Validating a survey for self-reporting cognitive load

Jeremy Munsell, [1] Tianlong Zu,[1] and N. Sanjay Rebello[1,2]

[1]*Department of Physics and Astronomy, Purdue University, 525 Northwestern Ave., West Lafayette, Indiana, 47906*
[2]*Department of Curriculum and Instruction, Purdue University, 100 N. University Ave., West Lafayette, Indiana, 47906*

Cognitive load theory (CLT) describes the usage of working memory resources during problem solving. CLT is a tripartite scheme that serves as a theoretical framework to motivate the design of instructional materials. Intrinsic load is directly related to learning objectives, while extraneous load refers to the resources wasted by attending to irrelevant information, and germane load is affiliated with generative processing. A semi-structured interview was conducted with N=13 participants to validate a cognitive load survey that was provided to students upon completion of a physics exam to determine the subjective cognitive load that students experienced while solving the exam questions. The survey consists of eight statements designed to delineate the different types of load. Interview participants were asked to group statements into any of three piles based on thematic similarity, and answer questions that probed their understanding of the statements. Participants overall grouped survey items as per the triarchic model proposed by CLT, thus validating the survey.

I.INTRODUCTION

Working memory is often referred to as a cache to store information for immediate use in operational tasks. Cognitive load theory (CLT) is concerned with the characteristics of instructional materials and dynamics of working memory resources during learning and problem solving [1]. CLT demarcates cognitive load into three separate types: intrinsic, extraneous, and germane.

Intrinsic and extraneous load can both be tuned by the design of instructional materials. Intrinsic cognitive load (ICL) is determined by the complexity of the problem. ICL reflects the number of interacting elements that the problem solver must reserve in working memory to execute the solution to the problem. Interacting elements are those that are processed simultaneously (and therefore interact), rather than being processed sequentially [1].

Extraneous load (ECL) originates from the presentation of information in the statement of a problem. Poor problem design practices such as including extraneous information and using confusing language cause extraneous cognitive load for the student. The learner must process information while selecting potentially useful pieces and discarding those which are irrelevant to the solution. The prior knowledge of the problem solver also influences both ICL and ECL. For example, the same information which imposes low ICL/ECL for high prior knowledge learners could be high ICL/ECL for low knowledge learners since they lack the knowledge to handle the information or differentiate relevant information from irrelevant.

Germane load (GCL) deals with constructing a schema of the situation. It is associated with the working memory resources devoted to processing the intrinsic load while organizing and synthesizing pieces of information. Germane load is high when motivation of the learner is high. Meanwhile, ECL and GCL are both correlated with the total energy devoted by the problem solver. Working memory resources are limited and consequently instructional materials should be designed in such a way as to not require more resources than those that are available. Therefore, it is important to study various problem design approaches and their consequences to the learner within the framework of CLT.

We developed a survey to measure the three dimensions of cognitive load experienced by students during a conceptual physics assessment. The items on the survey are intended to have students self-report the cognitive loads they incurred resulting from various aspects of the assessment. This tool provides a source of feedback from students and facilitates instructor awareness.

Previously a principal component analysis performed on N=139 responses to this survey showed a three-factor solution aligning with the three facets of CLT [2]. In an additional series of interviews students solved problems wherein the different types of load were manipulated, and the varying load was reflected in their responses to the survey [2]. The goal of this study was to aid the foregoing works in providing construct validity to this qualitative measure of cognitive load. Specifically, we conducted interviews to help answer the following research questions. 1) To what extent do students group the survey items in ways that align with the three dimensions of CLT? 2) What interpretations do students provide about their groupings of the survey items?

II. BACKGROUND AND SIGNIFICANCE

Traditional measures of cognitive load have focused on objective measurement techniques including physiologic indicators [3, 4]. These however can be time intensive and obtrusive to the participant. Non-intrusive methods such as eye tracking have been used to measure the three types of cognitive load [5]. The subjective cognitive load rating questionnaire [7] has been a cornerstone in subjective approaches to measuring cognitive load. Subjective methods were found to be sensitive to the various types of load [6, 8] while offering a less intrusive approach to measuring it. It was found that survey methods could be used to measure cognitive load extemporaneously or upon the completion of a task.

