Validation of a theory about functions and effects of embedded support devices in distance education learning materials

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In this contribution a theoretical model is explored and validated that describes and explains learning based on learning materials where the basic content is enriched with embedded support devices. Embedded support devices (ESD) are elaborations of the basic content of a course, intended to support students learning in a distance educational context. Examples are: questions with feedback, advance organizers and study guidelines. The model represents the interaction of a large set of variables and processes and has been tested using a variety of research studies, each focusing on specific interrelations and/or variables.

The research results support the positive impact of embedded support devices in written learning materials on study outcome. Furthermore the results indicate the impact of individual variables, such as prior knowledge and attitude towards computers. These variables influence the way students process the learning materials and/or use the task environment and have an interaction effect on study outcomes.

Introduction

One of the basic characteristics of learning materials in distance education contexts, is the provision of embedded support devices (ESD) that have been added to the domain specific knowledge base (basic content). These devices comprise questions, content pages, illustrations, examples, activities, tests, examples, schemes, cases, etc. Given the large amount of ESD in learning materials, they can be clustered considering hypothetical basic functions and effects as suggested by Valcke, Martens, Poelmans and Daal (1993):

- **orienting ESD**: learning objectives, references to other learning materials, references to required prior knowledge, etc.
- **processing ESD**: indexes, additional learning materials, advance organizers, illustrations, glossaries, introductions, study advice, summaries, tables, examples, etc.
- **testing ESD**: self-test items, exercise items, answers and feedback.

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The support devices can make up to 45% of the learning materials. Learning materials developers design their materials, building on expectations about the hypothetical functions and effects of ESD. These devices form the base of “course models” (learning unit model, text book, working book model, etc.) and are aspects that are integrated into templates to design the materials. The learning materials, discussed in this article are either presented in printed format (printed learning environment PLE) or presented on a computer screen (interactive learning environment ILE).

The weak theoretical base for ESD

ESD have been the subject of a vast body of research since printed texts play a major role in learning materials. In the seventies and eighties some major reviews of this research have been elaborated (cf. Alesandrini, 1984; Barnes & Clawson, 1975; Hartley & Davies, 1976; MacDonald-Ross, 1977; Rothkopf, 1970; Waller, 1979; etc.). This sounds to be in contrast with our statement: there is no theoretical base nor a clearcut empirical base to found the use of ESD. An analysis of the nature and design of this research body is needed to understand this statement:

- Earlier research, was rarely aimed at distance education or focused on independent learning.
- Research set-ups did not reflect natural learning contexts and were mainly set up in isolated lab-like settings (Lockwood, 1992).
- This research focused on single, isolated support devices in contrast to educational practice where the complex mixture of devices supports independent learning.
- Researchers focus especially on “product” effects of the use of embedded support devices; for instance study outcomes or posttest scores. As a consequence, researchers hardly know what learners actually do when they are presented with text-embedded support (cf. Driscoll, Moalllem, Dick, & Kirby, 1994). It is for instance not sure whether students use or know how to use these support facilities (Winne, 1983). Despite the growth of distance education, little systematic knowledge is available concerning the ways in which students use the distance teaching materials provided to them (Clyde & Crowther, 1983; Lowijck & Simons, 1991; Marland, Patching, Putt, & Putt, 1990; Schuemer, 1993). Students working at a distance with printed learning materials have complete veto power over learning (Rothkopf, 1970).
- Therefore, researchers sometimes train students to use ESD in a certain way. A similar approach is adopted by Bernard (1990) and De Jong and Simons (1988).
- The question is not only whether students use the embedded support devices or whether they know how to use them, but also whether they need the support provided. Waller (1979) mentions e.g., different user objectives when dealing with study texts: entertainment, recapitulation/reviewing, browsing, studying in depth, searching for a particular item. Each user perspective affects the potential effects/functions of ESD. Most ESD are designed to evoke some kind of behaviour of students. Wade and Trahen (1989, p. 40) however state: “(...) despite their popularity, there is no consistent empirical evidence that these techniques are any more effective than more passive methods of reading-only or repetitive reading...”.
- Even when – from a theoretical point of view – functions and effects are assigned to specific ESD, there is the problem Meyer and Watson (1991) and Schuemir (1993) signal: practical implications derived from this are often not useful.

