2016

Informing Instructional Design by Cognitive Load Assessment in the Classroom.

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Abstract
Cognitive Load Theory is an approach that considers the limitations of the information processing system of the human mind. It is a cognitivist theory that has been conceived in the context of instructional design. One of the main open problems in the literature is the lack of reliable models and technologies to assess cognitive load of learners, thus limiting the application of the theory in practice. This project was aimed at tackling this open problem through the use of a previously developed mobile, responsive web-based prototypical technology, to assess the cognitive load of students in a typical third-level classroom. It was also aimed at exploring the impact of such a technology to instructional design and the potential benefits it can bring to lecturers to improve teaching practices and optimally align their instructional materials to learners.

Keywords: cognitive load theory; mental workload measurement; third-level classroom; instructional design

Introduction

Cognitive Load Theory (CLT) (Sweller, Van Merrinboer, & Paas, 1998) has been conceived in the context of instructional and pedagogical design. CLT is an approach that considers the limitations of the information processing system of the human mind (Wickens, 2008). In particular, the cognitive capabilities devoted to the processing and retention of information, in a human learner, are limited (Miller, 1956) and this limitation can have a significant impact on learning. The intuitive assumption behind this theory is that if a learner is either underloaded or overloaded, learning is likely to be negatively affected (Figure 7.1).

In their seminal contribution, Sweller et al. (1998) proposed three types of cognitive load:

- intrinsic load – this is influenced by the unfamiliarity of the learners or the intrinsic complexity of the learning material under use;
- extraneous load – this is impacted by the way the instructional material is designed, organised and presented;
- germane load – this is influenced by the effort devoted for the processing of information, the construction and automation of schemas in the brain of the learners.

(Paas & Van Merrinboer, 1993)

