

# Educational Technology Expertise Center Open University of the Netherlands

## Research project proposal

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

Tasks	<input type="checkbox"/> Domain specific competence development <input type="checkbox"/> Learner guidance & support <input type="checkbox"/> Assessment of complex performances
Environments	<input type="checkbox"/> Domain specific competence development <input checked="" type="checkbox"/> Learner guidance & support <input type="checkbox"/> Assessment of complex performances
Communities	<input type="checkbox"/> Domain specific competence development <input checked="" type="checkbox"/> Learner guidance & support <input checked="" type="checkbox"/> Assessment of complex performances

### 1 **Candidate**

PhD student - To be recruited

### 2 **Project title**

A Cognitive-Load Approach to Collaborative Learning: Task and Learner Characteristics

### 3 **Place in the organization**

This project is part of the OTEC research program (2004-2008).

### 4 **Synopsis of the research problem**

While all levels of education are making use of collaborative<sup>1</sup> learning techniques in both traditional and electronic learning environments, the effectiveness of these types of education/learning has still not been proven. The results are mixed (at best) and educators often have to implement 'extra' measures to either ensure that the participants work together (e.g., requiring a specific number of contributions in electronic environments or requiring attendance in face-to-face environments) or ensure that all learners engage in the learning process (e.g., implementing roles, scripts, and assessment schemes). The basic assumption of this project is that if individual learners are to work together effectively in groups, the architecture of their cognitive system and the characteristics of the task must be understood, accommodated, and aligned. Specifically, this means that the characteristics of the (group) task must be such that the cognitive system of each of the individuals is not capable of accommodating its solution AND the group communication and coordination activities necessary for effectively functioning as a team (i.e., the cognitive transaction costs) do not impede the collaboration process. This project uses a cognitive load theory-based approach to develop a method to determine a group's cognitive load and to investigate how task complexity (i.e., intrinsic cognitive load) and the learner characteristics expertise and age can inform the design of effective group-based environments for lifelong learning.

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<sup>1</sup> Some people use the terms collaborative and cooperative interchangeably (knowing that there are differences, but accepting that in the larger view of things they have so many characteristics in common that for most situations they can be considered fairly synonymous) while others see deep educational and philosophical differences between them. The writers of this proposal have chosen for the former and will use the term collaborative in this proposal.

**5 Research team**

	Name / titles	Expertise/function	Dept.
PhD student		(Educational) psychologist or -technologist	OTEC
Chair	Fred Paas	Educational Technologist	OTEC
PhD supervisor	Paul Kirschner	Educational Technologist	OTEC

**6 Length of the project**

Begin date: September 1, 2005

End date: August 31, 2009

Total length: 4 years

**7 Intended output****a Publications and conference presentations**

Type	Nr	Planning
Conferences (scientific)	2	National: ORD
	4	International: EARLI, AERA, CSCL, AECT
Articles (SSCI journals)	4	Experiment 1 (2006) Experiment 2 (2007) Experiment 3 (2008) Experiment 4 (2008)
Dissertation	1	August 2009

**b Instruments and procedures**

Based on the complexity of the task, the expertise of the learners, the age of the learners, and interactions between these factors this project will result in instructional design guidelines for effective collaborative learning environments. In addition, an instrument to relate individual cognitive load ratings to the group's overall cognitive load will be developed.

**8 Further elaboration****a Further elaboration of the problem and aims of the research project, including scientific framework***Problem definition*

Contemporary learning paradigms situate lifelong learning in computer supported or mediated collaborative environments, which can be either synchronous or asynchronous and distributed or non-distributed. In these paradigms, collaboration is emerging as one of the promising learning approaches in education for educational reasons (i.e., acquiring many important competencies using authentic whole tasks requires working in teams and acquiring the needed 'soft' skills for such teamwork is now an explicit goal at many levels of education), social reasons (i.e., learning and working are seen as social activities where others are and must be involved), and economic reasons (i.e., mass education can no longer adequately foot the bill for the staff needed for individual teaching, guidance, and support). Collaborative learning models are based on the premise that learning is best achieved interactively rather than through a one-way transmission process. However, the research on (online) collaborative learning has revealed mixed results. Along with the positive findings showing at least the potential for positive benefits of collaborative learning (e.g., Cronjé, 1997; Gunawardena, 1995), mixed and negative findings have also been reported regarding the learning process itself (Gregor & Cuskelly 1994; Hallet & Cummings, 1997; Heath, 1998; Mason, 1991), and regarding group forming and group dynamics (Hiltz, 1998; Hobaugh, 1997; Hughes & Hewson 1998; Taha &

Caldwell, 1993). On the one hand, students seem to become more actively engaged in collaborative learning activities, they retain the information being learned longer (Morgan, Whorton, & Gunsalus, 2000), and their higher-order skills are fostered more than in the more traditional lecture-based learning environment (Sloffer, Dueber, & Duffy, 1999). All of this is primarily the case in highly structured and /or highly scripted learning environments (Dillenbourg, 2002). On the other hand, it has become clear that placing learners in a group and assigning them a task does not guarantee that they will engage in effective collaborative learning (Soller, 2001). We believe that the mixed results have, among other things, been caused by the dominant research focus on naturalistic studies in real contexts.

Kirschner, Martens, and Strijbos (2004) argue that most systematic design process models center on designing effective conditions for the attainment of individual learning outcomes (Van Merriënboer, Kirschner, & Kester, 2003) and attempt to control instructional variables to create a learning environment that supports the acquisition of a specific skill (i.e., student A will acquire skill B through learning method C). This control of the instructional variables is complicated by the use of groups in the case of collaboration. In groups, a multitude of individual and group-level variables affect the collaborative learning process making it practically impossible to predefine the conditions of learning or instruction for a group-setting such that interaction and competency development are controlled. Kirschner, Martens, and Strijbos argue that instead of a classical causal view of learning and design, the design of collaborative settings requires a more probabilistic approach to learning and design (see Figure 1).