Towards a theoretical model

In our opinion it is crucial to develop a theoretical model that describes and explains how
students learn from learning materials, considering the central role of ESD, but also appraising other key processes and variables. Figure 1 represents our theoretical model. This model pictures the interaction between variables and processes:

- A key variable is constituted by the learning materials themselves consisting of basic content enhanced with ESD.
- The materials have been developed to influence cognitive aptitudes such as the learning process.
- Moreover, since the learning materials are text-based, also the cognitive aptitude "reading comprehension" is influenced. The reading process is expected to interact with the learning process.
- Non-cognitive aptitudes, such as motivation and attitudes are expected to interact.
- Variables in the individual learner, such as prior knowledge, reading comprehension level, educational level, etc. are expected to influence directly or indirectly the learning process.
- The specific delivery mode of the learning materials (ILE or PLE) determines the task environment.

![Figure 1. A model to describe and explain learning based on learning materials enriched with embedded support devices.](image)

This article is about the validation of the model presented. We will focus on the possible functions and effects of ESD, on the intervening influence of individual variables (student aptitudes) and on the relation between approaching learning materials with ESD and study results. First we will elaborate in short the key processes and variables in our model as depicted in Figure 1.

**Key variables and processes**

*The learning process.* The theory of cognitive functioning of Sternberg (1986, 1988) is used as a base to approach the learning process. Cognitive functioning is – according to Sternberg – described with the concept "components". A component is "an elementary infor-
mation process that operates upon internal representations of objects or symbols" (1986, p. 225). Sternberg distinguishes three groups of components:

- Metacognitive components (MC): Metacognitive components control, evaluate and plan the activities of the other components. They are executive processes.
- Performance components (PC): Performance components are those processes that operate when a task is actually executed. The PC are grouped as stages when executing a task.
- Knowledge acquisition components (KAC): The knowledge acquisition components are involved when new information is getting integrated in already available information in memory. This integration process implies encoding, combining and comparing.

At a theoretical level, the theory of Sternberg has been used to derive functions and effects that can be assigned to specific ESD; e.g., "questions" activate the knowledge acquisition components. In a specific research set-up we will test these hypothetical theoretical functions and effects.

The reading process. In the literature, the theoretical view on discourse comprehension of Kintsch and van Dijk (1978) is dominant in theory and research about the nature of the reading process. In short, their approach can be described as follows: "Discourse comprehension, from the viewpoint of a computational theory, involves constructing a representation of a discourse upon which various computations can be performed, the outcomes of which are commonly taken as evidence for comprehension. Thus, after comprehending a text, one might reasonably expect to be able to answer questions about it, recall or summarize it, verify statements of it, paraphrase it, and so on." (Kintsch, 1988, p. 163). To date this view on discourse comprehension remains the most widespread and accepted view (cf. Rayner & Pollatsek, 1989; Britton & Gülgöz, 1991; van Oostendorp & Perek, 1991).

Reading (discourse comprehension) and learning are closely interrelated as already the Kintsch-text suggests: learning can be seen as a special form of reading with the intention to understand and/or reproduce the text. As a consequence reading ability does correlate with school achievement and general intelligence indices (Rost, 1989). Individual differences in reading ability are therefore expected to be an important interaction process and variable in the learning process (Oostendorp & Perek, 1991). When validating the model, interaction effects of reading comprehension measures will be considered.

The task environment. In our theoretical model, the learning materials are presented within the context of a task environment. It was stated that the specific delivery mode of the learning materials determines the task environment. The particular learning environment can be very different in a distance education context. In traditional distance education approaches, the materials are especially delivered in printed form. In the seventies there was a growing tendency to add audio-visual components. Since the eighties, the computer has enriched the learning environment. Nowadays multi-media and electronic communication media influence the task environment.

