



INTERACTIVE LEARNING ENVIRONMENTS TO SUPPORT INDEPENDENT LEARNING: THE IMPACT OF DISCERNABILITY OF EMBEDDED SUPPORT DEVICES

R. L. MARTENS, M. M. A. VALCKE and S. J. PORTIER

Open University of the Netherlands, Educational Technology Expertise Centre, P.O. Box 2960,
6401 DL Heerlen, The Netherlands

[E-mail: rob.martens@ouh.nl; martin.valcke@ouh.nl; Tel.: +31 45 5762317; Fax: +31 45 5762802]

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Abstract—In this article the effectivity of prototypes of interactive learning environments (ILE) is investigated. These computer-based environments are used for independent learning. In the learning materials, represented in the prototypes, a clear distinction is made between the basic content and embedded support devices (ESDs) that are expected to support learning. The prototypes differ in relation to the extent they support interactivity in manipulating the ESDs and the degree of discernability of the ESDs. In a large empirical research set-up ILE are compared with learning environments that are based on printed learning materials and a control situation with face-to-face lectures. The results indicate the effectivity of the ILE, when taking into account the significant impact of individual differences between students on study outcome. The interaction results show that discernability of ESDs is favourable for some students. For other students, however, discernability affects the learning outcome in a negative way. © 1997 Elsevier Science Ltd

INTRODUCTION

This article is based on the results of a collaborative study between the Open University of the Netherlands (OU) and the University of Ghent, Belgium. Among other aims, this study focuses on the evaluation of interactive learning environments (ILE) to support independent learning. For an extensive overview of the study, we refer to Martens *et al.* [1,2].

In this article we specifically concentrate on the effects of design characteristics of ILE in relation to (1) student characteristics and (2) learning results. As will be briefly discussed in the theoretical base of this study, student control over the learning environment is considered to depend on specific student characteristics (e.g. [3,4]). The effectivity in terms of learning outcomes of ILE is not the same for all students but may interact with student characteristics. Design features have to take these characteristics into account. We assume that interaction effects between student characteristics, learning conditions and learning outcomes are of major importance since these effects might direct future research on adapting learning materials to learner characteristics [5].

To measure the effectivity of the ILE, three prototype-versions are used in a research set-up. Moreover, two alternative learning environments based on printed learning materials (PLE, printed learning environments) and a control setting with lectures are incorporated into the research design. The learning environments are researched with university students taking a part of a statistics course.

LEARNING MATERIALS TO SUPPORT INDEPENDENT LEARNING

The OU sets up education in a distance-learning setting. Thus far, the delivery of education is mainly based on printed learning materials. The OU has invested a lot in enhancing the quality of the learning materials to “embed” all kinds of support to help students during their study. The didactical elaboration, embedded in the learning materials is supposed to take over the supportive role of a teacher who is normally present during a face-to-face lecture or working group.

Considering the independent learning setting, the high-quality elaboration of the learning materials is of prime importance to support a learning process:

- On the one hand, the learning materials consist of so-called “basic content” that reflects the domain specific (scientific) information. On the other hand learning materials incorporate embedded support devices (ESDs). Given the large amount of ESDs in learning materials, these are clustered according to three basic functions and effects as suggested by Valcke *et al.* [6]:

- orienting ESDs: learning objectives, references to other learning materials, references to required prior knowledge, and use of history.
- processing ESDs: additional learning materials, advance organizers, figures, glossary, introductions, study advices, summaries, tables, examples, extended learning materials.
- testing ESDs: self-test items, exercise items (on know, insight and apply-levels), answers.
- ESDs are integrated into the basic content where course material developers consider them to be of relevance. Taking account of our theoretical base (see below) and earlier empirical studies (e.g. [7]) the level of integration into the basic content is considered to be an important variable. Therefore, we distinguish between learning materials in which ESDs are hardly discernable and learning materials where the ESDs are explicitly discernable or identifiable. "Discernability" of support devices may have an important impact on the way students use the material because with discernable ESDs, students can decide in advance to use or to skip ESDs, whereas in the other mode the ESDs has to be read. However, discernability might also interrupt the visual coherence of the study material and hinder the study process.
- In printed learning materials, ESDs are available and incorporated depending on a-priori design-decisions that were made by the learning-material developers. In interactive (electronic) learning environments, we transfer the decision and responsibility to incorporate ESDs into the basic content to the student. In our theoretical base, this means that the degree of "interactivity" is considered as a basic feature of the learning environment. In the research set-up, this is reflected in sets of experimental conditions where two basic delivery modes are distinguished: printed delivery and interactive delivery.

The explicit distinction between basic content and ESDs, the level of ESD-discernability and the degree of interaction in manipulating ESDs form the main objectives of the present research.

THEORETICAL BASE OF THE STUDY

Our theoretical base positions learning with ILE in a complex framework of interrelated processes and variables [8]. The instructional design model of Snow and Swanson [5] is helpful to describe this theoretical base. These authors define the following matrix of interactions between variables and processes: aptitudes * learning types * content domain * instructional design * situations * populations.

