

Designing optimal peer support to alleviate learner cognitive load in Learning Networks

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DESIGNING OPTIMAL PEER SUPPORT TO ALLEVIATE LEARNER COGNITIVE LOAD IN LEARNING NETWORKS

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ABSTRACT

In Learning Networks, learners have to engage in social interactions for sharing knowledge to achieve their personalized learning goals. When working on complex tasks, self-organized knowledge sharing imposes too much cognitive load and this is detrimental to learning. According to pedagogical guidelines of cognitive load theory, learning environments should not only avoid activities that distract learner attention but also focus learner attention on relevant activities that contribute to learning. This paper applied these guidelines in two studies, both meant to explore how to design an optimal peer support system. Study 1 aimed to alleviate learner cognitive load by using an automated peer tutor selection system. However, the results could not support our assumption that finding available peers for those who need knowledge sharing alleviates learner cognitive load. Study 2 explored how to support the interaction process of knowledge sharing by enhancing different competencies, namely content knowledge and tutoring skills. The results showed that supporting learners with different competencies alleviates cognitive load on different dimensions. Interestingly, students supported with content knowledge felt significantly more frustrated than those with tutoring skills. Our future research aims to design an optimal peer support system by 1) alleviating learner cognitive load through refining selection criteria to find suitable peers for knowledge sharing and 2) optimizing interaction process by designing support structures based on content knowledge and tutoring skills during knowledge sharing.

KEYWORDS

Learning networks, peer support, peer tutor selection, peer tutor competencies, cognitive load

1. INTRODUCTION

Learning Networks (LNs) are a particular kind of online social network designed to support self-directed lifelong learners in a particular domain. Akin to web-based communities, they comprise of groups of people who use learning resources to learn at the place, time and pace that suits them best (Sloep 2009). Within our notion of a LN, learners have to take responsibilities to organize their own learning activities to acquire knowledge from others to achieve their personalized learning goals (Kester et al. 2007). During the learning process, it is likely that learners in LNs have the same needs as formal learners: they need to share and construct knowledge through interaction with others. In particular, when working on complex tasks, it is likely that learners need collaboration and knowledge sharing to acquire more cognitive resources from others. In formal learning settings, this is usually done by either consulting the teacher or sharing knowledge with other students within the social structure of a class. However, without support, knowledge sharing does not magically occur in the environments of LNs: without a social structure of a class or group, learners do not know who others are; without a common learning history, learners do not know what others know. When learners self-organize knowledge sharing, they need to first find out who relevant knowledge sharers are and then maintain social interactions with others. Without support, self-organizing these two activities imposes extra cognitive load.

Cognitive load (or mental workload) refers to the learner's limited cognitive capacity that is actually allocated to performing a particular task; it has been recognized as an important factor that influences learner performance (Sweller et al. 1998). The pedagogical value of measuring cognitive load is to inform instructional design or design of educational environments by quantifying the mental cost incurred by a learner to achieve a particular level of performance (Sweller et al. 1998; Beckmann 2010). Considering human limited cognitive capacities, cognitive load theory (CLT) suggests that an optimal design of

instruction or learning environments should not only prevent learners from paying attention to processes that are irrelevant to learning but also direct their attention towards processes that are relevant to learning (Sweller et al. 1998; Van Merriënboer and Sweller 2005). When working on complex tasks, learners have to allocate many of their cognitive resources to process numerous information elements and element interactivity and this imposes a high cognitive load (Sweller 2006). Thus, without support self-organized knowledge sharing on complex tasks easily overloads learners' working memory and this is detrimental to learning (Hsiao et al. 2011). The aim of this study is to explore how to design a peer support system for online learning networks by applying the instructional implications of CLT and measuring cognitive load to verify the effects of our approach to support.

Using a peer support system to alleviate learner cognitive load

The way of involving peers to share knowledge is similar to a mixture of two peer-learning approaches commonly applied in formal educational settings: peer tutoring and collaborative learning. On the one hand, when learners support others in need, their role task is to perform instructional tasks (akin to peer tutoring). On the other hand, to achieve common understanding knowledge sharing requires mutual social interaction, namely collaboration (akin collaborative learning) among peer tutors and tutees. The success of these two approaches depends on teachers' arrangements of composing pairs (or groups) and instructions of expected social interactions. When teachers' arrangements are missing in LNs, peers will not automatically act as peer tutors to share knowledge with those in need. In addition, arranging for teacher tutoring in LNs easily overloads teaching staff. Our colleagues have developed two automated peer support systems to move tutoring load from teaching staff to peers and their results show that peers are able to provide satisfactory and timely answers (Van Rosmalen 2008; De Bakker 2010). In this study, we investigate whether using such peer support systems that include automated peer tutor selection and a collaborative communication medium (wiki) alleviates learner cognitive load. This aligns with the first didactic principle of CLT that the design of learning environments should not distract learners' attention to processes irrelevant to learning. In other words, we want to know whether using a peer support system in LNs decreases cognitive load imposed by finding others to help (Study 1).

