Educational Technology Expertise Center
Open University of the Netherlands

Research fellow project proposal

This project falls in the following research theme(s):

Design
☐ Competency analysis / domain modeling
☐ Learning tasks & learner support

Delivery
☐ Composing instructional messages
☐ Computer-mediated communication

Diagnosis
☐ Performance-based assessment
☐ Quality control & assurance

1 Project chair
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2 Project name
English: Split-attention and modality effects in case-based multimedia learning
Dutch: Verdeelde aandacht en modaliteitseffecten in een multimediale probleemgestuurde leertaak

3 Place in the organization
Delivery theme of the research program of the Educational Technology Expertise Center (Otec)

4 Synopsis of the research problem
English
The proposed PhD-project intends to refine cognitive load theory (Sweller, 1988; Sweller, van Merrienboer, & Paas, 1998) in relation to instructional design. The emphasis is on investigating split-attention and modality effects in using worked examples, implemented in a case-based multimedia learning environment. The split-attention effect indicates that the use of different information sources causes a higher cognitive load of working memory, and therefore impedes the learning process. However, this can be prevented by integrating the information sources. An alternative solution is offered us by combining auditory and visual information. This leaves memory space for the actual learning process, since the theory presupposes different processors in working memory, one for each modality. The relationship between split-attention effect and this ‘modality’ effect is at the centre of the research. In addition to this we’ll look at the influence of task complexity and prior knowledge, which will result in a subsequent specification of cognitive load theory. The main hypothesis in this research project is that when integration of words and pictures is required, combining auditory and visual information sources in multimedia systems will promote learning processes - especially for learners with low prior knowledge. The project will provide guidelines for the development of multimedia learning environments, and is co-funded by SPC Group in Den Bosch.
The proposed AIO-project aims to further refine cognitive load theory (Sweller, 1988; Sweller, van Merrienboer, & Paas, 1998) in relation to the design of instructive environments. The focus is on investigating the split-attention effect and the modality effect when using worked examples. This involves the application of these concepts within a case-based multimedia learning environment. The split-attention effect indicates that the use of different information sources increases cognitive load and hence hinders learning processes. By integrating information sources, this can be prevented. Another solution is the combination of auditory and visual information. This way, more space is available for the actual learning process, as according to the theory for different modalities separate processors exist in working memory. The relationship between this modality effect and split-attention is central in the research. Furthermore, we look at potential influences of task complexity and prior knowledge, which will lead to a further elaboration of the cognitive load theory. The main hypothesis to be investigated in this project is that a proper combination of auditory and visual information sources in multimedia systems can promote learning tasks where the integration of word and image plays a significant role - especially for learners with little prior knowledge. The project will provide practical guidelines for the development of multimedia learning environments and is partly financed by SPC Group.

### Composition of the research team

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<thead>
<tr>
<th>Name and titles</th>
<th>Expertise/function</th>
<th>Department</th>
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<tbody>
<tr>
<td>a Project Chair</td>
<td>dr. Rob Martens</td>
<td>educational technologist</td>
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<tr>
<td>b Project team</td>
<td>drs. Huib Tabbers</td>
<td>PhD student (AIO)</td>
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<tr>
<td>c Ph.D. supervisor</td>
<td>Prof. dr. Jeroen van Merriënboer</td>
<td>head of the research department</td>
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<td>d Consultants</td>
<td>dr. Otto Jelsma</td>
<td>boardmember SPC group</td>
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<td></td>
<td>Prof. dr. John Sweller</td>
<td>School of Education</td>
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### Length of the project

- **Begin date:** 01/09/1998
- **End date:** 31/08/2002
- **Total length:** 4 years

### Intended output

- **a. Publications and conference presentations**
  - The result of the literature study will be an Otec-report.
  - Each experiment will result in a scientific article as well as a short report for the SPC Group.
  - The experimental results will also be presented at several conference meetings.
  - The research project will eventually result in a dissertation written by the AIO, and a final report for the SPC Group.