Applying this matrix to our research, we get:

aptitudes:	cognitive and non-cognitive (motivation) aptitudes
learning type:	independent learning in interactive or printed learning environments
content domain:	statistics in social sciences
instructional design:	learning materials where ESDs are separated from the basic content
situation:	independent learning
population:	adult students

This model comprises:

- **COGNITIVE APTITUDE** related to **LEARNING** as described by the three-component theory of Sternberg [9]. This cognitive psychological theory is helpful to describe cognitive processes related to learning. In earlier studies we have described how this theory can be related to the functions and effects of ESDs in learning materials [6].
- **COGNITIVE APTITUDES** related to **READING**. Since the textual representation of the learning materials is still a predominant representation mode, even in ILE, reading comprehension is an important process. The focus is on discourse comprehension and not on the decoding processes, however. In our model, reading comprehension is considered as a basic process related to the learning process, but also as an individual variable that interacts with the other variables and processes in the model.
- The influence of the **NON-COGNITIVE APTITUDE** motivation. For example Ames and Ames [10] have indicated the overall importance of motivation in relation to learning. Also in the context of independent learning and the specific design of learning materials, authors refer to the central role of motivation. Waller [11] points out at motivational effects of typographic access structures for educational texts. Elshout-Mohr [12], and Van Hout-Wolters and Willems [13] mention that motivation

can be enhanced by presenting a specific set of ESDs, such as objectives, questions/tasks, examples, introductions, feedback, content pages and structure pages.

Considering the specific task environment, also the "attitude towards learning with computers" is presumed to be a relevant non-cognitive variable.

- The **LEARNING MATERIALS** that are used as input for the learning process (basic content+ESDs). In the research literature, a vast set of theoretical and empirical studies help to base the functions and effects of embedding support devices in (printed) learning materials [6,14–17]. In general, it was found that ESDs in PLE are highly used, appreciated positively and lead to better study results. There are many ways to structure learning materials. The presentation and lay-out of the material is a relevant tool to make learning materials more suitable for self study. Lay-out variations may provide support to the student by indicating specific functions of certain parts of the learning materials. An example of a lay-out variation in order to support the learning process by providing explicit structure is operationalised by varying the discernability of ESDs.
- The **TASK ENVIRONMENT**: the interactive learning environment. An interactive learning environment is defined as a context that supports learners to interact with a knowledge base in order to attain clearly defined learning objectives. Support is especially realised by the possibility to adapt to the individual learner.

ILE, as conceptualized in our research, are related to a variety of instructional technology applications. There is, for instance, a strong relationship with Hypercourseware† when the focus is on learner control and the availability of a large knowledge base [18,19]. ILE have analogies with "microworlds" and "ILE" as defined by Lawler [20] when we concentrate on the active exploration and manipulation of a rich knowledge base. Also, ILE have a strong connection with (intelligent) computer assisted instruction, adaptive learning environments [21] and (intelligent) tutoring systems [22] when the focus is on the adaptive qualities [23].

ILE resemble computer managed learning systems and especially the emerging interactive on-line advisory systems when we consider the "adaptive" possibilities of the system.

The task-situation is distance (independent) learning. Distance learning techniques are borrowed increasingly by more conventional institutions in higher education to make their own teaching more effective, efficient or flexible [24]. One goal of this research is to investigate whether traditional lectures in higher education can be replaced by self study, thus allowing teachers to spend more time on activities to support students' learning.

- **INDIVIDUAL VARIABLES** that interact with study behaviour and the way the learning environment is used and processed. In the present article we focus on a subset of individual variables: reading comprehension, prior knowledge and use of ESDs. The variable reading comprehension has already been discussed. The second variable refers to the prior knowledge a student already has before starting the learning process. Many authors have indicated the importance of this variable as a determinant for future learning [25–27]. Dochy [27] reveals in this context the multi-dimensional nature of prior knowledge. In our research we will, for instance, make use of the distinction between the behavioural and knowledge dimensions in prior knowledge. The former refers to the "mastery" level a student can perform in relation to a specific body of knowledge (knowing, insight into, application). The latter refers to the specific "type" of knowledge he or she masters (facts, concepts, relations, structure, method). The use of ESDs can be measured by means of computer log-files, that indicate what ESDs are used. This way it is also possible to use the level of ESD use (low or high) as an individual variable, and investigate what its impact is on study outcome.

RESEARCH HYPOTHESES

There are many possibilities of adapting ILE to student characteristics. In this research subjects are not assigned to certain conditions based on individual variables, but are ascribed randomly to research conditions. The purpose of this research set-up was to investigate the interaction between conditions and individual variables.