In our model, we focus on the way text, enhanced with ESD, is delivered. Considering the context of the Open University (OU) of the Netherlands, two main delivery modes are researched: printed learning environments where the materials are printed in textbooks, working books, etc. versus interactive learning environments where the learning materials are delivered by making use of computers. The delivery mode is expected to influence to a large extent the learning process of students. The degree of interactivity with the learning materials is for instance completely different. In electronic learning environments, students can actively manipulate or select text parts, browse through the materials, etc. This is expected to be of particular importance in relation to the use of ESD.

Next to the delivery mode, also the way ESD are presented is important: are they embedded into the basic content of the learning materials and as a consequence hardly discernable, or are they clearly discernable and put next to the basic content?
The theoretical model does not suggest that delivery mode, the degree of interactivity and the degree of discernability have a straightforward impact on study outcome. The interrelation between the processes and variables in the model also indicates that the effectiveness of a particular task environment can depend on individual variables and is to be related to the cognitive and non-cognitive aptitudes.

*Individual variables.* The model stresses the importance of individual variables in relation to the other processes and variables. It is hypothesized that differences in students influence the use and effectiveness of ESD. This suggests that the optimal choice and/or combination of ESD could be different for different students and might depend on for instance prior knowledge level, learning style. The importance of the individual variables may not be underestimated in a distance education context. The student population of the Dutch Open university is for instance very heterogeneous. Especially the "open" character of the education paradigm invokes a variety of student needs and demands that have to be met. In this section we will introduce a set of potentially relevant individual variables.

Only a subset will be manipulated in our research set-up to validate the theoretical model. The variables discussed originate from widely different theoretical positions or frames of reference.

There is a comprehensive theoretical base to found the impact of *prior knowledge* on the acquisition of new knowledge (e.g., Ausubel, 1968; Mayer, 1979; Reigeluth & Stein, 1983). Prior knowledge at the beginning of a study is an important variable to predict students progress and study results. Not only does prior knowledge reflect the availability of relevant skills and knowledge in students, but it can also reflect general ability or interest in the subject of a course (Tobias, 1994). Dochy (1992) has tried – in a distance education context – to use prior knowledge state tests to orient the learning process. He approached prior knowledge as a multi-dimensional concept and distinguished two major educational-psychological dimensions in prior knowledge: a behavioral dimension (knowing – insight – application) and a knowledge dimension (facts, concepts, relations, structures, methods). These knowledge profile dimensions have been empirically validated and are helpful to differentiate between groups (Dochy & Valcke, 1992; Keeves, 1988).

*Learning style* is a multi-componential construct, containing several cognitive style components. Van Rijswijk and Vermunt (1987 a,b,c) and Vermunt (1992) distinguish three learning regulation styles: external regulation, self regulation and no regulation. They describe four types of learning style. Regarding the concept of learning style, there are many relations with ability, aptitudes, strategy and motivation (cf. Kii, 1994; De Diana & van der Heiden, 1994). As a result the construct validity of the concept learning style is sometimes questioned (Corno & Snow, 1986). The use of computers as learning medium makes it possible to monitor what students are actually doing while studying. For instance it can be monitored by means of log files what support devices are actually used by students, thus providing information about some aspects of students' learning styles.

In literature, *field dependence/field independence* is put forward as an important individual variable. According to Kii (1994) it is the most important independent dimensions of cognitive style, different from intelligence and creativity. Individuals classified as field independent are able to overcome the embedding context of a field and tend to perceive certain parts of the field as discrete from the surroundings. Individuals labelled as field dependent are guided by the field as a whole and are influenced by the field factors and complexity of the surrounding visual area. They depend on external cues to make judgements. It is found that this variable affects educational achievement.

When discussing the task environment, we already indicated the importance of individual variables to explain the effective use of learning environments or the impact of particular delivery modes. The individual variable “*preference for a perceptual mode*” can be directly related to the latter. Preference for a “verbal” or “visual” representation differentiates between students: students using sequential methods of processing information rely on verbal representations; students adopting parallel processing methods rely rather on visual representations.
Not surprisingly, individuals classified as visual are better than their verbal counterparts in the recall of highly visual material (Kini, 1994).