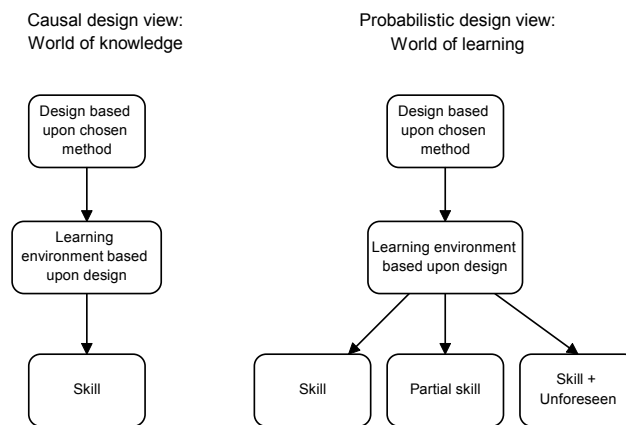


Figure 1 Causal and probabilistic views of design

This focus often leads to a complex pattern of interactions between cognitive, motivational, and social factors that are difficult to interpret. An example of this, as will become clear in the rest of this proposal, is the assumed trade-offs between individual, group and distributed cognitive load. We acknowledge that, ultimately, the research on group-based learning requires an interrelated perspective integrating cognitive, motivational, and social aspects. However, to be able to disentangle the contributions of each of these factors to the learning processes and outcomes of group-based learning, they need to be studied within tightly constrained experimental environments, one at a time, keeping all other aspects constant.

According to evolutionary biologists, humans have evolved a cognitive capacity for cooperation and populations of cooperators have higher average fitness than populations of uncooperative individuals. Michod (2003), for example, states that “the formation of cooperative interactions among lower-level individuals [is] a necessary step in evolutionary transitions; only cooperation transfers fitness from lower levels (costs to group members) to higher levels (benefits to the group)” (p. 291). To exploit

this capacity for the learning of complex cognitive tasks, collaborative learning environments need to be properly aligned with human cognitive architecture. The basic assumption of the present project is that if individuals are to work together and learn effectively in groups, the architecture of their cognitive system and the task must be understood, accommodated, and aligned. The human cognitive architecture, specifically the limitations of the working memory capacity at the individual level, can be considered an important reason to assign tasks to groups rather than to individuals.

This project uses a cognitive load theory-based approach to investigate how task and learner characteristics can inform the design of effective group-based environments for lifelong learning. In the past two decades, cognitive load research has generated a substantial knowledge base on the design of instruction for individual learners. However, previous research on group-based learning has made clear that there is no one-to-one mapping of instructional design guidelines for individual learning and group-based learning (see the earlier stated position that learning in teams is not causal, but probabilistic; see also Chapter 2 of Kreijns, 2004 and Kreijns, Kirschner, & Jochems, 2003). Therefore it could be important to use the cognitive load perspective to analyze group-based learning environments to determine the conditions under which they may or may not be effective.

An example of how this one-to-one mapping problem could play a role was presented by Kirschner (2002). In his inaugural address he posited that most computer supported collaborative learning research, but this can be generalized to collaborative learning in general, focuses on surface characteristics (e.g., synchronicity or asynchronicity, 'optimal' group size is, if the task was a case, a problem or a project). This surface level approach disavows fundamental questions such as: Was collaboration necessary? Did learners design (i.e., the goal being divergent and creative) or prove or diagnose something (i.e., the goal being convergent and specific)? Who determined the goal, how to reach it, and what is correct? More fundamental questions which need to be studied deal with the nature/characteristics of the task, especially such non-surface level factors as:

- *character* (i.e., How complex is the task? Is the task monodisciplinary, multidisciplinary or interdisciplinary in nature? Where does the task lie along a continuum running from constructed, well-defined, convergent tasks to authentic, ill-defined (wicked), divergent tasks?),
- *ownership* (i.e., Who determines or is responsible for determining what each of the participants in a collaborative learning environment must do and who provides the (social) steering?), and
- *control* (i.e., Who determines who does what within the learning situation? Who determines which solution or solution path is most adequate, most applicable or best?).

This project deals with the first characteristic, namely the character of the tasks prescribed and, in particular, to their *complexity*. This increase in complexity can lead to costs for the learners (group members) since an increase in complexity can, on the one hand lead to an increase in misunderstandings, differences between understanding and agreement and differences in perspective with respect to what has to be done and who has to do it while on the other hand it can lead to an increase in (positive) interdependence, individual and group accountability, and promotive interaction (Kirschner, Strijbos, & Kreijns, 2003).

Cognitive load theory (CLT: Paas, Renkl, & Sweller, 2003, 2004; Sweller, 1999, 2004) is concerned with the learning of complex cognitive tasks, where learners are often overwhelmed by the number of interactive information elements that need to be processed simultaneously before meaningful learning can commence. Instructional control of this (too) high load has become the focus of CLT. The theory suggests that learning occurs best under conditions that are aligned with human cognitive

architecture. CLT assumes a cognitive architecture that consists of a long-term memory (LTM) and a working memory (WM). LTM is viewed as the central structure of human cognition. It contains huge amounts of knowledge structures that can be described as hierarchically organized schemas that allow us to categorize different problem states and decide the most appropriate solution moves. Learning is defined here as a change in content and structure of LTM (Kirschner, Sweller, & Clark, in press). WM can be equated with consciousness. We are only conscious of the information currently being processed in WM and are oblivious of the far larger amount of information stored in LTM. WM has two well-known characteristics: when processing novel information, it is very limited both in duration and capacity. With regard to duration, almost all information stored in WM and not rehearsed is lost within 30 sec. The processing capacity of WM is limited to only 4 plus or minus 1 element (Cowan, 2001). The interactions between WM and LTM may be even more important than the processing limitations. The limitations of WM only apply to new, yet to be learned information. New information such as new combinations of numbers or letters can only be stored for brief periods with severe limitations on the amount of such information that can be dealt with. In contrast, when dealing with previously learned information stored in LTM, these limitations disappear. In the sense that information can be brought back from LTM to WM over indefinite periods of time, the temporal limits of WM become irrelevant.