Considering the theoretical base and the specific design of our ILE and PLE, the following hypotheses are put forward. Some hypotheses focus on the effectivity of the learning environments used. Others

† The term "Hypercourseware" is used to cover software products which provide some combination of hypertext capabilities, e.g. HyperCard™, SuperCard™, LinkWay™, Guide™, Toolbook™ and Plus™.

focus on the interaction between student characteristics, the use of the learning environments and study outcome. In our view, the latter hypotheses are the most interesting, because these actually are focused on determining an optimal task environment that is adapted to (an) individual variable(s).

1. Subjects who study in ILE will achieve at least equal study outcomes as subjects who study in PLE
2. Subjects who use ESDs benefit from learning environments where ESDs are less discernable. In contrast, subjects who do not use much ESDs benefit from learning environments where ESDs are discernable.

This interaction is expected because low-users may want to skip certain ESDs. When ESDs are non-discernable this might hinder these learners because they have to read the ESDs before they know what ESDs it is. On the other hand high-users who always tend to read ESDs might find the different lay-out of ESDs obstructive [14].

3. Students who study in ILE achieve higher study outcomes than students using a non-interactive (but still electronic) learning environment.

This hypothesis is based on the assumption that the action of choosing ESDs leads to higher awareness of functions of these ESDs.

4. Prior knowledge is positively related to the use of functionalities of the ILE and is a significant interaction variable in the relation between treatment and study outcome.

Previous research has shown the important impact of the variable prior knowledge on the learning process. We expect subjects with high prior knowledge to explore more in ILE, and therefore to make more use of ESDs in ILE. We also expect a significant interaction with prior knowledge in the relation between characteristics of the learning material and learning outcome.

5. Good readers use less ESDs to support their study activities; reading comprehension is an interaction variable in the relation between treatment and study outcome. No predictions are made about the direction of the interaction.
6. Motivation, attitude towards learning with computers and ESD-use are interrelated positively; their interaction influences study outcome. No predictions are made, however, about the direction of the interaction.

THE INTERACTIVE LEARNING ENVIRONMENT PROTOTYPE

Basic features

The interactive learning environment prototype is a demand driven environment in which students are actively involved in selecting, exploring and studying from a knowledge base of learning materials. Prototyping is seen as an essential part of courseware development to enhance the quality [28] and to provide information whether a user actually uses the functionalities that are offered. Students can either browse through the learning materials in a sequential order by using the page-forward or page-backward button, or follow a "hyperlink" strategy by choosing any part of the learning materials from the "Topic" option in the main menu. The basic content and the embedded support devices can be simultaneously presented in different windows. Choosing a topic (paragraph) returns by default the specific basic content (see Fig. 1).

In the main menu bar students can choose the "ESD" option and "select" any ESD. This selection actually concerns a pre-selection. After this pre-selection the ESDs will be available for further activation at the level of each topic/paragraph. At paragraph-level, the prototype helps to activate or deactivate pre-selected ESDs. Activation of ESDs is supported from within the "local active" window or from within the "local inactive" window (both in the right part of the screen). If an ESD is selected and active, it is "embedded" in the basic content, as represented in the central text screen (Fig. 2).

Figure 2 clearly shows that ESDs are separated from the basic content. Tables and illustrations can be accessed by clicking hot-words.

The "Tools" option in the main menubar gives access to a *history* provision and the "glossary". Activation of the "history"-tool lists all paragraphs that already have been looked at during a session. Activation of the second tool, the "glossary", results in the presentation of an alphabetic list including all main concepts of the statistics domain covered in the set of learning materials. Selecting one of the concepts leads to the presentation of a short definition of that topic. Furthermore, the glossary can, on demand, provide the student with an example and if needed, the student can add an annotation to the

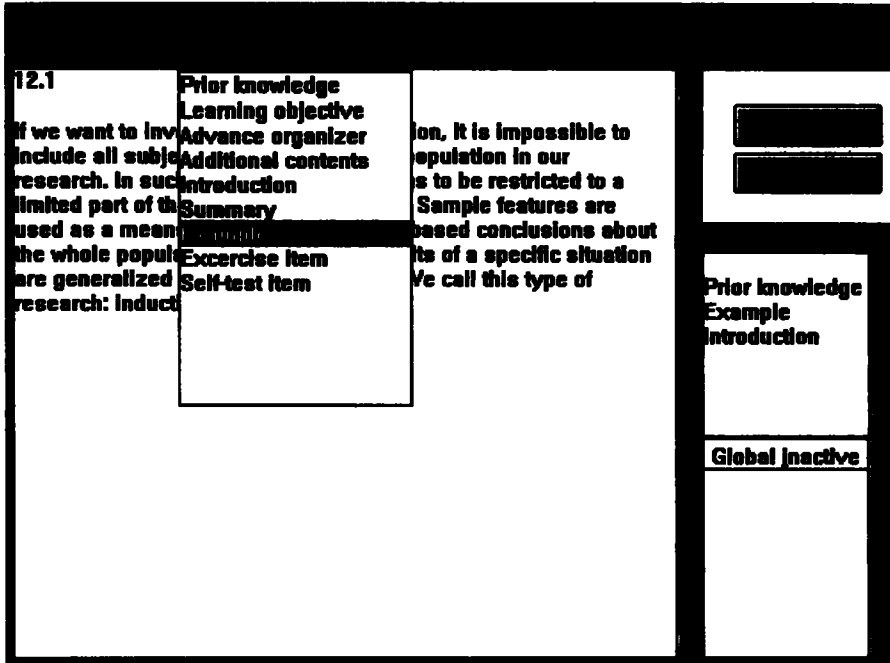


Fig. 1. Selection of ESD from the main menu.

definition. This annotation is stored separately for each individual student.