*Metacognition* is used to describe the conscious steps a learner has to take to direct and monitor his or her learning activities. Many research has shown that students differ in metacognitive abilities (e.g., Elen, 1992). It is not clear to what extent this is related to the other aptitudes that are indicated in this section (e.g., motivation, prior knowledge, learning style). Moreover, since it is difficult to make a clear distinction between metacognition and behaviours that are related to learning style or cognitive style we will not treat metacognition as a separate individual variable aptitude.

The “open” nature of the Open university educational provisions has as a consequence that students can start studying at university level without specific entrance requirements. *Educational level* is therefore an important variable influencing the learning process. Embedded support devices can play a major role in this context since these devices give students help in getting access to the learning materials, help to process the knowledge base and help students to test their mastery. Reviewing the literature, the impact of educational level is still not clear. De Bruijn states for instance (1993, p. 12): “(...) it appeared that the relatively high educated adults had a stronger need for abstract conceptualisation, reflective observation, and active experimentation than the less educated subjects”. Also Daal (1991) found in her study with OU students a positive relation between educational level and study progress. But, Poelmans & Janssen (1994) signal that there is only a weak relationship between educational level and drop out in distance education.

Another consequence of the open character of the Dutch Open university approach, is the difference in *age levels* of students (18 to 82 years). One can question whether this influences the learning process and the way students work in specific learning environments.

The Dutch Open university deploys an active policy to promote emancipation of *female students* (gender). For instance, when designing OU-courses, the course developers have to indicate explicitly what they will do to take the gender variable into account. In the literature explicit reference is made to differences in learning between male and female students. De Bruijn (1994, p. 12) found: “(...) it appeared that the female subjects had a stronger need for concrete experience and active experimentation, while the male subjects’ primary need was for abstract conceptualisation.” Lang, Gaynor, Erwin and Williams add to this (1994, p. 20): “Intrinsic motivation may prove an important self-management issue for females more than for males, whereas males’ self-management may be linked to a more broadly-based satisfaction with their academic life”. Research at the OU of the Netherlands revealed that female students tend to do more and in line they were instructed to do. They also tend to make more use of study guidance facilities in distance education (Poelmans & Janssen, 1994). The same authors point at the interrelation between gender and work load: women have more problems in saving enough time from household activities for study time than male students.

To the former list of individual variables that might play a role in the way students learn and use learning materials in a distance education setting, a long list of other variables discussed by a variety of authors can be added (Clyde & Crowther, 1983; Corno & Snow, 1986; De Bruijn, 1993; Elen, 1992; Holmberg, 1986; Kember & Gow, 1989; Marland et al., 1990; Pask, 1976; Van Joolingen, 1993; Vermunt, 1986; Willems, 1989). This list indicates how difficult it is to set up research in educational contexts. Control of all these variables, especially when researching in ecologically valid contexts is hardly possible:

- intelligence
- course-focused versus interest-focused;
- holist learners, serialist and versatile learners;
- deep-level processing versus surface-level processing;
- deep level, concrete and stepwise processing;
- student conceptions about the study process;
- experienced versus novice students;
Functions and Effects of Embedded Support Devices in Learning Materials

- need for concrete experience versus need for abstract conceptualisation;
- cognitive complexity versus simplicity (the degree of differentiation or hierarchic integration);
- reflectivity versus impulsivity;
- willingness to take risks in pursuing goals;
- convergence versus divergence (the tendency to converge toward or diverge from the obvious in hypothesis generation);
- intrinsic versus extrinsic motivation;
- learning intentions (performance versus pleasure in learning);
- experimenter – theorist

Processes and variables in action

In the previous sections we discussed a large number of individual variables that possibly affect the learning process. These variables are expected to interact with cognitive and non-cognitive processes as supported by a specific task environment. We also already stressed the importance of the task environment (e.g., ESD, delivery mode) in dealing with individual variables to support the learning process.