The effects of peer tutor competencies on alleviating learner cognitive load

The aforementioned peer support systems have each applied different criteria to select peer tutors to facilitate asynchronous and synchronous peer support. Content competency refers to either learner up-to-date knowledge acquisition within a LN that relates to the questions asked by tutees (Van Rosmalen 2008; De Bakker 2010, proximity) or the prior knowledge that learners bring into a LN (De Bakker 2010, previous result). Tutor competency is either defined objectively as "the ability of a peer learner to act as a tutor" by using actual performance data of how a peer tutor behaved in previous questions (Van Rosmalen 2008) or subjectively as learners' perceived competency of which question type (i.e., theoretical or organizational questions) they are competent to help (De Bakker 2010). Van Rosmalen and De Bakker's content and tutor competencies conform to tutoring studies taken place in formal educational setting. These studies suggest that content knowledge (e.g., subject-matter) and tutoring skills (e.g., pedagogical and process-facilitation skills) are correlated and both are related to effective tutoring (Schmidt and Moust 1995; De Grave et al. 1999). However, since the tutoring skills dimension was not actually applied or investigated in our previous studies, we do not know the relative effects of these two competencies on supporting knowledge sharing.

Considering the design guidelines of CLT, we should further find out how to support the interaction process to focus learner attention on relevant activities that contribute to learning. Supporting learners with relevant content knowledge can achieve this. Van Rosmalen (2008) applied Latent Semantic Analysis (LSA) to find out three text fragments related to tutee questions: learners who acted as peer tutors found that these text fragments were helpful to answer tutee questions. This shows evidence that supporting content knowledge does alleviate tutoring load. To contribute to learning, peer-learning approaches have emphasized the importance of the occurrence of certain social interactions that trigger extra cognitive processes such as explaining, asking and answering each other's questions, etc. Supporting learners with tutoring skills not only focuses learner attention on relevant learning activities but also increases the possibilities that certain social interactions take place during knowledge sharing. Numerous studies of peer tutoring and collaborative

learning have applied interaction structures or prior training to strengthen tutoring or team skills (e.g., King 1997; Prichard et al. 2011). On the other hand, recent collaborative learning studies have suggested supporting learners with communication and coordination skills during the interaction process to decrease the transaction costs (Kirschner et al. 2009; Kirschner et al. 2009). Only when these transaction costs are eliminated, peer-learning can in turn alleviate high cognitive load imposed by complex tasks. To better support knowledge sharing, we investigate whether supporting learners with content knowledge or tutoring skills results in different effects on learner cognitive load (Study 2).

2. STUDY 1

In Study 1, we investigated whether using a peer support system alleviates learner cognitive load and promotes learning performance on complex tasks.

2.1 Method

2.1.1 Design and procedure

We used a factorial design with two between-subject variables: supports (Control vs. Forum vs. PT) and task complexity (simple vs. complex). Three levels of supports were administered: no support as control group (i.e., learners have no opportunity to interact with others), forums that only support communication, and peer tutoring (PT) that supports finding available knowledge sharers and a collaborative communication medium (wiki). Table 1 shows the steps involved in the PT model. When one of the invited learners accepts the request (i.e., to act as peer tutor), our peer support system creates a wiki exclusive to this pair to share knowledge about the tutee question.

To recruit participants, we announced a course *Internet Basics* of 10 modules on different websites. In total, 534 volunteers expressed their interests. When recruiting participants, we announced that they would be awarded a certificate after they finished all requirements of this course. Before the course started, we randomly assigned participants to each group, 89 to 90 participants per group. To start with a module, participants first had to take the prior knowledge test of that module after which they were issued an enrollment key. There were separate enrollment keys for each of the modules. Participants could access the module by entering the enrollment key. For each module, they were supposed to learn the content, finish the knowledge sharing task, take the post-test and fill in two mental effort measures. At the learning phase, we asked participants to rate the mental effort needed to complete the knowledge sharing task. At the testing phase, we asked them to rate the mental effort it took to take the post-test. We define complexity of knowledge sharing tasks based on element interactivity: a complex task includes multiple interactive information elements whereas a simple task includes very few interactive information elements (Sweller 2010).