The fourth option in the main menu bar, "Answers", gives access to the correct answers and solutions for the tasks and exercises included as ESDs in the learning materials.

For investigation purposes, all student interactions with the system are stored in a log-file. ESD-interactions, use of hyperlink features and glossary consultation are considered as measures for active involvement of a student. Note that discernability of ESDs is one of the group conditions and cannot be manipulated by students in this experiment.

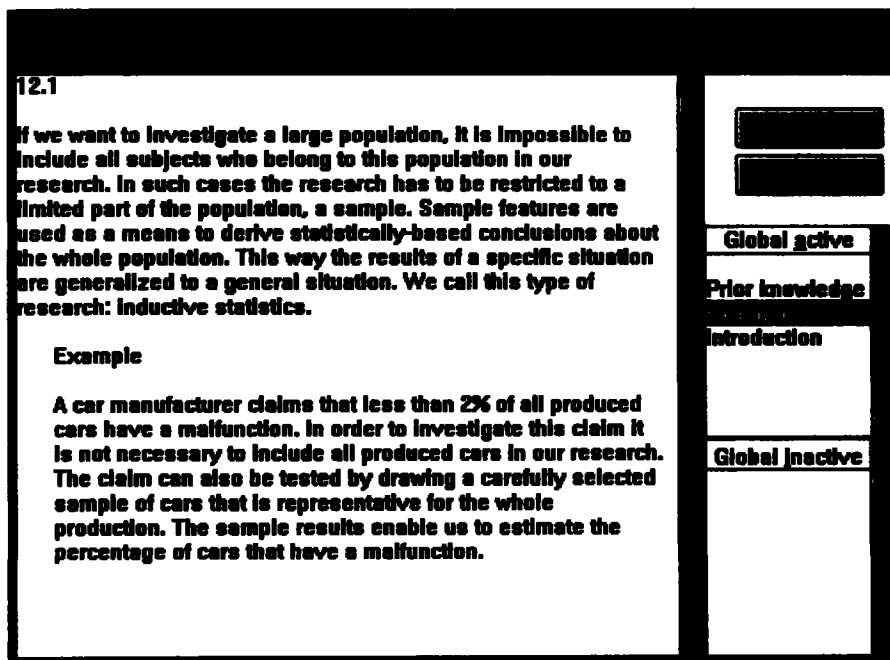


Fig. 2. Integration of ESD in basic content.

Versions of ILE

The distinction between basic content and ESDs is a basic feature in our ILE. Considering the degree of discernability of the ESDs and the degree of interactivity in selecting and/or activating the ESDs, three versions of interactive learning environments have been elaborated.

In a first version, the interaction possibilities with the ESDs have been blocked. In this way, the interactive learning environment is reduced to a simple, straightforward electronic textbook.

In two other versions, students are presented with a different way of embedding the support devices; the ESDs are either discernable or not discernable in the context of the basic content. In the former setting, the ESDs and basic content are clearly separated, and each ESDs is preceded by a header, indicating the type of ESDs which is presented (see the example in Fig. 2). In the latter setting the ESDs and basic content are completely integrated.

PRINTED LEARNING MATERIALS

Basic features

As stated earlier the OU still mainly supports independent learning with printed learning materials. A variety of models has been elaborated; e.g. textbook-working-book model, learning unit model, case model, etc. The printed learning environments have in common the fact that the basic content is enhanced with a rich set of ESDs.

Versions of PLE

Analogous to the ILE the distinction between basic content and embedded support devices is essential. However, the degree of discernability of the ESDs can vary. For research purposes, two different versions of PLE have been elaborated. In the first version, the ESDs are discernable and preceded by a header. In the second version, all ESDs are completely integrated into the basic content and, as a consequence, are no longer discernable. The effects of discernability will be measured both in ILE and in PLE.

METHODOLOGY

The entire first-year student population, studying "Psychology and Educational Sciences" at the University of Ghent, Belgium ($n=502$) participated in the study. Students were assigned, randomly, to any one of five experimental groups or to the control group (Table 1). Students in the control group were not subjected to any particular treatment. They followed the regular face-to-face lectures, given by their usual professor. In the results section, only the scores and behaviour of students who participated in all three experimental sessions or corresponding lectures will be included in statistical analysis. Moreover, students with a higher educational background ($n=31$) and students taking the course for the second time ($n=79$) are excluded from statistical analysis. Students were not given any (printed) materials during the research in order to avoid studying at home and, thus, compensating for less suited conditions. Study time in all conditions was made as equal as possible (either three experimental sessions or three face-to-face lectures of 2 h each). The statistical content was exactly the same for all conditions.