- **b. Instruments and procedures**
  - To test our hypotheses we’ll develop a multimedia learning task

### Further elaboration

- **a Further elaboration of the problem and aims of the research project**

  The use of multimedia technologies in an educational setting offers new challenges to instructional designers. New kinds of learning tasks can be created adding assets like audio and video. This raises the question how to use these new technologies in order to construct efficient instructions. How can we design multimedia learning tasks that make the student learn with the least effort? In this research project we examine the role of integrating verbal and visual information in instructions, especially for the teaching of complex cognitive skills. A theoretical framework is offered by cognitive load theory, which takes the learners limited processing capacities as a starting point for instructional design.

  **Theoretical Framework: Cognitive Load Theory**
Cognitive load theory (Sweller, 1988; Sweller, Van Merrienboer & Paas, 1998) has been
developed to provide guidelines for instructional design. The theory assumes the learner has a
limited capacity of working memory as well as an effectively unlimited long-term memory, holding
cognitive schemata that vary in their degree of automation. It is through the building of increasing
numbers of ever more complex schemata, by combining elements consisting of lower level into
higher level schemata, that skilled performance develops. Often, this acquisition of schemata is
an active, constructive process. One of the obvious functions of schemata is to provide a
mechanism for knowledge organization and storage. But they also reduce working memory load,
as they can be treated as single entities. In addition, automation is an important process in the
construction of schemata. Automaticity occurs after extensive practice. With sufficient practice, a
schema can be activated with minimal conscious effort (i.e. with minimal working memory load).

This cognitive architecture suggests that an important goal of learning complex skills is the
construction and the automation of schemata that are useful for solving the problems of interest.
Although schemata are stored in long-term memory, in order to construct them, information must
be processed in working memory. Relevant sections of the information must be extracted and
manipulated in working memory before being stored in schematic form in long-term memory.
The ease with which information may be processed in working memory is the prime concern of
cognitive load theory. Working memory load may be affected either by the nature of the to-be-
learned material (intrinsic cognitive load), or alternatively, by the way in which the material is
presented (extraneous cognitive load).

Intrinsic cognitive load cannot be altered by instructional interventions because it is intrinsic
to the material being dealt with. Its main aspect is the amount of information-elements a learner
has to keep in working memory at the same time. However, the size of these elements is
dependent on the schematic knowledge available to the learner. For an example, a child who
has just started learning to read will consider each letter as a single element, whereas an
experienced reader will take a whole word, or even part of a sentence as one element. So, to
determine the intrinsic load of learning material, one always has to bear in mind the prior
knowledge the learner brings to the task.

Extraneous cognitive load on the other hand, is mental load inflicted on the learner by the
instructional format. Appropriate instructional design should try to keep this load as low as
possible, in order to leave maximum working space available for the actual learning process. In
other words, keeping the extraneous load as low as possible is conditional to optimal learning.
However, this is only part of the story, as we also want the learner to invest enough mental effort
into the learning process itself, by embedding the information into long-term memory. So, the
second aim of instructional design should be to motivate constructive learning processes.

Some successful attempts to minimize extraneous cognitive load by redesigning instructions
include the goal-free effect (e.g., Bobis, Sweller & Cooper, 1994), worked examples (e.g., Paas
& van Merrienboer, 1994a), and completion problems (e.g., van Merrienboer, 1990; van
Merrienboer & de Croock, 1992). The goal-free effect is found in comparing conventional and
goal-free problems. Goal-free problems alter learner activities in a manner that reduces the
extraneous cognitive load caused by means-ends problem solving. In that way they encourage
schema construction and yield better performance on transfer tasks than conventional problems.
The effect of worked examples is found in comparing traditional problem solving with studying
worked-out examples. Again, worked-out examples seem to reduce extraneous cognitive load,
improve schema construction, and yield higher transfer performance. The same effects are
found for completion problems, in which a partial worked-out example is provided to the learners
which has to be completed by them. The advantage of completion problems over worked
examples is that the former forces the learner to actively engage in the learning task.