CLT distinguishes between three types of cognitive load. The load is called 'intrinsic' if it is imposed by the number of information elements and their interactivity. If it is imposed by the manner in which the information is presented to learners and by the learning activities required of learners, it is called 'extraneous' or 'germane'. Whereas, extraneous load is imposed by information and activities that do not directly contribute to learning, germane load is related to information and activities that foster learning processes. Intrinsic, extraneous, and germane load are considered additive in that, taken together, the total load cannot exceed the memory resources available if learning is to occur (see, Paas, Tuovinen, Tabbers, & Van Gerven, 2003). The relations between the three forms of cognitive load are asymmetric. Intrinsic load provides a "base" load that is irreducible other than by constructing additional schemas and automating previously acquired schemas; in other words, by an increase in expertise. Any available WM capacity remaining after resources have been allocated to deal with intrinsic load can be allocated to deal with extraneous and germane load. These can work in tandem in that, for example, a reduction in extraneous load by using a more effective instructional design can free capacity for an increase in germane load. If learning is improved by an instructional design that reduces extraneous cognitive load, that improvement may have occurred because the additional working memory capacity freed by the reduction in extraneous cognitive load has now been allocated to germane cognitive load. As a consequence of learning new cognitive schemas, intrinsic load is reduced. A reduction in intrinsic load reduces total cognitive load, thus freeing WM capacity. The freed WM capacity allows the learner to use the newly learned material in acquiring more advanced schemas. A new cycle commences and over many cycles, very advanced knowledge and skills may be acquired.

Human cognitive architecture, specifically the limitations of the working memory capacity at the individual level, can be considered an important reason to assign tasks to groups rather than to individuals. When we treat groups as information processing systems with the individuals' working memories connected in parallel or series, it can be argued that the more complex the task (i.e., the higher the intrinsic cognitive load), the more efficient it will become for individuals to cooperate with other individuals in a fashion that reduces this load; thus it is task AND cooperation form independent. From a CLT perspective, collaborative learning will only be more effective than individual learning if the task demands exceed the cognitive resources that a single individual can supply plus the cognitive costs associated with the

communication and coordination of the knowledge between the group members (we call this *cognitive transaction costs*). Group coordination manages the interdependencies between group members so that every group member knows exactly which activities other members are carrying out, or will carry out, in order to effectively determine what one's own activities at the moment and in the future should entail (for a general discussion about coordination theory see Malone & Crowston, 1990). Group coordination has to happen at both the group level (e.g., allocating resources and defining workflow, see Ellis, Gibbs, & Rein, 1991) and the task level (e.g., a shared editor use requires group members to know exactly where others are typing, see Dourish & Bellotti, 1992; Gutwin, 1997). According to CLT, these communication and coordination activities impose an extraneous cognitive load (if they are not effective for learning), which should be minimized for collaborative learning to become effective. The extraneous cognitive load due to coordination will be highest in distributed asynchronous learning environments, lower in distributed synchronous learning environments, and lowest in non-distributed synchronous learning. Because we want to keep the extraneous load as low as possible, the current project will focus on non-distributed synchronous learning environments with coordination support.

Whereas valid and reliable instruments have been developed in the context of individual learning (for an overview see, Paas, Tuovinen, Tabbers, & van Gerven, 2003) there are no standard methods to determine the cognitive load of a group of collaborating learners. It is not clear if and how these individual measurements can be used to get a reliable estimate of the group's cognitive load, in other words whether an individual-level model can be used as a basis to understand group-level load. In this respect it is important to consider the distributed cognition paradigm (Hutchins, 1995), which attempts to provide an explanation that goes beyond the individual, in order to conceptualize cognition as embodied and situated within the context in which it occurs (Rogers & Ellis, 1994). The first experiment of this project is motivated by the lack of a method to determine the cognitive load experienced by groups of collaborating learners. The study is targeted at the development of a method to calculate the cognitive load of a group of collaborative learners by examining the amount of mental effort invested by the individual group participants.

The second experiment aims at identifying the level of task complexity (i.e., intrinsic cognitive load) at which it becomes more effective for learning, to assign tasks to groups rather than to individuals (Experiment 2). The third and fourth study focus on two learner characteristics that have been found to affect those aspects of human cognitive architecture (i.e., the manner in which cognitive structures are organized) that might determine the effectiveness of a group-based learning environment, and the relationships between these factors and the complexity of the task. Task complexity, defined as the number of interacting elements in a task, is relative to the number of schemas in LTM and the efficiency of WM processes. Whereas the number of schemas in LTM is mainly related to learner expertise, learner's age has been identified as an important factor affecting the efficiency of WM processes. Therefore, it can be expected that the task-complexity threshold at which cooperation becomes more effective than individual work will vary as a function of learner expertise (Experiment 3) and learner age (Experiment 4).

Experts possess a large number of domain-specific schemas which allow them to avoid processing overwhelming amounts of information and effectively reduce the burden on limited capacity working memory. In addition, experts are able to bypass working memory capacity limitations by having many of their schemas highly automated due to extensive practice (Kalyuga, Ayres, Chandler, & Sweller, 2003). Experiment 3 will investigate the hypothesis that task complexity needs to be higher for experts than for novices for cooperation to become effective.