Table 1. The main steps of the PT support modified from Van Rosmalen et al. (2008)

Context	A Learning Network of Internet Basics with ten modules and learners with information of their (past) working load.
Main steps	Anne uses <i>Pose your question</i> to ask a question concerning a specific module or knowledge sharing task. The system determines the available learners and selects the most suitable ones. The selected learners receive an invitation to act as a peer tutor. The system sets up a <i>wiki</i> containing the question and role specifications as guidelines. Anne and the peer tutor discuss and formulate results in the wiki. When they finish the discussion, Anne closes the discussion, rates the results.
Data	The system stores results, discussion log, and ratings of the answer.

2.1.1 Measures

Cognitive load (CL) measure. For CL measures participants reported how much *mental effort* they invested by rating on a 9-point cognitive load rating scale for doing the knowledge sharing tasks and taking the post-tests (Paas 1992; Paas and Van Merriënboer 1994). This rating scale ranged from a *very very low effort* (1) to a *very very high effort* (9).

Prior knowledge tests and post-tests. For every module, there were a prior knowledge test and a post-test. Both tests were identical and they consisted of a few content-related multiple choice questions or matching questions. Additionally, each of the post-tests included one CL measure. The order of questions and pertinent answer options was randomized.

Frequencies of knowledge sharing. To validate the effects of different levels of support, we recorded all knowledge sharing events to obtain frequencies on the number of questions asked and answers provided.

2.2 Data analysis and results

Though 534 volunteers registered for this course, only 415 actually logged onto the course sites and only 329 of them started at least one module. Therefore, the final number of participants for the dataset was 329. Although 89-90 people were assigned to each of the treatment groups, on average only 24.1 learners enrolled for the modules, 13.6 learners answered the mental effort measures of knowledge sharing tasks and 21 learners finished post-tests. This showed there were many missing values in our dataset: not all participants completed the measures on all ten modules. A significance level of .05 was used for all analyses.

The data were analyzed with a 3 (supports: Control vs. Forum vs. PT) \times 2 (task complexity: simple vs. complex) analysis of variance (ANOVA) with between-group measures on both factors. With regards to scores of prior knowledge tests and post-tests, no effects were statistically significant at the .05 significance level. As for mental effort on knowledge sharing tasks, the main effect of using different supports was not significant either. However, there was a significant main effect for task complexity, $F(1, 808) = 12.54, p < .05$, such that the average mental effort was higher for complex tasks than for simple tasks (see Table 2). The interaction effect was significant, $F(2, 808) = 13.84, p < .05$, indicating that the control group experienced significant lower cognitive load on complex knowledge sharing tasks than did the Forum and PT groups.

The frequencies of knowledge sharing showed that there were only a limited number of questions asked by both Forum and PT groups. The response rates were low: for Forum groups, only half of the questions were answered; for PT groups, fewer than half of the questions were answered. Among these responses, only a small proportion of responses provided valid answers to the questions. Therefore, our finding does not support our assumption that finding available peers alleviates learner cognitive load. It is likely that the intervention of Forums and PT were *not* used sufficiently to have any detectable effects.

Table 2: Effect of task complexity and types of support on mental effort

		TASK COMPLEXITY		
		Simple task	Complex task	
TYPES OF SUPPORT	Control	$M = 4.73, SD = 1.20$	$M = 4.36, SD = 1.35$	$M = 4.57, SD = 1.27$
	Forum	$M = 3.98, SD = 1.76$	$M = 4.78, SD = 1.25$	$M = 4.38, SD = 1.57$
SUPPORT	Peer tutoring	$M = 4.36, SD = 1.39$	$M = 4.96, SD = 1.37$	$M = 4.68, SD = 1.04$
		$M = 4.39, SD = 1.48$	$M = 4.72, SD = 1.34$	

3. STUDY 2

This study explored whether supporting learners with different competencies results in different learner cognitive load on complex tasks.