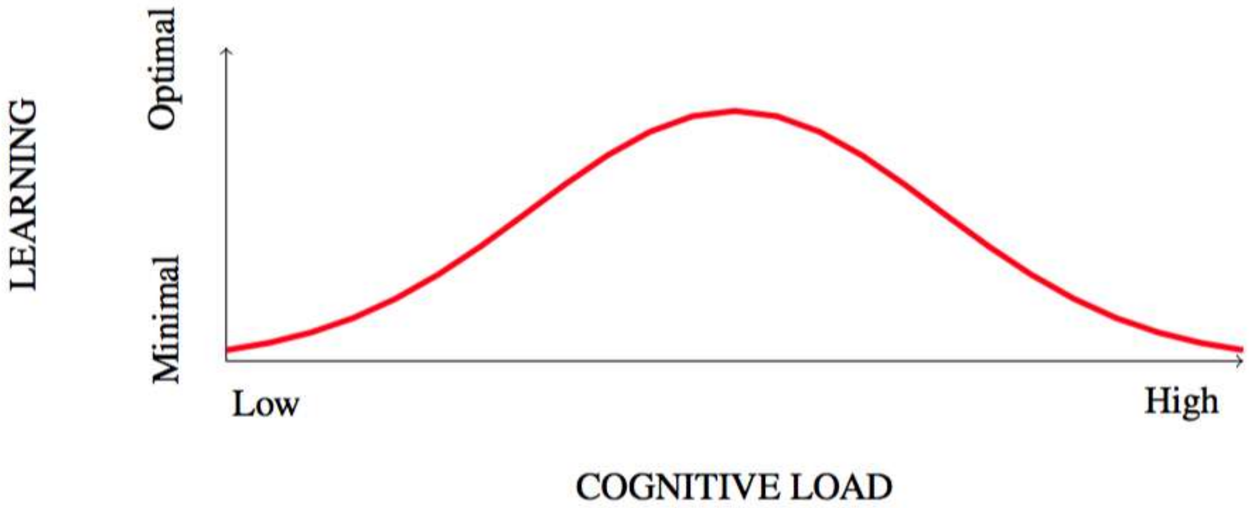

Figure 7.1: Relationships between cognitive load and learning

Intrinsic cognitive load is considered to be static, extraneous load should be minimised (Mousavi, Low, & Sweller, 1995) and germane load promoted (Debue & van de Leemput, 2014). According to Cognitive Load Theory (Sweller et al., 1998; De Jong, 2010), an acceptable cognitive load occurs when there is an equilibrium between the inherent complexity of the pedagogical material (intrinsic load), the means with which the material is transferred and transmitted to a student (extraneous load) and the volume of effort devoted by the student to absorb the new knowledge and allocate it with the existing one (germane load). In short, CLT has been conceived for designers eager to create instructional resources that are presented in a way that encourages the activities of the learners and optimises their performance, thus their learning (Chandler & Sweller, 1991). Unfortunately, the experience of mental workload is different on an individual basis (Longo, 2014), changing according to a learner's cognitive style, own education and training (Paas & Van Merrinboer, 1993). As a consequence, modelling and assessing mental workload is far from being a trivial activity (Longo, 2012, 2015, 2016; Rizzo, Dondio, Delany, & Longo, 2016). The main objective of this research activity is to explore the use of a responsive mobile/web-application, aimed at quantifying the cognitive load imposed on learners, in a typical third-level classroom, and to understand its impact and the benefit it can deliver to lecturers.

Outline of Project

A piece of software has been built by the author over the past number of years and it is aimed at assessing the cognitive load of students in a typical third-level classroom. In detail, this is a responsive web-based application that allows a lecturer to gather a set of psychological measures of learners through a set of questions and it assesses the cognitive load of each student in the classroom. The study received institutional research ethics committee approval with the requirement for individual student consent for participation. At the end of a teaching session, a lecturer can benefit from a dashboard (Figure 7.2) containing:

- general analytics about the class;
- a distribution of the overall cognitive load levels experienced by students ;
- a quantification of the three type of loads, as designed in the Cognitive Load Theory (intrinsic, extraneous and germane load).