Other instructional interventions to stimulate learning processes mainly include techniques
that promote the elaboration and deep processing of new learning materials, such as asking
questions in order to promote self-explanation (for an overview of techniques, see Jelsma, van
Merrienboer, & Bijlstra, 1990; Martens, 1998; van Merrienboer, 1997; van Merrienboer, Jelsma,
& Paas, 1992). Here, it is critical that learners are promoted to link new information to their prior
knowledge and to induce more general schemata on the basis of a varied range of cases (also
called the “variability effect”; Paas & van Merrienboer, 1994a). Problem-based and case-based approaches have repeatedly been found to be effective in promoting elaboration and deep processing of new learning materials (for a review, see Schank, 1996).

According to the above, (multimedia) instructions for the teaching of problem solving skills will be more successful when adopting a case-based approach. In our project, worked examples for each case will be presented to the learners because this may decrease the extraneous cognitive load. The focus of our research is on the relationship between the design of these worked-out examples and the obtained learning results.

**Split-attention and modality**

The worked-out examples used in our experiments will consist of pictorial information (e.g., diagrams, causal nets, flow-charts) together with explanatory texts. Two effects are of interest: the **split-attention effect** and the **modality effect**.

The split-attention effect indicates that worked examples do not always lower the extraneous load. If they require learners to integrate different sources of information (e.g., text and diagrams), they are often not effective. The learner has to switch between text and picture, and is forced to keep information-elements in working memory for a longer time, causing a higher extraneous load. To decrease this load, the learning material should be redesigned by integrating the information-elements. This can be accomplished by putting the text into the picture, thereby reducing the amount of visual switching (e.g., Chandler & Sweller, 1991; Sweller, Chandler, Tierney, and Cooper, 1990).

Multimedia instruction can offer another way of reducing extraneous load, by presenting different information-elements in different modalities. By hearing narration while looking at a picture, the learner uses two senses rather than one. A number of studies show that dual-modality presentation techniques (i.e., presentation techniques in which the verbal information is presented as spoken rather than written text) may have beneficial effects on learning. Mousavi, Low and Sweller (1995), and Tindall-Ford, Chandler and Sweller (1998) tested for the modality effect and found dual-modality instructions to be consistently superior to purely visual instructions. Jeung, Chandler and Sweller (1997) refined these results, as they showed that the modality effect is only found when the visual complexity of a picture is low, or when the explanatory text is supported with visual cues. In our first experiment, we will look at the relationship between split-attention and modality effects, by comparing different instructional formats.

**Explanation of the modality effect**

The modality effect can be viewed from two different perspectives. Firstly, according to Paivio’s dual coding theory (Paivio, 1988), human memory has different subsystems for processing verbal and non-verbal information. Learners will remember information best when it presented both modes, provided that text and picture enter working memory at the same time. In that case a referential link can be made, resulting in a richer memory trace. The best way to put both text and picture in working memory at the same time is by presenting them in different modalities. Translated to cognitive load theory, this means that the modality effect is the effect of an optimal integration of information-elements, preventing split-attention.

An alternative view follows the assumption that working memory includes partially independent sub-components to deal with auditory and visual information (Baddeley, 1992). As Penney (1989) indicated in a detailed review of experimental psychological literature, effective working memory capacity can be increased by using both visual and auditory input rather than either sub-component alone. Although less than purely additive, there seems to be an appreciable increase in capacity available by the use of both modalities, rather than a single one.

The second experiment aims at a careful investigation of the modality effect. The main question is whether the modality effect can be seen as the prevention of split-attention (as in Paivio), or mainly as a consequence of an increase in available working memory (as Sweller et al. suggest)? Or is it the result of a combination of both mechanisms?

