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Cognitive modeling meets instructional design: Exploring Cognitive Load Theory with ACT-R

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Abstract

This project aims to link instructional theory with methods from cognitive science within a collaborative learning scenario. From instructional perspective, it focusses on the Cognitive Load Theory (Sweller, 2005), separating the overall construct of cognitive load into the facets of intrinsic, extraneous and germane cognitive load. Each of them relates to certain aspects in the process of learning from given instructional material. Although those facets are described theoretically, empirical assessment is rather difficult, providing the need to apply alternative methods of inspection. On this account, the cognitive architecture ACT-R (Anderson, 2007) ties in for its strength in formalizing basic human cognition. Additionally, the facets of cognitive load are addressed in terms of collaborative learning as well, since such settings become increasingly relevant in educational contexts.

Introduction

Nowadays, due to the fast pace of information, consistent societal changes and the increasing demand of lifelong education, learning depicts an omnipresent feature in modern societies. Particularly the use of media-supported instructions gains more and more relevance within the learner's attempt to acquire knowledge as efficient as possible, since learning often occurs in rather self-organized settings. This raises the issue of a conducive design of instructional material, being able to foster learner's achievement in an optimal manner. In this vein, a core aspect to consider entails human cognition while facing such instructional material, as "without knowledge of human cognitive processes, instructional design is blind" (Sweller, Ayres, & Kalyuga, 2011). Approaching this goal, there exist various theories that aim to shed light on the interaction between information structures and cognitive processes. They consider characteristics like modality, complexity, design or load resulting from the instructional material. The aspect inspected within the current project comprises that of cognitive load, according to Beckmann (2010) resulting from the learner's subjective evaluation about the complexity to cope with a certain task in a given situation.

Cognitive load in instructional design

In the late 1980s, John Sweller (Sweller, 1988) introduced the Cognitive Load Theory (CLT), by now a well-known and extensively used framework in educational cognitive load research. Over the last decades, the initial theoretical base underwent a variety of extensions, specifications and formalizations (e.g. Paas, Van Gog, & Sweller, 2010; Sweller et al., 2011). Amongst its basic assumptions, the theory postulates a practically unlimited storage capacity of long-term memory, the mental representation and organization of knowledge via schemata and a limitation of short-term memory, both in terms of duration and capacity. Especially in more recent research, a separation of the overall cognitive load construct into different facets is postulated. Intrinsic cognitive load (ICL) is assumed to result from the complexity of the used learning material (referred to as element interactivity) and learner's previous knowledge. In contrast, extraneous cognitive load (ECL) arises from the instruction itself, e.g. by interesting but irrelevant content. Relevant processes of schema acquisition and automation, depicting crucial aspects while learning certain content, are assigned to germane cognitive load (GCL). Initially, those facets were said to operate additively, implying an increase in relevant processing just in case irrelevant processing decreases. However, more recent research queries the assumption of additivity as well as the separability of load facets (e.g. de Jong, 2010; Kalyuga, 2011). This goes along with the difficulty to satisfactory measure these facets with the methods used so far, e.g. by applying questionnaires, although there are recent approaches to gain insights into related cognitive processes via using fMRI (Whelan, 2007).

Characteristics of collaborative learning

According to Kirschner, Paas and Kirschner (2008, 2009), assumptions and facets of the CLT not only yield relevance for individual learning, but within collaborative settings as well. Especially due to the increasing popularity of virtual cooperation of learners and lecturers, this new issue in cognitive load research gains more and more importance. In fact, the huge advantage of collaborative compared to individual learning consists in the possibility to handle tasks of higher complexity, described as collective working memory effect (Sweller et al., 2011). This effect states that individuals are able to achieve higher learning outcomes by collaborating in contrast to learning alone, since element interactivity can be distributed among several working memories. Nevertheless, collaborative learning scenarios face certain challenges as well that have to be considered, most notably transaction cost arising from the need to coordinate and communicate the joint work (Kirschner et al., 2008), holding either effective or ineffective influence. In summary, from the current point of research collaborative learning seems to achieve better outcomes only in case task complexity outweighs transaction costs, but further research is needed to clearly examine this effect.