Considering the importance we attach to these individual variables and especially the fact that we suggest that specific learning environments are expected to be better suited for specific students, our research fits into the research tradition called Aptitude-Treatment-Interaction (ATI). In ATI-research (Snow 1992; Cronbach & Snow, 1977) the relation between student abilities or characteristics (Aptitudes), educational settings or learning methods (Treatment) and learning outcomes is investigated. Crucial is the assumption that the effects of treatments are related to aptitudes (Boekaerts & Simons, 1993). ATI-research outcomes often contradict each other, results often cannot be replicated or are ambiguous (e.g., Simons, 1982; Crombag, 1979; Thijsen & Span, 1985). This is in part due to the vague nature of the concept “aptitude” that leads to an almost infinite collection of concepts, methods, etc. that might affect students’ academic performance (Long et al., 1994).

In the context of this article a further elaboration of the ATI-paradigm is not relevant. The focus on the validation of our theoretical model puts forward the validation of other interrelations and effects, next to the ATI-prepositions. Moreover, our focus on the exploration of potential interrelations within the model does as yet not imply that students are assigned to specific treatment conditions on the basis of individual variable measures to attain a specific study outcome.

From theory to research

The elaboration of the theoretical base for this study and especially the review of ESD-related research resulted, next to a theoretical model, in a set of guidelines to direct more effective and efficient research. We summarize these guidelines as far as they have been incorporated into our consecutive research designs:

- Research the actual learning behaviour in relation to study outcomes. Often there is a weak relation between behaviour as measured by aptitude tests and the behaviour required for achieving learning outcomes (Boekaerts & Simons, 1993).
- Assess time investment and learner engagement as potential co-variables (cf. Como & Snow, 1986).
- Check particularities of the study process that might reflect compensation for less suited learning conditions (e.g., studying longer and with more effort).
- Choose for a high ecological validity of the research setting.
- Since aptitudes are interrelated, multivariate analysis techniques should be used to analyze the research data. The statistical techniques should also be helpful to unravel the influence of interaction and co-variables.
- Design different experimental conditions so that they can lead to differences in outcomes. Often conditions in research are rather similar (cf. Crombag, 1979).
- Use basic concepts to describe individual differences. The concept of "reading comprehension" for instance is more basic than the concept "learning style".
- Differences between experimental treatments should be easy to interpret and generalizable.
- Make use of on line measurements to grasp what students are actually doing while studying.

Review of the validation research: printed learning environments

The findings of four research projects are reported here that are helpful to validate or explore aspects of our theoretical model. After a brief review of each set-up and the results, a conclusion is drawn in relation to the model. These four researches have in common that they build on printed learning environments when focusing on the functions and effects of ESD in the learning materials. In a next section we add the results of research with interactive learning environments. We repeat that the set-up, analysis procedure and results section in relation to each research project will only be discussed in brief. We refer to specific research reports for a more elaborated presentation.

Research with the interview method. In a first research set-up twenty-five law students of the OU of the Netherlands were interviewed in detail about the way they study OU-learning materials (Valcke, Martens, Poelmans, & Daal, 1993).

The research results indicated that students use ESD to a high extent (varying from 60% to 100%) and highly appreciate them. A distinction can be made referring to aspects of study regulation: surface level versus deep level studying (Marton & Säljö, 1984). Students who use ESD to a high extent and at a deep level, attain significantly higher study outcomes. Studying at a surface level implies "only" reading and learning by heart; deep level learning puts emphasis on comprehension. It was found that especially higher educated female students tend to make more use of ESD. The very high general use of ESD made it difficult to find interactions between use of ESD, student aptitudes and effects of use of ESD.

This research set-up also checked whether students assign functions and effects to the embedded support devices in line with functions and effects as derived from our theory. The results are clear: students assign personal functions and effects to embedded support devices. Moreover, they approach them differently according to the phase in their learning process. The results of this study indicate the high importance students attach to the embedded support devices. They also indicate the importance of individual variables in our model where they affect the use of embedded supported devices. But, it remains unclear how ESD affect the learning process in terms of components of cognitive functioning.