**Prior knowledge and redundancy effect**

Learning should be a constructive process. Thereby, we mean that a student should link new
knowledge to existing schemata. Giving explanatory texts without considering what someone already knows may overload this person with unnecessary information. In terms of cognitive load theory, this is called the redundancy effect. Part of working memory space is filled with information already available in a person's long-term memory, thereby leaving less space for the learning of new parts of the information. Kalyuga, Chandler, and Sweller (1998) showed the redundancy effect in some training program for electrical engineers. Mayer (1997; see also Mayer & Anderson, 1992) reviewed six studies concerning for whom multimedia instruction is effective, and concluded that the modality effect is probably strongest for learners with low prior knowledge. This can be seen as a consequence of the redundancy-effect, as the learners with high prior knowledge receive unnecessary information when presented both text and pictures. A more effective instruction could be to present text only when someone needs it to understand the pictorial information.

The problem with giving someone only the necessary information is that this will differ for each individual. To prevent complex assessment procedures, we might let the student decide for him- or herself which verbal information is given when confronted with pictorial information. Again, multimedia-technology gives us the tools to support this process, by using clickable maps, pop-up balloons etceteras.

In the third experiment we will investigate the learning-effects of this 'information on demand', including the role of the modality in which the information is presented.

Experiments
The proposed three experiments aim at a refining of the cognitive load theory by not only taking the modality effect but also the split-attention effect into account. The main hypothesis investigated in the proposed experiments is that mixing auditory and visual information sources may be especially helpful to learners with low prior knowledge who are confronted with complex learning tasks.

In the first experiment we will study the relationship between modality effect and split-attention in a case-based multimedia learning task. Worked examples provided for each case will consist of diagrams and explanatory texts. Generally speaking, four experimental conditions will be compared to one another:

- **visual/non-integrated.** Diagrams and texts both presented in a traditional, non-integrated visual format (e.g., diagram on one part of the screen, explanatory texts on another part of the screen). This presentation format is expected to yield high extraneous cognitive load combined with low effective working memory capacity.

- **visual/integrated.** Diagrams and texts presented in a visual, integrated format (i.e., explanatory texts are clearly linked to the relevant parts in the diagram). This presentation format is expected to yield low extraneous cognitive load combined with low effective working memory capacity.

- **audio-visual/non-integrated.** Diagrams are presented visually and explanatory texts are presented orally, without integrating the diagrams and the spoken text by visual cues. This presentation format is expected to yield high extraneous cognitive load combined with high effective working memory capacity.

- **audio-visual/integrated.** Diagrams are presented visually and explanatory texts are presented orally. The part of the diagram that is explained in the spoken text is simultaneously highlighted (e.g., by flashing or color coding). This presentation format is expected to yield low extraneous cognitive load combined with high effective working memory capacity.

Given the theoretical framework, main effects of modality and integration are expected, showing impaired learning for the visual/non-integrated condition and superior learning for the audio-visual/integrated condition. More in particular, the visual/integrated and audio-visual/non-integrated conditions will be compared with regard to possible interactions. In the latter condition, we expect a lot of variance as a result of individual differences in visual search.

To examine the modality effect more closely we will create a new split-attention factor in the second experiment. We'll use the same four conditions as in the first experiment, only in the non-integrated conditions we'll offer the verbal and pictorial elements of the instructional material
sequentially instead of simultaneously. A main effect of both modality and integration can be expected, but there'll be some interesting interaction effects. According to the Paivio-view, by separating text and picture in time, dual-modality instruction loses its advantage over purely visual instruction, and thus learning results should be comparable. However, according to the Sweller-view sequential dual-modality instruction should still give better learning results, as a consequence of the increase of available memory resources.

As we haven't taken prior knowledge into consideration yet, the third experiment will concentrate on this issue. We'll compare two different instructional formats, one in which students who have some kind of prior knowledge of the subject will have to go through a complete explanatory text and one in which they can get explanation on demand. The latter will be implemented by making a cursor in the shape of a question mark, which can be placed on those parts of the pictorial information that the student wants more information about. The verbal information will be presented as a narration or as text balloons. So again we'll have four conditions, and we expect main effects of choice and modality. However, there could be an interaction, as it can be argued that written text gives students the possibility to skip more easily through unnecessary parts of the information.