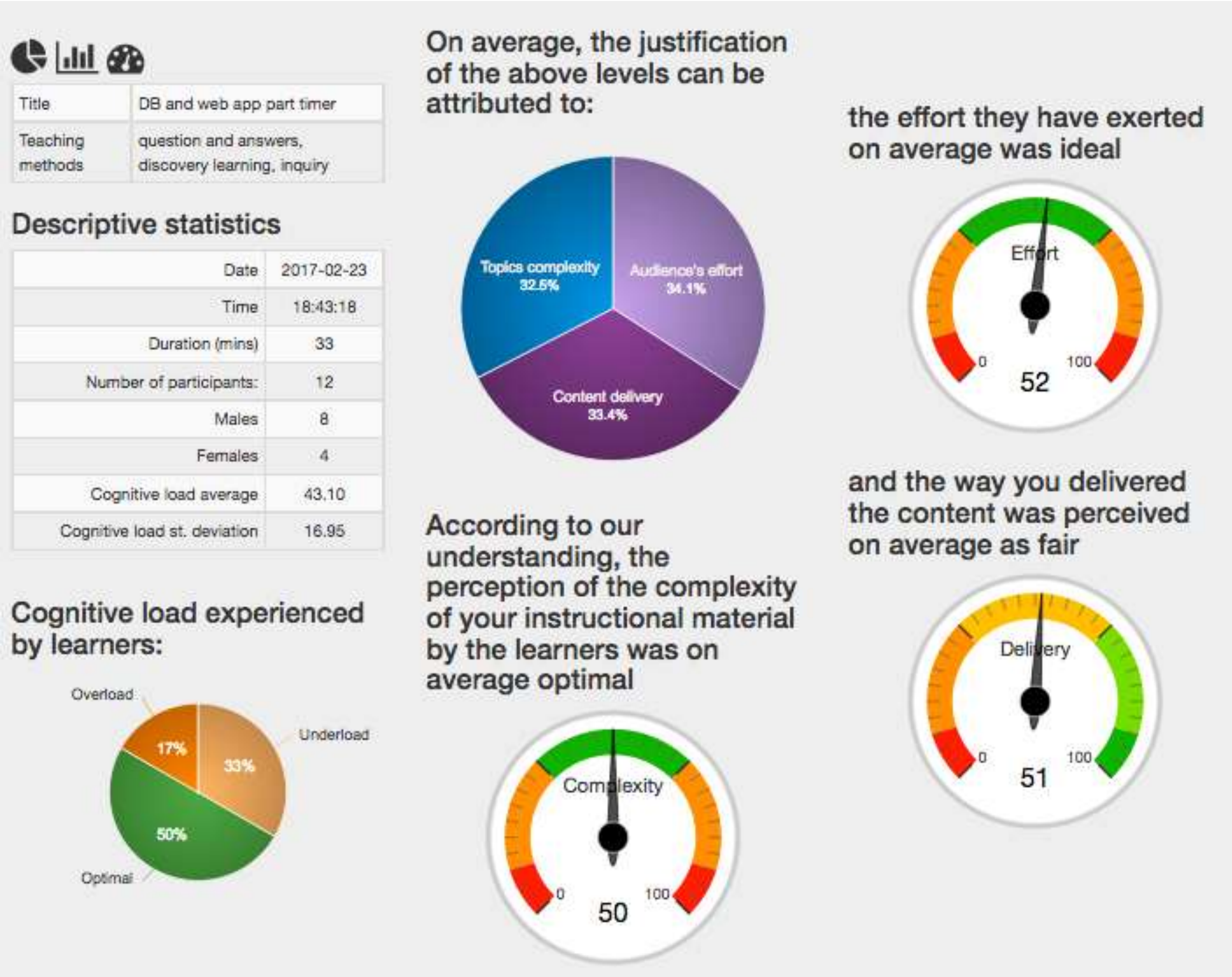

Figure 7.2: Dashboard of an application for assessing cognitive load of students in the classroom

The main benefits of the above learning analytics are to inform a lecturer of the cognitive load experienced by learners, their effort (germane load), the complexity of the instructional material delivered (intrinsic load), and the goodness of the teaching style and method employed in the classroom (extraneous load). All these three pieces of information can be used to better design subsequent classes. In particular a lecturer can get an indication of the complexity of the material delivered, whether it was high or low, whether a better method of delivery of information and knowledge should be tried or whether the learners needed more engagement.

The work programme of this research activity included the following steps:

- Preliminary technology application – application of the web-based technology in third-level classrooms with two identified lecturers in the School of Computing at DIT as well as three other lecturers abroad. These applications showed the impact of the technology on leaners as well as giving a preliminary perception of its usability by lecturers and students.
- Preliminary data understanding – analysis of the preliminary data as collected by the designed technology. This activity was aimed at getting familiar with the collected data, to identify data quality problems, to discover first insights into the data, and/or to detect interesting subsets to form hypotheses for hidden information.
- Preliminary data preparation – This activity covered the construction of a dataset that allowed the generation of indexes of cognitive load using a pool of state-of-the-art mental workload assessment and computational techniques. The rationale behind this activity was to identify the most appropriate technique/s for the generation of cognitive load numerical indexes that are sensitive, diagnostical and valid.
- Preliminary future experimental design – The previous activities were instrumental to inform the design of a wider and more focused experimental study devoted towards the application of such a technology across different disciplines and classrooms in third-level institutions. It also highlighted that a preliminary training would be ideal to instruct lecturers on the appropriate use of such a technology.

- Preliminary design of promotional material – Following the preliminary data obtained and the design of future applications of the technology, it was necessary to sketch a set of promotional materials both for promoting the use of such a technology as well as demonstrating the potential benefits for instructional design at third-level institutions and in Higher Education.

Evaluation and Conclusions

The evaluation of the work carried out in this project included:

- the evaluation of the subjective feedback from the identified lecturers, within DIT, in relation to the usability of the proposed technology and its impact on their teaching dynamics. Additionally, feedback was given in relation to the impact of the indexes of cognitive loads, as generated by the technology, on teaching practices and on the enhancement of student experience and learning. This was a qualitative study that included interviews. The outcome of this activity highlighted some issues concerning the usability of the technology suggesting areas of improvement.
- the evaluation of subjective data, collected by the technology – this included the application of formal statistical and state-of-the-art analytical techniques on collected data. The first goal was to identify the best set of questions to ask students (using the technology) before and after a typical third-level teaching session. The goal was to remove redundant ones, amend some of them and in turn simplify the use of the technology itself. The second goal was to identify the most appropriate computational mental workload assessment technique/s for quantifying in real-time the cognitive load of learners in the classroom.
- the evaluation of the interest of stakeholder – this activity was devoted to exploring the interests of stakeholders generated by live demos of the technology. This gave an initial idea of how the community of educators positively reacted to the proposal of this novel technology and informed the definition of future activities.