Research with questionnaire method. At the OU of the Netherlands, the department OID sets up yearly an evaluative study involving about 2000 students, based on the use of questionnaires. Students taking courses in different subject domains participate in these studies. In 1992, a part of the questionnaire consisted of questions about ESD use and the link of ESD-use with study success (Martens, Poelmans, Daal, van Staa, & van Meurs, 1993; van Staa, & van Meurs, 1992).

Student appreciation of ESD is high. Only 7% of the students prefer learning materials without ESD. Students studying "Cultural Sciences" appreciate ESD to a lesser extent (Pearson correlation coefficient -0.24, p<0.01). No interrelations between the use of ESD and the level of study success can be found. This might be partly due to the way study success was operationalised: the time it takes to attain study credits.
No specific conclusions can be drawn from this research to validate the theoretical model.

Different versions of one course. In this research project, the main focus was on the central role of ESD to influence learning: Does making use of ESD during the learning process have a positive effect on study outcomes? Two versions of a learning unit of the OU-course “Introduction to governmental law” were elaborated (Martens, Poelmans, Daal, & Valcke, 1993). A first version of the course was a replication of the original printed OU-textbook. This version incorporated a large set of embedded support devices. The second version proved to be about 40% shorter in length after deleting most embedded support devices (such as schemes, summaries and learning objectives). Care was taken that this omission did not alter the basic content and did not affect the coherence of the text. Thirty-six students from the University of Limburg (RUL) studied one of both course versions. Several tests and questionnaires were developed to measure the effects of course versions on study success and the potential interrelation of study success with independent student variables. The tests used to measure study success were carefully constructed in order to detect differences in mastery level (knowing, insight, application) or differences in mastery of specific knowledge types (facts, concepts, relations, structures, methods).

No significant effects in use of study time, student evaluations of the learning access level and “knowledge” questions could be observed. But students who studied the course version with ESD, achieved significant higher scores on “insight” questions (ANOVA, F(1,34)=3.47, p<0.05). Interrelations with the independent variables prior knowledge, time used, reading comprehension, educational level and gender were tested. These variables were added to the ANOVA models as covariables. No relevant interactions were detected.

The results of this study indicate the importance of embedded support devices in our model as they relate to the learning process. Since the effect on study outcomes is especially found in relation to “insight questions”, one can suggest that ESD especially influence particular components of cognitive functioning.

Eye movement registration. Eleven subjects participated in this in-depth research (Martens, Poelmans, Daal, Valcke, & Stolk, 1994). The students studied one learning unit of an OU-course in the law-domain. In the learning materials used, ESD were integrated into the text. The eye movements were monitored by means of the corneal reflection/pupil centre technique with an infrared camera (Stolk, Smulders, & Belsmaeker, 1991. Eye movement patterns were compared between text parts with ESD and those without ESD. For each text part a computer program computed the total reading time per word. Prediction hypotheses were formulated as to the reading time of each specific ESD as compared to the reading time for regular text.

It was found that the average reading time was for most ESD in line with the hypotheses. For instance content pages have shorter reading times per word and questions are read longer per word, thus indicating a deep level use. Furthermore it turned out that every ESD analyzed was looked at, at least once by each student.

The very reliable research set-up confirmed the earlier results indicating a very high level of ESD-use.

Review of the validation research: interactive learning environments

When analyzing the use of printed learning environments, the possibilities have not been researched to adapt learning materials to student needs or questions. The research projects in the next section of this article either focus on the adaptation feature or compare student activities and outcomes of groups making use of these features.