One of the central findings of cognitive aging research is that the capacity of working memory declines with age in adults, impairing their ability to engage in

complex cognitive tasks for which the successful completion is highly dependent on the availability of sufficient cognitive resources. Paas, Camp, and Rikers (2001) have shown that instructional techniques that compensate for the reduced capacity can disproportionately enhance elderly people's performance. As such, collaboration or sharing cognitive load can be considered as a potential compensatory technique. Experiment 4 will investigate the hypothesis that the threshold for cooperation to become more effective than individual work, is lower for older adults than for younger adults.

The results of this project contribute to our understanding of the impact the factors age, expertise, and task complexity on the effectiveness of collaborative learning environments, and will aid in developing guidelines for these environments.

## **b Importance for the Open University of the Netherlands and the place of the research in the OTEC Research Program, as well as the relation with other OTEC programs**

### *Scientific importance*

This research will shed light on problems within two realms of scientific research that are both very current. The first deals with the realms of collaborative working and learning on the one hand and computer supported collaborative learning on the other. Although there is much ongoing research, design and development in these fields, there is little information as to when and how collaborative learning is effective and efficient. This research will add fundamental information dealing with the characteristics and nature of tasks in collaborative learning and working to the ongoing discussion.

The second realm is cognitive load theory. Although there is a wealth of current research on CLT, there is very little – if any – research with respect to how CLT can be used in learning by more than one individual. Cognitive science and socio-cultural science are studying phenomena as shared cognition, shared mental models, and other structures of collectively created meaning that emerge in and coordinate activities of groups. This research could provide a breakthrough in thinking about these phenomena.

### *Importance for the OUNL*

The OUNL is an institution for life long learning. As such, it has a population of students that is very heterogeneous, of which some are mature or even senior in age. In contrast with this, the gross of educational and educational psychological research takes place either in K-12 or traditional higher education. Added to this, the OUNL is making greater use of the possibilities of collaboration in teams for learning. This project specifically researches the role that age may play in determining the need and desirability of mature learners learning in teams.

### *OTEC research program*

The OTEC-research program aspires to develop a detailed and comprehensive theory of instructional design for open learning tasks, open learning environments, and open learning communities in higher (distance) education. This project will attempt to make a contribution to this effort, and namely with respect to the following two themes in the program:

1. Domain-specific expertise development and its implications for instructional design for complex learning.
2. Learner guidance and support mechanisms in learning communities and environments based on rich learning tasks.

### *Relation with other OUNL/OTEC programs*

The results of this research can be used (implemented) in both the Implementation and the Master of Active Learning programs. Development is busy with organization and self-organization in learning communities. This research, and especially Experiment 2 where the 'tipping point' from working alone to working in teams is studied, is particularly relevant in this respect.

## c Design & Methods

### *Participants*

Participants are recruited from the department of Cultural Sciences at the Open University of the Netherlands and from the department of Psychology at Erasmus University Rotterdam (EUR).

### *Groups*

In this research, a conscious choice has been made for making use of groups of three participants. The reasons for this are twofold. The first reason is a conceptual one. We have chosen not to work with dyads because, as the following three bullets show, the transaction costs required for this research will probably not occur in dyads.

- Research on verbal brainstorm productivity (Diehl & Stroebe, 1987; Mullen, Johnson, & Salas, 1991) indicates that dyads perform about as well as nominal groups (equal numbers of single brainstormers working alone) and that size effects become clear in groups larger than two. Verbal brainstorming groups, for example, suffer from process losses that increase with the size of the group due to production blocking, social loafing, evaluation apprehension, and cognitive interference.
- Rafaeli and Sudweeks' (1997) distinguished between three modes of communication: one-way, two-way, and interactive (including networked and whole group interactions). The first two take place in both dyads and groups larger than two participants, but on the third - which could cause an exponential increase in transaction costs - can take place in groups larger than dyads.
- Fuchs, Fuchs, Kazdan, Karns, Calhoun, Hamlett & Hewlett (2000) compared dyadic and four member groups' performance on a complex task. In that research, (small) group compositions elicited more cognitive conflict (i.e., disagreement and negotiation). This study suggests a relationship between group size and interaction.

The second reason is more practical, namely due to the fact that the design of the experiments requires a large number of groups, each additional group member would require a geometric increase in the number of participants (hard to find) and compensation costs.

### *Domain and learning environment*

The research is carried out in the domain of Psychology. Students are required to learn about classical psychological phenomena by studying their properties, inducing the underlying theory for themselves from existing data, and thinking about a possible experimental design to demonstrate the phenomenon. The task is presented as an interactive module consisting of a multimedia simulation of the phenomenon. Four levels of task complexity are distinguished and at each level two phenomena are selected from the following list of phenomena:

- Stroop - interference in serial verbal reactions (Stroop)
- Mental rotation - rotation of novel visual stimuli to determine whether the stimuli had the same shape or different shapes (Shepard)
- Partial report - how much information can be gathered in a single percept (Sperling)

- Attentional blink – the time after paying attention to one stimulus where attention cannot be focused on a subsequent stimulus
- Encoding specificity - whether an item will be remembered at a particular time depends on the interaction between the processing that occurred during encoding and the processing that occurs at retrieval (Tulving)
- Sternberg search - how information was retrieved from STM (Sternberg)
- Simon effect - people are faster and more accurate responding to stimuli that occur in the same relative location as the response, even though the location information is irrelevant to the actual task (Simon)
- Memory span – determine the limited capacity of our memory (Salthouse)
- Serial position - people have a great deal of difficulty remembering items near the middle of serial lists (Henson)

### Experiment 1:

#### *Goal.*

Determine the impact of task complexity on the amount of cognitive load people experience individually or in a group and develop a method to calculate the cognitive load of a group of collaborating learners.