Considering the theoretical model for this research, a large number of processes and variables have to be dealt with. Some variables can be controlled for by the specific research design (e.g. random selection of students). The variables have to be explicitly measured or evaluated by making use of the following instruments (with Cronbach's alpha as a measure of psychometric reliability):

- a reading comprehension test ($\alpha=0.69$);

Table 1. First-year student population at the University of Ghent, Faculty of Psychology and Educational Sciences, course statistics I ($n=502$)

	Experimental groups		Control group
	Discernable ESDs	Non-discernable ESDs	
Interactive learning environments (ILE)	I ($n=40$)	IIIa ($n=20$)	V ($n=342$)
Printed learning environments (PLE)	II ($n=40$)	IIIb ($n=20$) non-interactive	

- a prior-knowledge-state test (used as a pre-test; 19 items, $\alpha=0.75$);
- a subject-oriented mastery test (used as a post-test) to determine study outcome (20 items, $\alpha=0.61$);
- a three-part questionnaire:
 - part A includes questions about motivation, age, study habits, educational level and gender (no psychometric reliability is calculated because of the predominantly nominal variables);
 - part B asks students to judge the degree of accessibility of the learning materials ($\alpha=0.82$);
 - part C puts forward questions about the use and appreciation of each specific embedded support device ($\alpha=0.93$);
- a measuring scale on attitude towards learning with computers ($\alpha=0.87$);

The research procedure is reported in chronological order:

- Administration of a questionnaire including the scale on attitude towards computer based learning and the reading comprehension test, prior knowledge state test and OU-questionnaire part A.
- Assignment of students to an experimental or control group. We controlled for differences in prior knowledge.
- Introduction session on using the ILE
- Taking the course: the alternative approaches
 - Students in the experimental conditions study during three sessions of two hours each with the specific learning environment. After each session they fill in the OU-questionnaire, part C.
 - Students in the control condition follow the regular lecture-format. Three lectures were given, each lecture focusing on one of the selected chapters on inferential statistics.
- Administration of the subject-oriented mastery test and OU-questionnaire part B (test administration was organised one week after the research sessions were finished).
- The final examination. (At the end of the academic year, students have to take a statistics examination as a part of their final assessment of the first year. The results of this regular examinations are considered as long-term study outcomes and can be compared partly with the scores of the subject-mastery test.)

RESULTS

Comparing the five different conditions for study outcome

Table 2 presents an overview of mean post-test scores and standard deviations for the different research conditions. Analysis of variance (ANOVA) is used to reveal whether differences in mean post-test scores are significant (Table 2). The analysis showed that none of the conditions leads to better study outcomes than any of the other conditions ($F(5,233)=0.541$; $P=0.745$).

A similar analysis is used to test for long-term learning effects (final examinations). Analysis of variance revealed no significant effects of experimental condition on final examination scores, however.

Use of ESDs in ILE

Analysing the data of the on-line registration of student-activities in the ILE (log-files) shows that about 47% of all ESDs are actually used by the students.

Table 2. Post test scores as a result of experimental condition

Condition	I Electronic, discernable, interactive	II Paper, discernable	IIIa Electronic, non-discernable	IIIb Electronic, non-discernable	IV Paper, non-discernable	IV Lectures
Mean score	7.58	7.69	7.65	6.38	8.19	7.97
Standard deviation	2.38	2.69	2.98	2.97	2.58	3.38
N	24	29	20	8	26	1.32

Delivery mode and study outcome

In this analysis a comparison is made between the groups I, IIIa and IIIb (ILE) and the groups II and IV (PLE). This comparison, based on ANOVA, does not show significant differences in study outcome ($F(1,50)=1.44$, $P=0.236$).

Interactivity mode and study outcome

In this ANOVA, the results of group I and IIIa are combined (interactive functionalities available) and compared with the results of group IIIb where the interactive selection of ESDs was prohibited. We found no significant main effects or interactions of the independent variables on study outcome ($F(1,26)=1.05$, $P=0.315$). However, multiple classification analysis (MCA) shows that the mean deviations from the grand mean of study outcome are negative when ESDs cannot be interactively selected. The groups that could work with a full interactive version of the prototype achieve predominantly higher study outcomes than the grand mean.