3.1 Method

3.1.1 Participants and settings

Participants are students from a Chinese Beginners Course at the University of Tilburg, who voluntarily participated. Participants are *true peers* because they have a similar level of domain knowledge in Chinese language (teacher personal observation). The course demands students to do a speaking assessment, which requires students to work in pairs to perform interactive conversations in Chinese for six minutes in total. There are two rounds of this assessment and the teacher informs students of the topics about 6 weeks in advance. For the first round, each student has to find a classmate to create a conversation based on one of the topics and perform it during the assessment. Prior to the second round, students are matched randomly with another classmate and each pair is assigned another topic to prepare. For the second round, students have 15 minutes to create and practice a conversation to a mastery level with their just-assigned partner. The teacher has been implementing the same assessment since 2010 and she observed that many students experienced two types of overload: when they simultaneously prepared many subject exams (i.e., for the first round) or they did not know how to process such complex tasks with just-assigned partner within a short time (i.e., cognitive overload, for the second round). In Study 2, we aimed to investigate whether the intervention of supporting different peer tutor competencies can reduce cognitive load resulting from task complexity and working collaboratively with others.

3.1.2 Tasks

The tasks used in Study 2 aimed to simulate the second round of this speaking assessment. There are two tasks. The first one was to prepare a conversation to order a famous Chinese dish at a Chinese restaurant and the second one was to practice this conversation till a particular mastery level was reached (i.e., performing the conversation without any visual aids).

3.1.3 Design and procedure

The results of Study 1 have shown that it is difficult to measure cognitive load in a non-formal online LN. To precisely measure cognitive load, Study 2 was conducted as a *field experiment* in a classroom setting instead of conducting a web-experiment through recruiting participants from the general public in a natural LN. Study 2 uses a *quasi*-experimental design because it is practically not feasible that classes of students are mixed and randomly assigned; instead, a class of students was assigned randomly to each level of the independent variable (peer tutor competencies): the morning class was supported with tutoring skills and the afternoon class with content knowledge. In this study, students worked in pairs with their just-assigned partner to prepare for the speaking assessment. One student of each pair was assigned the role of tutor and this student-tutor received instructions for tutoring skills (i.e., step-by-step prompts about how to process each task) that guide learners to process tasks or content knowledge (i.e., a list of learned sentence patterns and vocabulary). Student-tutors were told to take responsibility to use instructions and to finish the task on time. Each task took 15 minutes and the time-limit was displayed.

3.1.4 Measures

The NASA-Task Load Index (NASA-TLX) was used to measure students' cognitive load (mental workload) after each task. The NASA-TLX consists of six subscales that ask learners to indicate experienced workload when performing a task: mental, physical, temporal demands, frustration, effort and performance (Hart and Staveland 1988; Hart 2006). All scales range from "low" to "high" and are divided into 20 sections except for the performance scale that ranges from "good" to "poor". Students have to tick one of the 20 sections that best represents their experience for each dimension. The response score ranges from 1 to 20, where a high score indicates a higher level of cognitive load. The mean of the raw scores from the six subscales constitutes the overall workload. To facilitate completion of the questionnaire, students are also given descriptions to accompany each subscale. For example, the description for mental demand states "How much mental demand and perceptual activity was required? (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?"

3.2 Data analysis and results

Since the data of NASA-TLX are ordinal, medians are reported to describe central tendency in Table 3. For Task 1, each class of students experienced cognitive load differently on sub-scales. For Task 2, except mental demand and effort, students supported with tutoring skills experienced less cognitive load on the other four

sub-scales than those with content knowledge. Since these two tasks are strongly related to each other (i.e., Task 1 is the pre-requisite of Task 2), differences of cognitive load between these two tasks were examined. For students supported with tutoring skills, they experienced lower cognitive load on temporal demand and performance of Task 2 than Task 1. For students supported with content knowledge, they experienced lower cognitive load on five sub-scales of Task 2 than Task 1.

Table 3. Medians of NASA-TLX ratings on two sub-tasks

		TASK 1: MAKE A CONVERSATION					
		mental demand	physical demand	temporal demand	performance	effort	frustration
Tutoring skills	Median	14.00	5.00	16.00	10.00	12.50	3.50
Content knowledge	Median	14.00	10.00	14.00	7.00	12.00	9.00
		TASK 2: PERFORM THE CONVERSATION					
		mental demand	physical demand	temporal demand	performance	effort	frustration
Tutoring skills	Median	14.00	5.50	9.50	6.50	13.00	3.50
Content knowledge	Median	10.00	8.00	10.00	7.00	10.00	7.00

To understand cognitive load on each sub-scale, learner's ratings of cognitive load on each sub-scale for the two tasks were combined into one variable. The standardized alpha of NASA-TLX was 0.61. The greatest increase in alpha would come from deleting the performance subscale but with only 0.03. All items correlated to the total score to a poor degree (lower $r = 0.11$).