#### *Design and procedure.*

Participants in the study are 60 first-year Psychology students from Erasmus University Rotterdam with an average age of 19 years. For each of 4 levels of task complexity (lowest, low, high, highest), 2 tasks in the domain of psychology (classical phenomena) will be developed. Task complexity or intrinsic cognitive load is determined by using Sweller and Chandler's (1994) method based on the number of interactive elements in a task. Thirty participants start to work individually on 4 tasks of 4 different complexity levels and then work in 3-person teams on 4 other tasks at these 4 complexity levels. Thirty other participants start to work in 3-person teams on these problems and then individually. So, for each participant the order of individual and teamwork is counterbalanced and the order at which the complexity levels are presented is randomized. The participants have to study and solve each problem and rate its cognitive load using Paas's (1992) mental effort rating scale. In addition, it will be determined how these ratings can be used to get the most reliable estimate of a group's cognitive load. The resulting computational method will be analyzed regarding its reliability and validity and implemented in a software tool that can be used in the experiments 2-4 of this project.

### Experiment 2:

#### *Goal.*

Determine the relationship between the load imposed by a task, the available cognitive capacity, and learning effectiveness. In addition, this experiment can give an indication of the level of task complexity (i.e., intrinsic cognitive load) at which it becomes more effective for learning to assign tasks to groups rather than to individuals.

#### *Hypothesis.*

An interaction between task complexity and cognitive capacity, indicating that at a low level of task complexity individual learning is more effective than group-based learning, at a high level of complexity group-based learning is more effective than individual learning.

#### *Design and procedure.*

Participants in the study are 60 first-year Psychology students from Erasmus University Rotterdam with an average age of 19 years. In a complete within-subjects design with Cognitive Capacity (individual vs. group) and Task Complexity (low vs. high) as factors, the learning effectiveness will be studied for 60 participants, either

learning individually or as a member of a 3-person group. Both learning effects due to order of learning individually or in a group and order of low, medium, or high complexity tasks are compensated by counterbalancing. That is, the participants will be randomly assigned to one of the Cognitive Capacity conditions in such a way that 30 participants work individually first and collaboratively second, the other 30 work in the reverse order. Each group of 30 participants will be randomly assigned to one of two orders of Task Complexity conditions in such a way that 15 participants work on three tasks in with a low-medium-high task complexity order, while the other 15 work on the tasks in a high-medium-low complexity order. The low and high complexity tasks are identical to the lowest and highest complexity tasks of Experiment 1.

After a general introduction to the whole group (15 min), the participants start in the learning phase working on the first experimental task (either in a group or individually, either high or low complexity). They have 30 min to work on the task. After the task each student has to rate the amount of mental effort on a 9-point cognitive load scale originally developed by Paas (1992). Next, the participants start to work on the second task (either in a group or individually, medium complexity), for which they also have 30 min. After the task they have to rate the cognitive load. Finally, in the learning phase, the participants start to work on the third task (either in a group or individually, either high or low complexity, depending on the first task), for which they also have 30 min. After this task they have to rate the cognitive load again. Both the group and individual sessions in the learning phase are videotaped to gather qualitatively data on the communication processes. From this qualitative data, the researchers should be able to determine both the types of transactions and amounts of transaction costs within the teams when carrying out the tasks. After the learning phase, participants have 1 hour to solve near transfer problems requiring them to individually apply the newly learned principles in familiar situations, and far transfer problems requiring them to use the principles in new, unfamiliar situations. Cognitive load is measured for each problem of the near and far transfer test. Mental efficiency is calculated with the formula of Paas and van Merriënboer (1993): High efficiency indicates a transfer test performance higher than might be expected on the basis of the overall cognitive load during the learning phase, while a low efficiency indicates a transfer test performance lower than might be expected on the basis of the overall load during the learning phase. Furthermore, the motivation of the students in each condition is computed as their "task involvement" (Paas, Tuovinen, van Merriënboer, & Darabi, in press). High task involvement is characterized by high investment of mental effort in learning yielding high transfer test performance; low task involvement is characterized by low investment of mental effort in learning and low test performance.

#### *Variables.*

Independent variables:

Cognitive Capacity (individual vs. group)

Task Complexity (low vs. high)

Dependent variables:

Learning: performance, processes, time, and effort

Test: performance (memory, transfer), time, effort, mental efficiency, and task involvement.

Transactions and transaction costs: coordination, communication, negotiation, interaction (with respect to types and amounts).

#### *Analysis.*

A 2 (Cognitive Capacity: individual vs. group) x 2 (Task Complexity: low vs. high) ANOVA with repeated measures on both variables is used to determine the hypothesized interaction effect of task complexity and cognitive capacity on learning effectiveness.

### Experiment 3:

#### *Goal.*

Determine the optimal trade-off between task complexity (i.e., intrinsic cognitive load) and learner expertise for the effectiveness of collaborative learning environments.

Note: the low-complexity tasks in this experiment are identical to the high-complexity tasks of Experiment 2.

#### *Hypothesis.*

At a low level of task complexity group-based learning is more effective than individual learning for novices, but not for more advanced learners. At a high level of task complexity group-based learning is more effective than individual learning for both low expertise and high expertise learners.

#### *Design and procedure.*

Participants in the study are 120 Psychology students from Erasmus University Rotterdam. In a mixed design with Task Complexity (low, high) and Cognitive Capacity (individual vs. group) as within-subjects factors and Learner Expertise (low vs. high) as between-subjects factor, the learning processes and outcomes will be studied for twenty 3-novice groups and twenty 3-expert groups as a function of expertise. The high expertise participants are familiar with some psychological phenomena, but not with the ones used in this study (Note: pretesting will determine this; see below). The low expertise participants have no prior knowledge regarding psychological phenomena. To avoid confounding among the variables Cognitive Capacity and Task Complexity, both variables are counterbalanced. That is, both in the low and high expertise group, the participants are randomly assigned to one of the Cognitive Capacity conditions in such a way that 30 participants first work individually and then collaboratively, the other 30 work in the reverse order. Within each group of 30, the participants are randomly assigned to one of the Task Complexity conditions in such a way that 15 participants first work with a low complexity task and then with a high complexity task, the other 15 work in the reverse order.