Discernable versus non-discernable ESDs: main effects and interaction effects

For this analysis the mean scores of groups I and II are compared with the mean post-test scores of groups IIIa, and IV. The purpose of this analysis is to investigate whether discernability of ESDs is beneficial. The analysis of variance reveals no significant main effect on study outcome. However, if the two-way interactions are taken into consideration, the analysis uncovers a significant interaction between discernability and the use of processing ESDs ($F(1,42)=5.66$, $P<0.05$) on study outcome (Fig. 3). Additionally, we find a trend interaction between discernability and use of testing ESDs ($F(1,41)=3.67$, $P=0.06$) (Fig. 4). The features of these interactions are analogous: students who use much processing and testing of ESDs, benefit from a condition (treatment) in which ESDs are non-discernable, i.e. integrated into the basic content. In contrast, ESD low-users seem to benefit from a condition in which ESDs can be clearly identified. In both cases the benefit of a correct discernability condition manifests itself in higher study outcomes.

Effects of treatment conditions on the use of ESDs

Multivariate analysis of variance reveals no significant main effects or interactions of discernability and interactivity mode on the use of ESDs. However, the use of ESDs is significantly affected by delivery mode. In order to analyze the effects of delivery mode on ESD-use we use the data that were collected

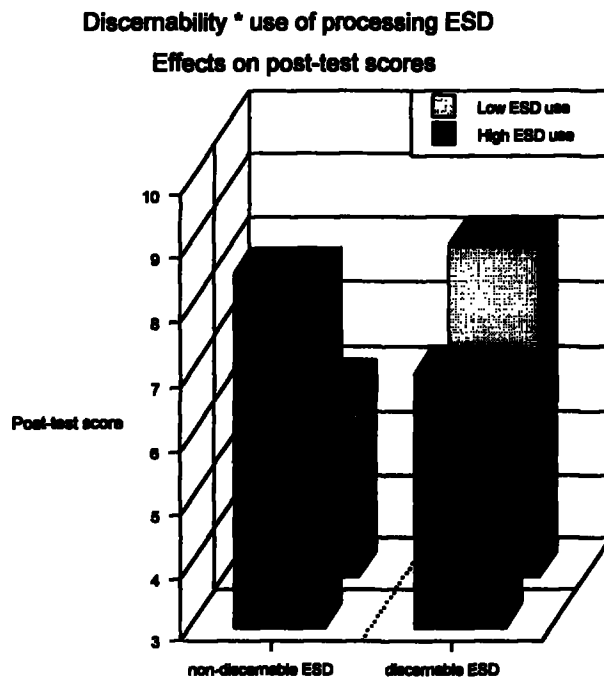


Fig. 3. Interaction effects between discernability and use of processing ESD on study outcome.

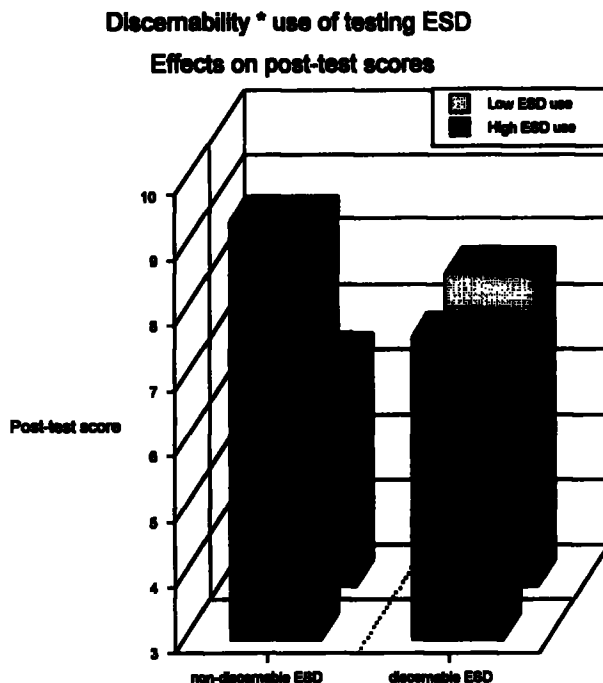


Fig. 4. Interaction effects between discernability and use of testing ESD on study outcome.

by means of questionnaire part C. Again, the ESDs are clustered according to the dimensions orienting, processing and testing and entered in a profile analysis procedure (parallelism test). The analysis produces a significant interaction between delivery mode and ESD-use, indicating that the computer groups use more testing ESDs, whereas the paper groups use more orienting and processing ESDs (Wilks' $\lambda=0.74$, $P<0.001$).

The impact of reading comprehension on use of ESDs

The results of the reading comprehension test are entered in regression analyses in order to investigate the predictive power towards the use of ESDs. None of the analyses reveal significant effects, which means that reading comprehension level and use of ESDs are seemingly unrelated.

The impact of prior knowledge on use of ESDs

In order to determine the effects of prior knowledge state (PKS) on the use of ESDs, we apply a multivariate analysis of variance in which PKS is defined as an independent variable and the uses of orienting, processing and testing ESDs are presented as dependent variables. The analysis reveals a significant interaction between PKS and ESD-use in this sense that PKS has an enhancing effect on ESD-use. Moreover, this effect is significantly more pronounced for processing ESDs and testing ESDs (Wilks' $\lambda=0.88$, $P<0.05$). The interaction effect is supported by univariate F -tests, which reveal that PKS has a significant, positive impact on the use of processing ESDs ($F(1,50)=6.12$, $P<0.05$) and the use of testing ESDs ($F(1,50)=3.99$, $P=0.05$), but not on using orienting ESDs.