To date, survey methods have focused on the cognitive load associated with learning new material. The literature is devoid of work done with survey methods intending to measure the cognitive load incurred in a testing situation.

We adapted a survey intended to measure cognitive load during learning [8] to our purpose of measuring cognitive load during test taking [9]. However, the items targeting germane load on the original survey could not be adapted to the testing situation. As a result, we included survey items related to germane load from previous studies [10, 11]. The statements of the survey are shown in Table 1.

TABLE 1. Students rate the items on a 9-point Likert scale.

1	The topics covered on the physics test were very complex.
2	The questions on the physics test had confusing language that was not clear to me.
3	I concentrated a lot as I answered the questions on the physics test.
4	The physics test covered formulas that I perceived to be very complex.
5	It was very hard to identify what information is relevant to answering the questions on the physics test.
6	I devoted a lot of mental effort in finding and applying the relevant concepts needed to answer the questions on the physics test.
7	The test covered concepts and definitions that I perceived as very complex.
8	There was a lot of distracting information in the question statements on the physics test.

Statements 1, 4, and 7 are intended to address intrinsic load associated with the complexity of the various elements of test taking. Statements 2, 5, and 8 are meant to cover the extraneous load following from various sources of confusion. Finally, statements 3, and 6 address germane load discussing notions such as concentration and mental effort.

III. METHODS AND MATERIALS

Individual interviews were conducted with N=13 participants from a conceptual physics course for pre-service elementary teachers taught by one of the authors at a large Midwestern university. Participants were offered extra credit equal to 1% of their total course grade for participating in this study. During a typical interview a participant was presented with the eight statements from the cognitive load survey in a randomized order. The student was then asked to group the statements into any of three piles based on thematic similarity between statements. The interview involved three piles because of the three-factor solution emerging from the principal component analysis performed previously [2]. While the statements were being sorted the interviewer left the room.

After the participants had finished the sorting task they were asked to elucidate their motivation for grouping specific survey items together, and what themes were common to a certain group of statements. They were further asked about any perceived similarities and differences between the members of each group.

Individual conceptions of terms such as complexity or effort tend to be highly subjective. Accordingly, each participant was asked additional questions to probe their understanding of some of the phraseology used in the survey. For example, they were directed to an exam that they had recently taken and asked to find an example of a question that was complex. Students were also provided with a sheet of formulas from a first-year mechanics course and asked to identify a complex equation. Student descriptions of their groupings were transcribed and coded.

IV. RESULTS

Most participants (9 of 13) created the following three groups of statements in Table 1: Group A (1, 4, 7), Group B (2, 5, 8) and Group C (3,6). These three groups corresponded to intrinsic load, extraneous load, and germane load respectively. These interviews led to a rich dialogue with students about their perception of the meaning of these statements. The discussion with students' and their descriptions about each group are shown below.

A. Intrinsic load

Students who grouped statements about intrinsic load together (11 of 13) commonly said that these statements had to do with complexity or difficult content.

When asked about any differences between these statements students responded that the statements spoke about different levels of organization such as “some of the items are about topics and the others are about sub-topics”. Statement 1 mentioned topics while statement 4 talked about definitions and formulas where statement 7 was about concepts. The majority of students ranked these three items with topics as the broadest category followed by concepts and definitions.

Additional questions were posed about what constitutes complexity. Students most frequently said that problems with a lot of interacting elements were complex. For example, “circuit problems incorporate a lot of different elements. There is an element of knowing how bulbs in series function, but there also bulbs in parallel, and there is also a switch”. Students also reported that a lack necessary knowledge also makes a question complex “For this question about the power delivered to these circuits you have to know the definition of power and resistors and understand how circuits work”.

When asked about what makes a formula complex they most often responded that the complexity is related but not completely determined by the length of the formula. Most students responded that Bernoulli’s equation was the most complex on the list because it was the longest, “there’s lots of different steps that you have go through to find the answer to the formula”. Another recurring theme was familiarity with the symbols used in the equation. Some students ranked the formula for angular displacement, which uses Greek characters, as more complex than Bernoulli’s equation because of the symbols.

