomplish this in future research a multidisciplinary approach should be chosen to analyze the information in which insights from psychology are combined with insights from linguistics.

With regard to timing, some inconclusive results were found concerning the extend to which learners were allowed to browse through the information and so could control the information presentation. In spite of findings that confirm that just-in-time information presentation is just in time, information presentation based on learner demand sometimes seems to facilitate learning. An interesting direction for future research is to compare timing of information presentation based on problem requirements and timing of information presentation based on learner demand. Moreover, modern technologies allow for information presentation based on visual attention. In a gaze-based interface information is presented just by looking at a particular element of, for example, a computer based-simulation. Using this and other promising technologies, such as augmented reality are particularly important for the design of problem solving instruction because more and more educational approaches stress the importance of meaningful problem solving in realistic learning tasks.

Samenvatting

Dit proefschrift beschrijft een 'just-in-time' informatie presentatie model gebaseerd op het 4C/ID model. Beide modellen zijn verenigbaar met de cognitieve belasting theorie waaruit richtlijnen voor instructieontwerp zijn afgeleid die rekening houden met de limitaties van het werkgeheugen.

Volgens het 'just-in-time' informatie presentatie model, beschreven in Hoofdstuk 2, is het beter ondersteunende informatie voor het oefenen te presenteren dan tijdens het oefenen. Op deze manier krijgen lerenden de kans de nieuwe informatie the integreren met relevante cognitieve structuren die reeds gevormd zijn. Dit proces wordt elaboratie genoemd. Het elaboreren van de ondersteunende informatie leidt tot de constructie van algemene en abstracte schemata die van pas komen bij het oplossen van onbekende aspecten van nieuwe problemen (transfer). Procedurele informatie daarentegen kan beter gepresenteerd worden tijdens het oefenen in plaats van voor het oefenen. Op deze manier worden lerenden in staat gesteld de informatie die op dat moment actief in het werkgeheugen te vatten in sterk domeinspecifieke representaties. Dit proces wordt kennis compilatie genoemd. De schemata die zo ontstaan worden iedere keer dat ze succesvol worden toegepast versterkt (strengthening) waardoor ze op een gegeven moment geautomatiseerd zijn. Deze geautomatiseerde schemata komen van pas bij het oplossen van bekende aspecten van nieuwe problemen.

Volgens de cognitieve belasting theorie is het ook beter de ondersteunende informatie voor het oefenen aan te bieden en de procedurele tijdens het oefenen. Ondersteunende informatie heeft doorgaans een hoge element interactiviteit. De intrinsieke cognitieve belasting die ontstaat door het tegelijkertijd oplossen van de oefenproblemen en het verwerken van de ondersteunende informatie zal waarschijnlijk het werkgeheugen overbelasten. Daarom is het beter deze informatie voor het oefenen aan te bieden zodat lerenden alle beschikbare werkgeheugencapaciteit vrij hebben voor het verwerken van de ondersteunende informatie. Het scheiden van de procedurele informatie en de oefenproblemen in tijd of ruimte verhoogt de irrelevante cognitieve belasting, waardoor waardevolle werkgeheugencapaciteit moet worden aangewend voor processen irrelevant voor leren, zoals, mentale integratie processen. Teneinde te voorkomen dat lerenden hun aandacht over verschillende noodzakelijke informatiebronnen moeten verdelen, hetzij in tijd, hetzij in ruimte, is het beter de procedurele informatie tijdens het oefenen aan te bieden.