Before learners start with the experiment, they receive a prior knowledge test. The prior knowledge test contains a small number of items to measure participants' knowledge of the subject matter domain and to double check the a-priori distinction between low- and high-expertise students. Next, after a general introduction to the whole group (15 min), the participants start in the learning phase to work on the first experimental task (either in a group or individually, either high or low complexity). They have 30 min to work on the task. After the task each student has to rate the amount of mental effort on a 9-point cognitive load scale originally developed by Paas (1992). Next, the participants start to work on the second task (either in a group or individually, either high or low complexity, depending on the previous task), for which they also have 30 min. After this task they have to rate the cognitive load again. Both the group and individual sessions in the learning phase are videotaped to gather qualitatively data on the learning processes. After the learning phase, participants have 1 hour to individually solve near transfer problems requiring them to apply the newly learned principles in familiar situations, and far transfer problems requiring them to use the principles in new, unfamiliar situations. Cognitive load is measured for each problem of the near and far transfer test. Mental efficiency is calculated with the formula of Paas and van Merriënboer (1993): High efficiency indicates transfer test performance higher than might be expected on the basis of the overall cognitive load during the learning phase, while low efficiency indicates transfer test performance lower than might be expected on the basis of the overall load during the learning phase. Furthermore, the motivation of the students in each condition is computed as their "task involvement" (Paas, Tuovinen, van Merriënboer, & Darabi, in press). High task involvement is characterized by high investment of mental effort in

learning yielding high transfer test performance; low task involvement is characterized by low investment of mental effort in learning and low test performance.

*Variables.*

Independent variables:

- Cognitive Capacity (individual vs. group)
- Learner Expertise (low vs. high)
- Task Complexity (low vs. high)

Dependent variables:

- Learning: performance, processes, time, and effort.
- Test: performance (memory, transfer), time, mental efficiency, and task involvement.
- Transactions and transaction costs: coordination, communication, negotiation, interaction (with respect to types and amounts).

*Analysis.*

A 2 (Task Complexity: low, high) x 2 (Cognitive Capacity: individual vs. group) x 2 (Learner Expertise: low vs. high) mixed ANOVA with repeated measures on the first two factors is used to determine the hypothesized interaction effect of task complexity, cognitive capacity, and learner expertise on learning effectiveness.

*Experiment 4:*

*Goal.*

Determine the optimal trade off between task complexity (i.e., intrinsic cognitive load) and learner age for the effectiveness of collaborative learning environments. Note: the low- and high complexity tasks in this experiment are identical to the low- and high-complexity tasks of Experiment 2.

*Hypothesis.*

At a low level of task complexity group-based learning is more effective than individual learning for older learners, but not for younger learners. At a high level of task complexity group-based learning is more effective than individual learning for both old and young learners.

*Design and procedure.*

Participants in the study are 60 Cultural Sciences students from the Open University of the Netherlands and 60 first-year Psychology students from Erasmus University Rotterdam.

In a mixed design with Task Complexity (low, high) and Cognitive Capacity (individual vs. group) as within-subjects factors and Learner Age (young vs. old) as between-subjects factor, the learning processes and outcomes will be studied for twenty 3-young-adult groups (Mean age = 19 years) and twenty 3-old-adult groups (Mean age = 60 years) as a function of expertise. To avoid confounding among the variables Cognitive Capacity and Task Complexity, both variables are counterbalanced. That is, both within the young and older adult group the participants are randomly assigned to one of the Cognitive Capacity conditions in such a way that 30 participants first work individually and then collaboratively, while the other 30 work in the reverse order. Within each group of 30, the participants are randomly assigned to one of the Task Complexity conditions in such a way that 15 participants first work with a low complexity task and then with a high complexity task, while the other 15 work in the reverse order.

After a general introduction to the whole group (15 min), the participants start in the learning phase to work on the first experimental task (either in a group or individually, either high or low complexity). They have 30 min to work on the task. After the task each student has to rate the amount of mental effort on a 9-point cognitive load scale originally developed by Paas (1992). Next, the participants start

to work on the second task (either in a group or individually, either high or low complexity, depending on the previous task), for which they also have 30 min. After this task they have to rate the cognitive load again. Both the group and individual sessions in the learning phase are videotaped to gather qualitatively data on the learning processes. After the learning phase, participants have 1 hour to individually solve near transfer problems requiring them to apply the newly learned principles in familiar situations, and far transfer problems requiring them to use the principles in new, unfamiliar situations. Cognitive load is measured for each problem of the near and far transfer test. Mental efficiency is calculated with the formula of Paas and van Merriënboer (1993): High efficiency indicates transfer test performance higher than might be expected on the basis of the overall cognitive load during the learning phase, while low efficiency indicates transfer test performance lower than might be expected on the basis of the overall load during the learning phase. Furthermore, the motivation of the students in each condition is computed as their “task involvement” (Paas, Tuovinen, van Merriënboer, & Darabi, in press). High task involvement is characterized by high investment of mental effort in learning yielding high transfer test performance; low task involvement is characterized by low investment of mental effort in learning and low test performance.

#### *Variables.*

Independent variables:

- Cognitive Capacity (individual vs. group)
- Learner Age (young vs. old)
- Task Complexity (low vs. high)

Dependent variables:

- Learning: performance, processes, time, and effort.
- Test: performance (memory, transfer), time, mental efficiency, and task involvement.
- Transactions and transaction costs: coordination, communication, negotiation, interaction (with respect to types and amounts).