An extra option would be to let the students choose not only which information they want, but also the presentation format. The rationale would be that some students will rather read information than listen to it, so giving them the choice could have beneficial effects on the learning result.

b Scientific importance of the research, including the importance for the Open University of the Netherlands and the place of the research in the Otec Research Program

Up to the present, cognitive load theory almost exclusively focused on instructional measures suitable to decrease extraneous cognitive load. Studies aimed at increasing effective working memory load by using multi-modality presentations are just beginning to appear. The added value of the proposed project is in its careful investigation of relationships between split attention and the modality effect, taking task complexity and prior knowledge of the learners into account. This will yield an important refinement of cognitive load theory.

From a practical perspective, the results provide a new instructional technique. Under split-attention conditions, rather than physically integrating disparate sources of information, learning may be facilitated by presenting textual information in auditory mode. This effect is especially important in the field of multimedia design. Multimedia instruction is becoming increasingly popular but much of the work is a-theoretical. Findings associated with the modality effect can provide both a coherent theoretical base and a set of highly practical guidelines for further multimedia investigations and applications.

As the Open University is moving to a third generation of distance learning, in which an electronic learning environment plays a central role, the question of how to construct effective multimedia learning materials is a crucial one. This project is embedded in the Otec Research Program. As it is concerned with the instructions in a multimedia surroundings it falls in the ‘delivery’-theme, and more specifically in its sub-theme ‘instructional message design for electronic delivery’.

c Design & Methods

Each experiment will use an acquisition phase and a performance phase. In the acquisition phase, subjects will work on a range of cases and study the worked examples which are presented according to the different conditions. In the performance phase, subjects have to solve a range of new problems for which no worked examples are available. A distinction is made between near transfer problems and far transfer problems. Compared to the worked examples studied during the acquisition phase, near transfer problems have a different surface structure but the same deep structure; far transfer problems have both a different surface structure and a different deep structure. The problems either concern explanation problems or the application of procedures, depending upon the experiment.

During the acquisition phase, the following measurements are taken for each case/worked example: (1) time needed to study the worked example, (2) cognitive load associated with the
study of the worked example, measured by a 9-point rating scale. During the performance phase, the following measures are taken: (1) time needed to solve the problem, (2) quality of the solution (which will be rated by two independent observers).

Following the experiment, subjects will receive a questionnaire concerning the motivational aspects of worked examples. It is known that multi-modality presentations and animations may increase motivation (cf. Rieber, 1991) and positively affect learning outcomes. For each of the experimental conditions, the relative mental efficiency will be determined using a technique developed by Paas and van Merrienboer (1993; for applications, see e.g. Paas & van Merrienboer, 1994b; Tindall-Ford, Chandler & Sweller, 1998). Their computational method combines the intensity of mental effort being expended by the learners with the level of performance attained. This efficiency approach is based on the conversion of raw mental effort data and raw performance data to z-scores, which can be displayed in a M(ental effort)-P(erformance) cross of axes. The combined effects on mental effort and performance of experimental instructional conditions can be deduced from the relative position of points on the display. All data will be analyzed with ANCOVA (with motivation as possible covariants) and/or MANOVA.

d Literature
instructional design. *Educational Psychology Review.*

<table>
<thead>
<tr>
<th>year</th>
<th>month</th>
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<tr>
<td>1998</td>
<td>sep-oct</td>
<td>literature study</td>
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<tr>
<td></td>
<td>nov-dec</td>
<td>stay at SPC group [ICO introductory course]</td>
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<td>1999</td>
<td>jan-feb</td>
<td>literature study, writing of report</td>
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<td>26 feb</td>
<td>feb-june</td>
<td>Otec-report about literature</td>
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<td>aug-oct</td>
<td>setting up and conducting first experiment</td>
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<td>dec-aug</td>
<td>writing final report and dissertation</td>
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11 Motivation for external partners
This project was originally set at the University of Maastricht. With no educational multimedia designers available, expertise outside the university was needed, and found at the SPC Group in Den Bosch. Secondly, SPC group was prepared to fund part of the project, and will offer a workplace and technical support to the AIO.

12 External financial support for project
The SPC Group will pay half the personnel costs of the AIO.

21/01/1999