We further examine the effects of different supports on cognitive load by combing scores of both tasks on each sub-scale. Probability-probability plots (Field 2009, p.134) of each sub-scale indicated that the data of each sub-scale were not normally distributed. The mean ranks of Table 4 showed that students supported with tutoring skills experienced different sources of cognitive load than those supported with content knowledge. Mann-Whitney tests on the effects of supporting two competencies showed only a significant difference for the sub-scale *frustration*. The learners supported by peers with content knowledge ($Mdn = 29.34$) experienced a significant higher level of frustration than those supported by peers with tutoring skills ($Mdn = 18.15$), $U = 135.50$, $z = -2.84$, $p < 0.05$, $r = -0.42$.

Table 4. Mean Ranks

	N	mental demand	physical demand	temporal demand	performance	effort	frustration
Tutoring skills	24	25.60	20.46	24.92	24.58	25.06	18.15
Content knowledge	22	21.20	26.82	21.95	22.32	21.80	29.34

4. DISCUSSION

Study 1 was designed to investigate whether introducing a peer tutoring (PT) support structure can reduce cognitive load (CL). It was confirmed that task complexity affected mental effort, but no main effect of peer support could be found. As it turned out, the participants did not use the instruments (supports of Forum and PT) as devised. Some obvious causes come to mind. Because the set-up of this experiment was meant for non-formal learning, participants had no obligation to complete knowledge sharing tasks and we could not force them to share knowledge by using the provided Forum and PT tool only. In addition, as the course was designed for self-study and was aimed at introductory level, course materials might not have triggered questions in particular as the set time-limit seemed to have spurred participants on to complete the course to meet the requirement for the 'attendance' certificate. Therefore, we cannot draw any firm conclusions with regard to learning performance and cognitive load. Nevertheless, the Control group showed significant lower cognitive load on complex tasks. These significant differences might result from the bias that participants in the Control group felt that they could learn individually without knowledge sharing. When task complexity is not high enough to trigger knowledge sharing, asking participants to do it might result in extra cognitive load and, paradoxically, might have resulted in higher perceived cognitive load in the forum and PT groups.

Study 2 examined the effects of supporting different competencies during knowledge sharing. The NASA-TLX appeared to have a moderate internal consistency despite the small sample. The higher cognitive load experienced by learners supported by peers with tutoring skills might result from anticipating to have to go through the steps specified by the prompts to complete the task, while students with content knowledge had more freedom to complete the task based on the information they received. This corresponds to goal-free effects within the CLT framework (Sweller et al. 2011). This might also explain why students supported with content knowledge peers eventually felt significantly more frustrated than those with tutoring skills: finding their own way to process the task might result in higher cognitive load. These findings indicate that content knowledge and tutoring skills alleviate cognitive load in different ways.

In formal education, numerous studies have applied pedagogical guidelines of CLT to design optimal instructions and used CL measurements to validate the effects of these designs. To the best of our knowledge, none so far has investigated the application of CLT and CL measures in non-formal learning environments such as LNs. While non-formal learning becomes more and more important for professional developments and lifelong learners, there are very few theories regarding non-formal learning contexts. Thus, at this stage it is inevitable that we need to apply theories from formal educational setting into non-formal learning environments; this paper unravels the limitations of this application. As implemented in most CLT studies, CL is measured in a very controlled setting with pre-designed tasks at a learning phase and a post-test at a testing phase. The results of Study 1 showed the failure of asking learners to carry out pre-designed tasks or to force them to respond to CL measures because this goes against learners' personalized learning goals and needs. However, when taking account of learners' self-directedness, the consequence was that we could not get data to validate the effects of our support system. In addition, the set-up of Study 1 was a newly-built online social network where participants had not developed a sense of community yet, such as trust and common expectations of learning (Rovai 2002). Although these factors were not our focus in Study 1, they might have been confounding variables that influenced the results: participants are not likely to interact with each other without a sense of community (Rovai 2002). To still obtain a measure of CL, Study 2 took place in a formal classroom where students were obliged to complete the pre-designed tasks with high cognitive load that are part of the course activities. This set-up enables us to initially examine the effects of supporting different competencies on cognitive load during knowledge sharing even though this limits the generalizability of the findings to non-formal environments of LNs.

In summary, this paper showed the challenges of applying formal learning theory of CLT into non-formal LNs, in particular measuring cognitive load. Future work will look into more elaborate selection criteria to arrive at an optimal peer support system in which peers are automatically selected. In addition, attention needs to be paid to the effect of content knowledge and tutoring skills on the interaction process of knowledge sharing.

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