#### *Analysis.*

A 2 (Task Complexity: low, high) x 2 (Cognitive Capacity: individual vs. group) x 2 (Learner's Age: young vs. old) mixed ANOVA with repeated measures on the first two factors is used to determine the hypothesized interaction effect of task complexity, cognitive capacity, and learner expertise on learning effectiveness.

#### **d Literature**

- Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral & Brain Sciences*, 24, 87.
- Cronjé, J. (1997) Interactive internet: Using the internet to facilitate co-operative distance learning. *South African Journal of Higher Education*, 11(2), 149–156.
- Diehl, M. & Stroebe, W. (1987). Productivity loss in brainstorming groups: Toward the solution of a riddle. *Journal of Personality and Social Psychology*, 53(3), 497-509.
- Dillenbourg, P. (2002). Over-scripting CSCL: The risks of blending collaborative learning with instructional design. In P. A. Kirschner (Ed.), *Three worlds of CSCL: Can we support CSCL* (pp. 61–91). Heerlen: Open Universiteit Nederland.
- Dourish, P., & Bellotti, V. (1992). Awareness and coordination in shared workspaces. In M. Mantel, & R. Baecker (Eds.), *Proceedings of the 1992 ACM conference on Computer-supported cooperative work* (pp. 107–114). New York, ACM Press.
- Ellis, C. A., Gibbs, S. J., & Rein, G. L. (1991). Groupware: Some issues and experiences. *Communications of the ACM*, 34(1), 38–58.
- Fuchs, L.S., Fuchs, D., Kazdan, S., Karns, K., Calhoon, M.B., Hamlett, C.L., & Hewlett, S. (2000). Effects of workgroup structure and size on student productivity during collaborative work on complex tasks. *Elementary School Journal*, 100(3), 183-212.
- Gregor, S. D., & Cuskelly, E. F. (1994). Computer mediated communication in distance education. *Journal of Computer Assisted Learning* 10(3):168–181.

- Gunawardena, C. N. (1995). Social presence theory and implications for interaction and collaborative learning in computer conferences. *International Journal of Educational Telecommunications* 1(2/3):147–166.
- Gutwin, C. (1997). *Workspace awareness in real-time distributed groupware*. Unpublished doctoral dissertation. Calgary, Canada: University of Calgary.
- Hallet, K., & Cummings, J. (1997). The virtual classroom as authentic experience: Collaborative, problem-based learning in a WWW environment. In *Proceedings of the annual conference on Distance teaching and learning: Competition-connection-collaboration*. Madison, WI: University of Wisconsin-Madison, pp. 103–107.
- Heath, E. F. (1998). Two cheers and a pint of worry: An on-line course in political and social philosophy. *Journal of Asynchronous Learning Networks* 2(1):15–33.
- Hiltz, S. R. (November, 1998). Collaborative Learning in Asynchronous Learning Networks: Building Learning Communities. Invited Address at WEB98, Orlando, Florida [Online]. Retrieved November 11, 2003 from [http://eies.njit.edu/~hiltz/collaborative\\_learning\\_in\\_async.htm](http://eies.njit.edu/~hiltz/collaborative_learning_in_async.htm).
- Hobaugh, C. F. (1997). Interactive strategies for collaborative learning. In *Proceedings of the annual conference on Distance teaching and learning: Competition-connection-collaboration*. Madison, WI: University of Wisconsin-Madison, pp. 121–125.
- Hughes, C. & Hewson, L. (1998). Online interactions: Developing a neglected aspect of the virtual classroom. *Educational Technology* 38(4):48–55.
- Hutchins, E. (1995). *Cognition in the wild*. MIT Press, Cambridge, Mass.
- Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist*, 38, 23-31.
- Kirschner, P. (2002). Can we support CSCL? Educational, social and technological affordances for learning. In P. Kirschner (Ed.), *Three worlds of CSCL: Can we support CSCL*. Inaugural address, Open University of the Netherlands.
- Kirschner, P. A., Martens, R. L., & Strijbos, J. W. (2004). CSCL in higher education? A framework for designing multiple collaborative environments. In P. Dillenbourg (Series Ed.) & J. W. Strijbos, P. A. Kirschner & R. L. Martens (Vol. Eds.), *Computer-supported collaborative learning: Vol 3. What we know about CSCL ... and implementing it in higher education* (pp. 3-30). Boston, MA: Kluwer Academic Publishers.
- Kirschner, P. A., Strijbos, J. W., & Kreijns, K. (2003). Designing integrated collaborative e-learning. In W. Jochems, J. van Merriënboer, & R. Koper (Eds.), *Integrated e-learning: Implications for pedagogy, technology & organization*. London: Taylor & Francis Books Ltd.
- Kirschner, P. A., Sweller, J., and Clark, R. E. (in press). Why Minimal guidance during instruction does not work: An Analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*.
- Kreijns, K. (2004). *Sociable CSCL environments: Social affordances, sociability, and social presence*. Unpublished doctoral thesis, Open Universiteit Nederland, Heerlen, The Netherlands.
- Kreijns, K., Kirschner, P. A., & Jochems, W. (2003). Identifying the pitfalls for social interaction in computer-supported collaborative learning environments: A review of the research. *Computers in Human Behavior*, 19(3), 335–353.
- Malone, T.W., & Crowston, K. (1990). What is coordination theory and how can it help design cooperative work systems? In F. Halasz (Ed.), *Proceedings of the conference on Computer-supported cooperative work* (pp. 375 – 370). New York: ACM
- Mason, R. (1991). Analyzing computer conferencing interactions. *International Journal of Adult Education and Training*, 2,161–173.
- Michod, R. E. (2003) Cooperation and conflict: Mediation during the Origin of multicellularity. In P. Hammerstein (Ed.), *Genetic and cultural evolution of cooperation* (pp. 291-293). Boston, MA: The MIT Press.
- Morgan, R. L., Whorton, J. E., & Gunsalus, C. (2000). A comparison of short-term and long-term retention: Lecture combined with discussion versus cooperative learning. *Journal of Instructional Psychology*, 27, 53-58
- Mullen, B., Johnson, C. & Salas, E. (1991). Productivity loss in brainstorming groups: A meta-analytic integration. *Basic and Applied Social Psychology*, 12(1), 3-23.
- Paas, F. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology*, 84, 429-434.