Recommendations to the DIT

This project was mainly aimed at showing a promising novel technology to advance the science of pedagogy and to provide an instrument to lecturers to enhance the quality of teaching and learning. It was aimed at investigating an alternative technology that can be applied by lectures to obtain feedback, through the concept of cognitive load, on the students' experience. The project has the potential to widen access, and expand opportunities for learning and continuing professional development. Furthermore, it can promote self-assessment practices in the higher education sector, to lift local, regional and international collaborations to a completely new level. This project is aligned to the recent report *Education for Sustainability. The National Strategy on Education for Sustainable Development in Ireland, 2014–2020* (Department of Education and Skills, 2014), in which it has been mentioned that "Some of the challenges that arise in relation to Education Sustainable Development (ESD) in higher education are similar to those that were identified earlier in relation to the school system, and specially at post primary level". Additionally, "lack of subject specific ESD content, concerns about the preparedness of lecturers to facilitate the type of participatory learning that is most frequently associated with effective ESD, and the need for a whole institution approach to ESD" has been identified as a core issue in third-level education. One recommendation to DIT is to push even further the exploration of new pedagogical methods and models aimed at enhancing the student experience and improving learning. The research activity conducted in this project will be of benefit to the DIT (Dublin Institute of Technology) and the TU4D (Technological University for Dublin) alliance because it empowers lecturers with learning analytics directly and rapidly employable for enhancing teaching practices and therefore customising the student experience as well as their learning. The technology used in the project, jointly employed with state-of-the-art cognitive workload assessment techniques has the vision to advance the science of pedagogy not only within DIT/TU4D, but potentially across several Irish and worldwide third-level institutions. This research project is aligned to the DIT institutional strategy to build digital capacity. In particular, the project is aligned to the vision highlighted in the reports on *Strategic and Leadership Perspectives on Digital Capacity in Irish Higher Education* (Devine, 2015) and *Teaching and Learning in Irish Higher Education: A Roadmap for Enhancement in a Digital World 2015–2017*, both commissioned by the National Forum for the Enhancement of Teaching and Learning in Higher Education. These two reports outline strategic and leadership perspectives on building digital capacity across the Irish higher education sector, a clear message circulated also by the European Commission's recent (October 2014) High Level Group (HLG) report *New Modes of Teaching and Learning in Higher Education*.

In summary, the findings of the project clearly emphasise the importance of cognitive load measurement for evaluating instructional design alternatives, teaching practices and styles, and as a consequence enhance existing pedagogical models. The institute should continue its activities to support research and lecturers in improving teaching practices, learning, professional development and self-assessment. Additionally, it should consider incrementing the funding to similar activities to bring these small-size projects to the next level, aiming to achieve a wider impact. The project carried out in the context of this Teaching Fellowship was very time consuming considering the minimal level of funding assigned.

Proposed Future Work

The novel idea proposed in this project will represent a general and reusable research expertise. The preliminary framework that has been formed through the Teaching Fellowship initiative at DIT enabled several different research opportunities and activities. These included the involvement of Master and PhD students in the School of Computing, who started putting in practice the theoretical notions behind cognitive load measurement in education. These postgraduates started empirical evaluation of preliminary collected data towards the demonstration of the impact of cognitive load assessment in the field of teaching and learning. These activities are intrinsically long-term and nontrivial, given the complexity and the nature of the project and the phenomena under investigation (the construct of cognitive load). However, their investigation and application is likely to have a significant impact in the future. In the short-term, the recipient of this Teaching Fellowship will continue the current research started with postgraduate students, in the School of Computing at DIT, and work on aspects and techniques relevant to cognitive load measurement and assessment. In the middle-term, these activities will contribute to increase the research capacity of DIT, through its AIRC[1] research centre, contributing to its national and international exposure. In the long-term, the recipient of this Teaching Fellowship wishes to provide the basis by which the various research findings and collaborations can be consistently collected and where further research can be built upon. The topic of this project is of such resonance that it might help the recipient of this Teaching Fellowship and his colleagues at DIT to attract further funding for high-profile research initiatives. The outputs of the project are significant to progress the work into a larger EU Horizon 2020 proposal, where the DIT School of Computing could play the role of the leading partner for Computer Science and the DIT/TU4D, playing the role of the leading partner for Education, Teaching and Learning.

Dissemination of Activities

A conference paper is planned, aimed at demonstrating the impact of such a technology on lecturers in third-level institutions as well as demonstrating empirically the impact of cognitive load measurement on learning. The development of an illustrative video is planned to show how to use the technology and demonstrate the potential it has for enhancing teaching practices and lecturers" self-assessment. Following this project, a research publication is also planned in a journal in the field of Education.

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