Hoofdstuk 3 beschrijft een studie waarin vier informatie presentatie formats worden vergeleken in het domein van statistiek (de theorie en toepassing van Chi-kwadraat toetsen). In het eerste format worden de ondersteunende informatie en de procedurele informatie beide voor het oefenen aangeboden. Het tweede format, het 'just-in-time' informatie presentatie format, presenteert de ondersteunende informatie voor het oefenen en de procedurele informatie tijdens het oefenen. In het derde format worden zowel de ondersteunende informatie als de procedurele informatie tijdens het oefenen aangeboden en, tot slot, in het vierde format wordt de ondersteunende informatie tijdens het oefenen aangeboden en de procedurele informatie voor het oefenen. Aangenomen werd dat het presenteren van de ondersteunende informatie voor het oefenen en het presenteren van procedurele informatie tijdens het oefenen positieve effecten zou hebben op het construeren en automatiseren van adequate schemata. Dit zou zich moeten uitdrukken in effectiever (d.w.z. een hogere test prestatie) en efficiënter leren (d.w.z. een hogere test prestatie met een lagere mentale inspanning). Deze verwachting kwam niet uit. Er werden geen verschillen gevonden tussen de formats met betrekking tot effectiviteit. Er kwam naar voren dat het aanbieden van ondersteunende informatie tijdens het oefenen en procedurele voor het oefenen in ieder geval efficiënter was dan het tegelijkertijd aanbieden van beide typen informatie voor het oefenen. Blijkbaar werd het leren vergemakkelijkt door een betekenisvolle context die geschapen werd door het aanbieden van ondersteunende informatie tijdens het oefenen. In dit onderzoek was het moeilijk de oefenproblemen te beschrijven in losstaande stukjes kennis en informatie. Alle onderwerpen in de statistiek hebben wel iets met elkaar te maken of bouwen op elkaar voort. Het was moeilijk strikt gelimiteerde problemen te formuleren en misschien vanwege deze onderlinge samenhang begrepen lerenden de taken beter wanneer ze in een context werden geplaatst. Teneinde dit probleem te omzeilen is er, in de studie die in Hoofdstuk 4 wordt beschreven, gekozen voor een ander domein waarin het wel mogelijk was gelimiteerde, afgeronde oefenproblemen te definiëren.

Hoofdstuk 4 beschrijft een studie die dezelfde vier informatie presentatie formats met elkaar vergelijkt maar dan met problemen in het domein van natuurkunde (nl., troubleshooten in elektrische schakelingen). Weer werd aangenomen dat het presenteren van ondersteunende informatie voor het oefenen en procedurele informatie tijdens het oefenen zou leiden tot effectiever en efficiënter leren. Hoewel er tussen de formats geen verschillen werden gevonden in effectiviteit en efficiëntie, wees het zoekgedrag van lerenden uit dat diegenen die de ondersteunende informatie voor het oefenen ontvingen en de procedurele tijdens het oefenen veel minder door het leermateriaal bladerden dan de andere lerenden. Het lijkt erop dat informatie presentatie volgens het 'just-in-time' format inderdaad 'just-in-time' wás. Helaas was dit niet van invloed op de effectiviteit en efficiëntie van het leermateriaal. Een mogelijke oorzaak voor deze bevindingen zou kunnen zijn dat het nog steeds noodzakelijk was de procedurele informatie en de elektrische schakeling mentaal te integreren omdat deze, weliswaar niet gescheiden in tijd maar gescheiden in ruimte werden aangeboden. Het onderzoek in Hoofdstuk 5 is erop gericht uit te vinden of deze mentale integratie processen het leerproces inderdaad negatief beïnvloedden.

Hoofdstuk 5 beschrijft een studie die twee informatie presentatie formats vergelijkt in het natuurkunde domein. In beide formats wordt de ondersteunende informatie voor het oefenen gepresenteerd en de procedurele informatie tijdens het oefenen. Het enige verschil is dat in het ene format de procedurele informatie naast de elektrische schakeling wordt gepresenteerd terwijl in het andere format diezelfde informatie en de schakeling worden geïntegreerd. Aangenomen werd dat het integreren van de procedurele informatie en de elektrische schakeling mentale integratie processen zal voorkomen wat zal leiden tot effectiever leren (d.w.z. hogere test scores). In deze studie werd gevonden dat een geïntegreerde presentatie van de procedurele informatie en de elektrische schakeling leidt tot een betere prestatie op de transfer test dan een gescheiden presentatie van de procedurele informatie en de elektrische schakeling. Er werd geconcludeerd dat de mentale integratie processen waarschijnlijk inderdaad ten koste gaan van leerprocessen en dat de noodzakelijkheid van mentale integratie in toekomstig onderzoek beter vermeden kan worden.