We will not discuss the design of interactive learning environments since this will be in part done in the contributions of Portier & Van Buuren (this issue) and Vuist (this issue). We will only focus on some basic characteristics of these environments as they are related to our theoretical model.
Interactive learning environments. To research the impact of ESD in ILE, we used a computer environment to present learning materials to students and to give them the possibility to manipulate the learning materials. The explicit distinction between basic content and ESD, the level of ESD-integration and the degree of interaction in manipulating ESD form the base of our studies with ILE:

- The database of learning materials in the computer program reflects the basic distinction between basic content and the embedded support devices in the learning materials.
- In printed learning environments ESD are integrated into the basic content where course developers consider them to be of relevance. In ILE, variations in levels of integration or the discernability can be realized. Two ILE with a different discernability mode have been developed. In the first environment the ESD are hardly discernable from the surrounding ascii content. In the second environment the ESD are explicitly discernable from the basic content and are preceded by a header indicating the type of ESD.
- In printed learning materials, ESD are available depending on the design-decisions of the learning material developers. In interactive learning environments, we transfer the decision and responsibility to activate and incorporate ESD into the basic content to the student. The degree of “interactivity” is considered as a basic feature of ILE. Therefore, two versions of an ILE with embedded support devices have been elaborated. In a first version, the interaction possibilities with the ESD have been blocked. In this way the interactive learning environment is reduced to a simple, straightforward electronic textbook. In the second version, students have full control to (de)activate the support devices at a global and/or local level. Moreover, comparing ILE with PLE in the same research design also builds on the differences in interactivity discussed here.

Interactive learning environments, a first research set-up. Portier and van Buuren (this issue) describe this research set-up in detail, thereby focusing on design features of ILE and a specific set of research hypotheses. A sample of 46 students participated in this study where next to students working with ILE, a control group participated in regular face-to-face lectures and working-groups. Computer interactions were continuously logged in a personal activities file. All students in the experimental condition used the same type of ILE.

The results reveal that study outcomes of students in the control and experimental conditions are not significantly different. Students in the independent learning situation attained comparable study outcomes.

Analysis of data in the log-files is helpful to link ESD-use to individual student variables. Students with a high level of prior knowledge interacted significantly more with the embedded support devices than students with a lower prior knowledge level.

Relating the results to our theoretical model, we see that the impact of individual variables is stressed again in the interaction with the task environment and the learning process.

Interactive learning environments, a comprehensive study. In this second study, interactive learning environments were contrasted with printed learning environments and face-to-face lectures (Portier & van Buuren, this issue). Moreover, types of ILE and PLE were researched, considering the discernability and interactivity modes described earlier. A large set of variables was controlled for, although the research was completely integrated into the normal learning set-up of the students. Students studied during three working sessions three chapters of a course on statistics. The independent learning sessions were set up at the university. Students did not get learning materials to take home. Automatic log-files stored the interactions of students working with the ILE and help to discern between low and high ESD-use.

All first-year students (n=502) of the university of Gent, Belgium (Faculty of Pedagogical and Psychological Sciences) participated in the study. Students were selected at random to participate in one of five research conditions (Table 1). The sessions were part of an obligatory part of the study program. Students could not take home the study materials.
Table 1
First-year student population at the University of Gent, Faculty of Psychology and Educational Sciences, Course Statistics 1 (N=502)

<table>
<thead>
<tr>
<th>Type of learning environment</th>
<th>Experimental Groups</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Discernable ESD</td>
<td>Non-discernable ESD</td>
</tr>
<tr>
<td>Interactive (ILE)</td>
<td>I (n=40)</td>
<td>IIIa (n=20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIIb (n=20) non interactive</td>
</tr>
<tr>
<td>Printed (PLE)</td>
<td>II (n=40)</td>
<td>IV (n=40)</td>
</tr>
</tbody>
</table>

Reading comprehension level, prior knowledge level and a set of other variables were measured and controlled for. At the end of the research period a posttest was used to measure study outcome. The final examination scores were used to measure long term effects.

We focus here on the results of students in condition I, IIIa and IIIb. This implies that differences in discernability mode and interactivity mode are expected. Embedded support devices are clustered according to the clusters discussed earlier: orienting ESD, processing ESD and testing ESD.

Comparing study outcomes of students in the two different discernability conditions, in relation to the use of ESD results in a clear picture (Table 2).