In the same discussion students were asked whether a long equation dealing with a simple situation was more complex than a short equation dealing with a relatively intricate phenomenon. Students almost universally said that a short equation dealing with conceptually difficult subject matter was the more complex of the two.

B. Extraneous load

Students who grouped statements about extraneous load together (9 of 13) commented that these statements were similar because they are about confusing information. “These statements have to with ambiguity, distraction, and confusion while taking a test and those things go together”. Students also related these statements to the language used in the test questions, “These statements deal with the language of the question rather than the content”, and “These were within the question itself. Like language and extra information, the wording of the test.”

When asked about what the made the statements in this group different from each other students responded that the statements had to do with different ways that things can be confusing. For example, “These statements are different because (5) is about finding the relevant information, (8) is about having too much information, and (2) is about the question being asked in a confusing way.”

When asked about the meaning of distracting information versus confusing information, one student responded: “confusing information is related to things I don’t understand, where distracting information is related to having more information than I need to solve the problem”. While another said “Language has a lot to do with the words you are using, distracting information deals with words and sentences that have no purpose.”

When asked about confusing test questions they most commonly responded that questions they weren’t able to answer were confusing. For example, “This question about electric field is confusing because I don’t know much about electric field”

C. Germane load

Students who grouped survey items related to germane load together (10 of 13) often said that these items were related to one’s subjective experience of the test questions saying things such as “These items covered what you felt towards the exam, not objective difficulty but more like your personal experience” or “These items dealt less with the test itself and more with the test taker, more about concentration and mental effort, having to put more thought into answering the questions instead of difficult concepts or the wording of questions”. Another student said “Both items had to do with thinking. This one (3) was concentrating a lot, and this one (6) was exerting a lot of mental effort to figure out what was needed”.

Students said that differences between the statements are mainly related to the differences in the concepts “mental effort” and “concentration”. This led to a very interesting line of discussion as most students were unable to articulate the precise difference between these two ideas. Their responses were things like “concentration is more like focus. Mental effort is more like thinking about the information you already know in order to find the answer."

When asked if concentration and mental effort are the same thing, most students replied that they were until they were asked to imagine the steps to solving a physics problem as 1) reading and taking in the information of the problem statement and 2) building a model of the problem and formulating a solution. Students universally said 1) required concentration while 2) required mental effort.

D. Other Groupings

Students who did not arrange these statements in a way that explicitly aligned with the three categories of CLT (4 of 13) still grouped many of them together, albeit with other items. The intrinsic load statements were combined by every student in this subset. Follow up questions showed that some students (2 of 4) thought of these statements as asking about their feelings towards the test questions while others (2 of 4) responded that they thought they were similar because they dealt with difficulty. The germane load items were grouped together by most of these students (3 of 4) as well, commenting that they were related to focus and the mental resources required to solve the problem. The extraneous load items were often found scattered in piles containing a mix of intrinsic load and germane load statements by the students in this group. Only one of the four placed all of the extraneous load items together, and that student grouped the extraneous load items together with the intrinsic load items.

V. CONCLUSIONS

Regarding research question 1, most students (9 of 13) grouped survey items in a manner that was congruent with the three dimensions of CLT. Moreover, students who did not explicitly group the three sets of items together (4 of 13) all grouped the ICL items together and a majority (3 of 4) grouped GCL items together, although with other statements. Concerning research question 2, student interviews seem to indicate that these groups of survey items are not only thematically similar but are implicitly discussing the types of cognitive load as defined by CLT.

In summary, cognitive load is a complex triarchic construct, therefore one concern is that most students who lack the higher order metacognitive skills would be able to distinguish between the different kinds of cognitive load that they experience during an assessment. The main implication of this study is that it demonstrates that students can indeed distinguish between the different kinds of cognitive loads measured by different items on this survey. This study, along with the confirmatory factor analysis and interviews showing that this survey was sensitive to manipulations of cognitive load [2], provide construct validity to our survey. Hence, when used in conjunction with other physics assessments, our survey can potentially provide useful insights into the types of cognitive loads that students experience when completing an assessment.

ACKNOWLEDGEMENTS

This work is supported in part by the U.S. National Science Foundation grant 1348857. Opinions expressed are of the authors and not necessarily of the Foundation. We thank the interview subjects who participated in our study.

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