In an additional analysis, we tried to unravel the prior knowledge effects. To this end, the data representing the two prior knowledge dimensions (behaviour and knowledge) were entered in stepwise multiple regression analyses as independent variables. As dependent variables, we entered the three types of ESDs: orienting, processing and testing ESDs. The results (Table 3) show that the use of processing and testing ESDs can be predicted from prior knowledge scores on the know and relation parameters (positively related to the use of processing ESDs), and scores on the insight and structure parameters (positively related to the use of testing ESDs).

Does the impact of PKS on ESD-use also influence study outcome, depending on the learning environment used? To answer this question, we compare the study outcome of students as a function of their PKS and type of learning environment. We discover that high-PKS students achieve higher study

Table 3. Stepwise multiple regression equations (PIN=0.05) for use of ESD-types as a function of prior-knowledge profile

Dependent variable	Predicting variables	Equation
Orienting ESDs	Behavioural parameters: know, insight, apply	None of the variables reached PIN=0.05 limit
Orienting ESDs	Knowledge parameters: concept, relation, structure, method	None of the variables reached PIN=0.05 limit
Processing ESDs	Behavioural parameters: know, insight, apply	Processing ESD=0.09+0.14 × know
Processing ESDs	Knowledge parameters: concept, relation, structure, method	Processing ESD=0.11+0.10 × relation
Testing ESDs	Behavioural parameters: know, insight, apply	Tested=0.17+0.16 × insight
Testing ESDs	Knowledge parameters: concept, relation, structure, method	Tested=0.16+0.17 × structure

outcomes than low-PKS students. This effect is most pronounced in the condition in which ESDs are integrated into the basic content ($F(1,43)=4.33, P<0.05$).

The impact of motivation and attitude towards learning with computers

Profile analysis (parallelism test) of the effect of motivation on the use of the three ESD-types uncovers no significant main effect or significant interactions. In contrast, the analyses of the effects of attitude towards learning with computers revealed a significant main effect (Wilks' $\lambda=0.89, P<0.05$), reflecting that a positive attitude leads to an increased ESD-use. This effect was significantly more pronounced for the use of testing ESDs (Wilks' $\lambda=0.91, P<0.05$).

Analysis of variance revealed no significant main effects or interactions between attitude towards learning with computers and discernability mode or interactivity mode. The picture that arises if we concentrate on delivery mode is completely different. The results indicate a classical disordinal interaction which is supported by a significant interaction effect between attitude and delivery mode on study outcome ($F(1,93)=4.32, P<0.05$). The interaction implies that the choice of a certain delivery mode depends on a student's attitude towards learning with computers. Students who like learning with computers will achieve better study outcomes in a computer condition, which is not very surprising. However, students who manifested a positive attitude towards learning with computers, but had to study in a PLE achieved worse study outcomes than their peers with a less positive attitude.

DISCUSSION

The discussion and interpretation of the results, will be structured according to the hypotheses.

Hypothesis 1: students studying in ILE will achieve a study outcome comparable to that of students studying in alternative learning environments.

Since the results reveal no significant differences in study outcome when comparing students in the treatment conditions, the hypothesis can be accepted.

For more information on the comparison of independent learning groups with the control group who received traditional learning approaches we refer to Dekeyser *et al.* [29]. Our results confirm the earlier findings of Weges and Ellerman [30], and Portier and Van Buuren [7]. Both studies found that students who study in a computer-based learning environment are able to pass the final examinations, achieve equal results in comparison with students in a traditional educational setting. Doubts about computer-based delivery as, for instance, expressed by Kozma [31] can be rejected when the latter studies are taken into account. Students are able to acquire the necessary knowledge and skills by reading and learning from a computer display.

Hypothesis 2: subjects who use ESDs benefit (higher study outcome) from the non-discernable condition; in contrast, subjects who do not use ESDs, benefit from learning materials where ESDs are clearly discernable.

The results show a significant interaction: students who use many processing and testing ESDs benefit from a condition in which ESDs are integrated into the basic content of the learning materials. In contrast, students who use only a few ESDs benefit from learning materials in which ESDs are clearly discernable. The interaction was only significant for students studying in the ILE. As a result, this hypothesis can only partly be accepted.

The results are in line with results reported by Portier and Van Buuren [7]: some students explicitly

indicated that they would prefer a discernable delivery of ESDs, whereas others seemed to prefer a completely integrated delivery.

Hypothesis 3: students who study in an interactive learning environment achieve a higher study outcome than students using a non-interactive learning environment.