Cognitive modeling as method to inspect cognitive processing

Due to the lack of direct opportunities to inspect the previously outlined facets and processes, the need to apply alternative methods of assessment arises. Since underlying cognitive processes are hardly to inspect by external means, cognitive modeling as method from cognitive science might be of benefit in this context. Its core strength consists in the possibility to precisely formalize basic human cognition, and on this account develop vested explanations for the resulting behavior. Especially the cognitive architecture ACT-R (Anderson, 2007) offers a broadly used, theory-based tool, distinguished by a modular, neurophysiological based structure, the representation of declarative knowledge in chunks, and the interaction via production rules. As a result of the computational implementation, it is possible to directly transfer the postulated model assumptions into formal code, which allows to derive predictions on the human performance within a given task setting.

Moreover, the theoretical background of ACT-R corresponds well with basic assumptions of the

CLT, i.e. mechanisms and structures can be accurately pictured within the ACT-R framework. For instance, limitations in working memory capacity might be mapped by decay in chunk activation, whereas production rule learning is suited for schema acquisition and automation. Additionally, in the course of developing his theory, Sweller (1988) already applied a production system framework – PRISM in this case – for the purpose of explaining cognitive load in a problem-solving task. Ayres and Sweller (1990) used a similar approach in the context of a geometry task. Although application was limited to a small task-setting and load facets were not addressed separately, this can be regarded as promising link to tie in within the existing project. As mentioned earlier, there are efforts to establish a neurophysiological foundation of the CLT as well (Whelan, 2007), depicting a further connection between both fields of research. Regarding the issue of collaboration, certain aspects are already queried within the ACT-R framework in terms of group communication (Matessa, 2001; Reitter & Lebiere, 2011) or educational reasoning (Zondervan, Verbrugge, & Taatgen, 2004). Taken together this shows the benefit of applying the method in contribution to the field of cognitive load investigation.

Project outline

Based on the previously outlined research, the three-year doctoral project aims to differ cognitive processes corresponding with the postulated facets of cognitive load within a collaborative learning scenario. On methodological accounts, the development of cognitive models in ACT-R as well as experimental designs will be applied. As shown in Fig.1, breaking up the project results in three circles of research, each comprising certain steps. First of all, the facets of cognitive load might be separated experimentally to extract relevant cognitive processes behind. They will be transferred into a formal model afterwards. The aspect of collaboration shall be inspected separately in the first instance, to refine the facets of cognitive load in the context of collaboration. This could be realized e.g. by applying player tracking within an experimental group game scenario. In the end, the model will be expanded in terms of collaboration with aid of the experimental results, to finally link all aspects (marked as yellow spot in Fig.1).

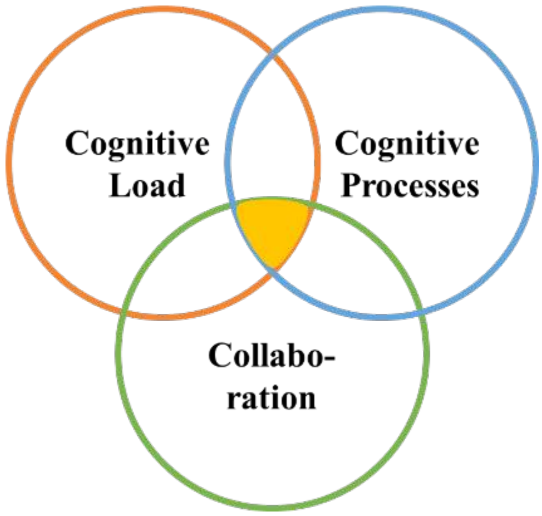

Fig.1: Circles of research within the project.

Conclusion

Overall, this project depicts a fine step forward in understanding cognitive processes while being confronted with certain instructional material. In doing so, it provides relevant insights into a so far rather vague defined theory and additionally contributes to interconnect approaches from different theories and disciplines. On practical accounts, it fosters the ability to include the findings into appropriate learning designs, to achieve optimal learning outputs. For this reason, it can be regarded as extremely valuable piece of research.

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