- Paas, F., Camp, G., & Rikers, R. (2001). Instructional compensation for age-related cognitive declines: Effects of goal specificity in maze learning. *Journal of Educational Psychology*, 93, 181-186.
- Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist*, 38, 1-4.
- Paas, F., Renkl, A., & Sweller, J. (2004). Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture. *Instructional Science*, 32, 1-8.
- Paas, F., Tuovinen, J. E., Tabbers, H., & van Gerven, P. W. M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist*, 38, 63-71.
- Paas, F., Tuovinen, J. E., van Merriënboer, J. J. G., & Darabi, A. (in press). A motivational perspective on the relation between mental effort and performance. *Educational Technology, Research and Development*.
- Paas, F., & van Merriënboer, J. J. G. (1993). The efficiency of instructional conditions: An approach to combine mental-effort and performance measures. *Human Factors*, 35, 737-743.
- Rafaeli, S., & Sudweeks, F. (1997). Networked interactivity. *Journal of Computer Mediated Communication*, 2(4). Retrieved March 5, 2005 from <http://www.ascusc.org/jcmc/vol2/issue4/rafaeli.sudweeks.html>
- Rogers, Y., & Ellis, J. (1994). Distributed cognition: An alternative framework for analysing and explaining collaborative working. *Journal of Information Technology*, 9, 119-128.
- Sloffer, S. J., Dueber, B., & Duffy, T. M. (1999). Using asynchronous conferencing to promote critical Thinking: Two implementations in higher education. *Proceedings of HICSS-32*, New York: IEEE.
- Soller, A.L. (2001) Supporting Social Interaction in an Intelligent Collaborative Learning System. *International Journal of Artificial Intelligence in Education*, 12(1), 40-62.
- Sweller, J. (1999). *Instructional design in technical areas*. Melbourne: ACER.
- Sweller, J. (2004). Instructional design consequences of an analogy between evolution by natural selection and human cognitive architecture. *Instructional Science*, 32, 9-31.
- Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. *Cognition & Instruction*, 12, 185-233.
- Taha, L. H., & Caldwell, B. S. (1993). Social isolation and integration in electronic environments. *Behaviour & Information Technology* 12(5):276–283.
- Van Merriënboer, J. J. G. (1997). *Training complex cognitive skills. A four-component instructional design model for technical training*. Englewood Cliffs, NJ: Educational Technology Publications.
- Van Merriënboer, J. J. G., Kirschner, P. A., & Kester, L. (2003). Taking the load off the learner's mind: Instructional design for complex learning. *Educational Psychologist*, 38(1), 5-13.

## 9 Work program and planning

Detailed planning first year: September 2005 - August 2006:

Month	Activity
9/2005	Orientation in OTEC / Formulate training and supervision plan
9/2005-12/2005	Literature study
12/2005-3/2006	Write literature review
3/2006-5/2006	Prepare experiment 1 Develop learning content (with expert and programmer)
6/2006-12/2006	Experiment 1: Set up, analysis and report the results

Global planning: September 2006 - September 2009

Month	Activity
1/2007–8/2007	Experiment 2: Set up, analysis and report the results
9/2007–7/2008	Experiment 3: Set up, analysis and report the results
8/2008–3/2009	Experiment 4: Set up, analysis and report the results
4/2009–9/2009	Dissertation.

**10 External partners**

The research will be conducted in close collaboration with Remy Rikers from Erasmus University Rotterdam and John Sweller from the University of New South Wales in Australia.

**11 Motivation for external partner**

Collaboration with the Australian and Dutch colleague is a continuation of a long-standing close research collaboration. In addition, most of the participants are students from the department of Psychology at Erasmus University Rotterdam.

**12 External financial support for the project**

Not applicable.

**13 Budget (internal and external staff)**

Person	To the account of	Hours/ week	Period	Cost in k€ <sup>2</sup>
PhD candidate	OTEC	38	48 months	€ 160
Fred Paas	OTEC	4	48 months	€ 33
Paul Kirschner	OTEC	1	48 months	€ 12
TWO capacity	OTEC	38	2 months	€ 10
Student assistant	OTEC	20	2 months	€ 4,5
			<b>total</b>	<b>€ 219,5</b>

**14 Budget (material)**

Materials and apparatus - Participant expenses:	Cost in k€
Experiment 1: 60 participants x € 20 <sup>3</sup>	€ 1,2
Experiment 2: 60 participants x € 40	€ 2,4
Experiment 3: 120 participants x € 40	€ 4,8
Experiment 4: 120 participants x € 40	€ 4,8
Dome mobile group observation camera and software	€ 3,2
<b>total</b>	<b>€ 16,4</b>

**15 Explanation / justification of material costs**

See Table

**16 Budget (travel)**

Purpose/justification	Cost in k€
2 National conferences (ORD)	€ 1
4 International conferences (EARLI, AERA, CSCL)	€ 6
<b>total</b>	<b>€ 7</b>

<sup>2</sup> All salaries are based upon the NWO-VSNU CAO 2003 (National Scientific Organization – University Federation Collective Bargaining Agreement 2003)

<sup>3</sup> € 10 / hour