Considering the results, this hypothesis has to be rejected. Interactivity is one of the basic functionalities of the prototype of the interactive learning environment. At the theoretical level, interactivity was implemented in our approach because of a constructivist perspective on learning (e.g. [32]) which states that the acquisition of new knowledge schemes benefits from an active self-directed learning process.

A possible explanation for the non-significant differences can be found in the relatively small number of students who studied in the non-interactive learning environment.

Hypothesis 4: the prior knowledge state of a student is positively related to the active use of the interactive learning environment, and is an interaction variable in the relation between treatment and study outcome.

The analyses reveal that PKS is positively related to ESD-use. Moreover, it appears that this effect is especially present for processing and testing ESDs. At a detailed level it is found that the use of processing ESDs can be predicted from particular subscores of the PKS ("know" and "relation"). In parallel, the use of testing ESDs is positively related to subscores on the "insight" and "structure" parameters. As a conclusion, we can state that the first part of the hypothesis can be accepted.

If we research the interaction of prior knowledge between ESD-use and study outcome, we perceive that the effect is significantly more pronounced in a condition where ESDs are not discernable, i.e. integrated into the basic content. Also the second part of the hypothesis can be accepted. This specific interaction can be explained as follows. Students with a high level of prior knowledge can compensate for the lack of structure in the low discernability condition [33] since they can rely on knowledge structures already available. Students with a lower level of prior knowledge do not have this knowledge, which leads to a negative impact on their study outcome if the task environment is also unstructured.

Hypothesis 5: good readers need fewer ESDs to support their study activities; reading comprehension is an interaction variable in the relation between treatment and study outcomes.

Considering the non-significant analysis results, the first part of this hypothesis is rejected.

In our theoretical model, the reading comprehension process is considered to be closely related to the learning process. Van Oostendorp and Peeck [34] argue that reading does not always imply a learning intention directed at changing an existing cognitive structure. The difference between reading and learning is associated with the intentionality of the reading process. Our reading comprehension test did focus on "comprehending" text fragments. However, the test did not focus on "learning" these text fragments. This might explain the weak relationship between reading comprehension level and the use of supportive elements in the learning materials.

Also, the results do not support the second part of the hypothesis, since there are no significant interactions between reading comprehension level and any of the experimental conditions. The discussion about the "intentionality" of the reading process is also relevant here. In addition, we may question what the relevance is of reading comprehension in the domain of learning statistics. It is possible that reading comprehension is clearly related to understanding and learning predominantly textual learning material, but a considerable part of a statistics course includes the application of methods (formulas), making exercises or solving problems.

Hypothesis 6: motivation and ESD-use are positively interrelated; their interaction influences study outcome.

Motivation does not seem to influence the use of ESD-types. This is in contrast with our model, since we expected an influence of motivation on the use of ESDs.

The concept of attitude is related to the concept motivation. A questionnaire on attitude towards computers shows that students' attitude towards learning with computers appears to be positively related to ESD-use. The latter effect is significantly more pronounced for testing ESDs. Post-hoc analysis showed a significant positive correlation between attitude and motivation.

As for the interaction effect of motivation influencing the use of the learning environment and thereby

influencing post test scores, no significant interaction effects have been found. However, if we introduce again the relation between "motivation" and "attitude towards learning with computers", a different picture appears. In the interactive learning environment, a student's attitude towards learning with computers is a significant, predictive variable for the variable study outcome.

In summary, hypothesis 6 is to be rejected but via the relation with attitude towards computers there is a relevant influence of a non-cognitive variable.

CONCLUSIONS

Regarding the main aims of the present study, the research results show the relative effectivity of independent learning materials and of ILE.

The ILE are not less effective than printed learning environments or face-to-face lectures. For efficiency reasons face-to-face lectures might be replaced by self study conditions. It must be noted however that the conditions in which we used self study materials were not completely self study conditions, because the materials could not be studied at home.

Although comparison of the different types of ILE does not directly result in significant differences in learning outcome, the significant interaction effects clearly show that individual student characteristics play a role in making use of the learning environment and as such influence study outcome. Depending on the degree to which particular settings of the interactive learning environment (discernability, interactivity, ESD-use) are in line with student characteristics, the effectivity of ILE is different. The latter is most clearly demonstrated by the interaction effects of discernability. Discernability of ESDs is not beneficial for students who use many ESDs. Giving these students the "wrong" discernability condition leads to significant negative effects on their study outcome.

Extrapolating these findings to the future design of ILE, this implies that students might be advised automatically about a preferred combination of settings (e.g. to select or deselect ESDs, to make them discernable or not, to get a printed version next to the interactive versions). However control to adapt the learning environment to individual needs should always be with the individual student. In future prototypes of ILE we will, therefore, try to improve the adaptivity to student characteristics and students' preferences. This will also imply the development of new, interactive ESDs. In this way, we hope to develop and implement an interactive learning environment that optimizes the task environment to the needs of the individual student.

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