In Hoofdstuk 6 wordt een replicatie van de studie uit Hoofdstuk 4 beschreven met als verschil dat de procedurele informatie en de schakeling tijdens het oefenen geïntegreerd worden. Vier informatie presentatie formats (d.w.z. ondersteunende informatie, gepresenteerd voor of tijdens het oefenen, in combinatie met, procedurele informatie, gepresenteerd voor of geïntegreerd, tijdens het oefenen) worden vergeleken. Superioriteit van het 'just-in-time' format wordt weer verondersteld. Dit zou tot uitdrukking moeten komen in effectiever (d.w.z. een hogere test prestatie) en efficiënter (d.w.z. een hogere test prestatie met een lagere mentale inspanning) leren. Deze aanname werd ondersteund in dit onderzoek. Lerenden die de ondersteunende informatie voor het oefenen kregen aangeboden en de procedurele tijdens presteerden beter op de transfer test en haalden hogere efficiëntie scores dan lerenden die beide informatie typen voor of tijdens het oefenen kregen aangeboden.

Concluderend, na wat fine-tuning wordt er ondersteuning gevonden voor het 'just-in-time' informatie presentatie model. Volgens de aannamen leidt het presenteren van ondersteunende informatie voor het oefenen en het presenteren van procedurele informatie tijdens het oefenen tot effectiever en efficiënter leren. Onverwacht bleek echter de presentatie van ondersteunende informatie tijdens het oefenen en het presenteren van procedurele informatie voor het oefenen ook tot effectiever en efficiënter leren te leiden.

Een aantal alternatieve verklaringen zijn naar voren gebracht teneinde dit onverwachte resultaat te verklaren en op basis hiervan zijn een aantal aanwijzingen voor toekomstig onderzoek geformuleerd. De informatie analyse in de verschillende experimenten bleef beperkt tot taakniveau. Het is mogelijk dat issues op tekstniveau een rol hebben gespeeld bij de leerprocessen die leiden tot het verwerven van een complexe cognitieve vaardigheid. Alle informatie, ondersteunend en procedureel, is op een beschrijvende manier aan de lerenden gepresenteerd. Het is mogelijk dat dit de manier waarop de lerenden de informatie hebben gepercipieerd heeft beïnvloed en vervolgens de leerprocessen waarop deze informatie betrekking heeft. Teneinde de juiste leerprocessen te eliciteren lijkt het belangrijk de informatie zo te formuleren dat er voor de lerenden geen twijfel over kan bestaan hoe deze informatie te interpreteren. Het is raadzaam in toekomstig onderzoek psychologische inzichten te combineren met inzichten uit de tekstwetenschap teneinde een beter onderscheid te maken tussen ondersteunende en procedurele informatie.

Het onderzoek laat een aantal tegenstrijdige resultaten zien met betrekking tot de mate waarin de lerenden vrij zijn geweest in het consulteren van de ondersteunende informatie. In tegenstelling tot de bevindingen die bevestigen dat het 'just-in-time' presenteren van informatie inderdaad 'just-in-time' was lijkt het alsof het presenteren van informatie op basis van acties van de lerende een faciliterend effect heeft op leren. Een interessante richting voor toekomstig onderzoek zou kunnen zijn informatie presentatie afhankelijk van taakvereisten te vergelijken met informatie presentatie afhankelijk van acties van de lerende. Bovendien, stellen moderne technologieën ons in staat informatie te presenteren afhankelijk van visuele aandacht. In een 'gaze-based' interface, bijvoorbeeld, is het mogelijk informatie te presenteren alleen door te kijken naar een specifiek element op het computerscherm. Het gebruik van deze en innovatieve technologieën zoals 'augmented reality' zijn in het bijzonder belangrijk voor het ontwerpen van instructie want steeds meer educatieve benaderingen benadrukken de importantie van het oplossen van betekenisvolle problemen in authentieke leertaken.