Table 2
Study outcomes as a function of ESD-use (low/high) and discernability of ESD (low/high), with size per group

<table>
<thead>
<tr>
<th>Discernability</th>
<th>Orienting</th>
<th>Processing</th>
<th>Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>low</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Low</td>
<td>7.90</td>
<td>7.40</td>
<td>6.00</td>
</tr>
<tr>
<td></td>
<td>(10)</td>
<td>(10)</td>
<td>(8)</td>
</tr>
<tr>
<td>High</td>
<td>7.77</td>
<td>7.36</td>
<td>8.17</td>
</tr>
<tr>
<td></td>
<td>(13)</td>
<td>(11)</td>
<td>(12)</td>
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</tbody>
</table>

Multivariate analysis of variance reveals no significant main effects of discernability, nor use of several types of ESD on study outcome. However, if the two-way interactions are taken into consideration, the analyses revealed a significant interaction between discernability and the use of processing ESD ($F(1,42)=5.66$, $p<.05$) on study outcome. In addition we find a trend interaction between discernability and use of testing ESD ($F(1,41)=3.67$, $p=.06$). Both interactions can be interpreted as follows: students who use much processing and testing ESD benefit from a condition (treatment) in which ESD are not discernable, i.e., integrated into the basic content. In contrast, low ESD-users seem to benefit from conditions in which ESD can be clearly identified.

Comparing the study outcomes of group I and IIIa with the results of group IIIb helps to test the impact of the interactivity mode. Analysis of variance reveals no significant main effects nor interactions of the independent variables on study outcome.

Reading comprehension levels do not interact with the use of embedded support devices. Portier and van Buuren (this issue) also report on the impact of prior knowledge in making use of ILE. They report that there is a significant interaction between PKS and ESD-use: one's level of prior knowledge influences the extent to which ESD are used. This effect is significantly greater for processing ESD and testing ESD ($\lambda=88$, $p<.05$).

Extending the analysis to a comparison between students studying in ILE and PLE, the analyses reveal no significant differences. Also a comparison between independent learning
situations and traditional face-to-face lectures does not result in significant differences in study outcomes.

Returning to our theoretical model, the results of this research stress again the impact of individual variables on learning in a specific environment and on the learning process. Prior knowledge levels influence the use of embedded support devices. Task environments that can be adapted to the needs of students (discernability) fit into this picture and meet the demands of specific groups of students.

Discussion

Combining the results of the research studies, we can conclude the following:

- Embedded support devices are used to a very high extent by most students.
- The use of ESD depends on individual variables, such as gender, educational background and especially on the variable prior knowledge.
- ESD influence the learning process and study outcomes.
- There is an interacting influence of student aptitudes in the relation between the task environment and learning outcomes.
- Active manipulation of features of the task environment, such as the discernability of parts of the learning materials are related to individual variables and the learning process.

We were not able to validate the hypothetical functions and effects of the embedded support devices. The results of the interview-based study show us that these functions and effects seem to be different for different students and even depend on the phase of their learning process.

The question now arises whether or not our model has been validated? We may conclude that the impact of the task environment (with ESD) in the interrelation between individual variables and the learning process has been validated. But, at a more important level, the research results also have shown us a clear direction for future research. The value of certain flexibility-features of interactive learning environments has been revealed. In this type of environments students can shape, adapt, select/deselect learning materials in accordance to their individual needs. This is in line with for instance de Diana and van der Heiden (1994): "... an increasing need is felt for adaptable educational software products that can be modified to the need of users" (p. 116). ILE also provide many additional features such as the possibility to make use of hypertext links (e.g., Picking, 1994).

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FUNCTIONS AND EFFECTS OF EMBEDDED SUPPORT DEVICES IN LEARNING MATERIALS 195


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Current theme of research:
Optimizing the embedded student support in printed and electronic self-study materials.
Most relevant publications in the field of Psychology of Education:


Current theme of research:

Instructional design and evaluation of learning environments. The theoretical base of distance learning and the provision of distance education learning materials.

Most relevant publications in the field of Psychology of Education:


