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The impact of cognitive architecture and Cognitive Load Theory on classroom assessment

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Abstract: *While there is no shortage of evidence that teachers' assessment practices fundamentally influence student learning and the classroom environment, few scholars have examined the impact of cognitive load theory or cognitive architecture research on classroom assessment practices. Given the increased emphasis on classroom assessment practices in response to the standards-based, accountability framework in North American education, exploring the relationship between cognitive load theory and cognitive architecture on classroom assessment practices is critical. The purpose of this paper is to (a) provide an overview of cognitive load theory and cognitive architecture research that has a direct impact on classroom instruction, and (b) to use this body of research to explore curriculum design and the modification of classroom assessments to improve student learning.*

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Keywords: assessment, cognitive architecture, Cognitive Load Theory

Proposed by John Sweller in the late 1980's (Sweller, 1988), cognitive load theory (CLT) has been used as a framework for research into cognitive processing and instructional design for decades (Paas, Renkl, & Sweller, 2003; Paas, Renkl, & Sweller, 2004). As a direct result of this research, CLT has had a tremendous impact on teacher education and classroom instructional strategies within North America (Paas, Renkl & Sweller, 2003; Leahy & Sweller, 2011). However, the impact of CLT upon classroom assessment practices is unclear.

While there is no shortage of evidence that teachers' assessment practices fundamentally influence student learning and the classroom environment (Shepard, 2000; Stobart, 2008), few scholars have examined the impact of CLT or cognitive architecture research on classroom assessment practices (Baker, 2007). Given the current accountability climate across Canadian schools, the influence of classroom assessment practices is even more pronounced with recent policies emphasizing teachers' integration of assessments throughout instruction to support student learning (Klinger, McDivitt, Howard, Munoz, Rogers, & Wylie, 2015; Manitoba Education, Citizenship & Youth, 2006; Ontario Ministry of Education, 2008). These policies are predicated on research arguing the benefits of assessment-driven teaching on increased student achievement (Black & Wiliam, 1998; Taras, 2007), metacognitive abilities (Earl, 2013), motivation and positive self-perception (Harlen, 2006), and enhanced teacher instruction (Harrison, 2005; Lee & Wiliam, 2005; Willis, 2010).

Given the increased emphasis on classroom assessment practices in response to the standards-based, accountability framework in North American education (Brookhart, 1999; Popham, 2013), exploring the relationship between cognitive architecture and CLT on classroom assessment practices is critical. The purpose of this paper is to (a) provide an overview of cognitive architecture and CLT research that has a direct impact on classroom instruction, and (b) to use this body of research to explore curriculum design and the modification of classroom assessments to improve student learning.

Cognitive Architecture and Cognitive Load Theory

Working Memory

Cognitive architecture is a hypothesis of how the various processes and components of the mind are related and engage with one another. Cognitive architecture divides cognitive processing into working and long-term memory. Working memory, in which conscious thought occurs, has limited processing power and no long-term knowledge storage capacity. Conversely, long-term memory has no processing power but near unlimited storage capabilities. How these two aspects of cognitive architecture interact with one another is at the crux of understanding how a student learns (Paas, Renkl, & Sweller, 2004; Sweller, van Merrienboer, & Paas, 1998).

Working memory is limited to approximately seven items of information, also called elements, at any given time (Miller, 1956). Where these elements are derived from, either newly experienced by the learner or drawn from long-term memory, does not matter as much as the degree to which the elements engage with one another. This engagement, called elemental interactivity, further limits the quantity of information working memory can handle to as little as two or three interacting elements. Elemental interactivity is critical to learning as it forms the basis of how knowledge becomes incorporated into long-term memory (Paas, Renkl, Sweller, 2004; Sweller, van Merrienboer & Paas, 1998).

Baddeley (1992) further divides working memory into three processors: the visual-spatial sketchpad, phonological loop, and central executive processor. The visual-spatial sketchpad is devoted to visual forms of information while the phonological loop attends to auditory information. Both forms of information are then sent to the central executive processor that, under Baddeley's model, can be considered almost synonymous with the original concept of working memory proposed by Sweller (1988).

A working memory with three kinds of processors provides insight into a psychological effect that is commonly used by classroom educators to improve learning efficiency: the modality effect. The modality effect postulates that information presented to students in both a visual and auditory manner can increase knowledge retention (Leahy & Sweller, 2011). One explanation for the modality effect is that if an item of information is presented to a learner in a visual and auditory manner, the same element is delivered to the central executive processor twice: once from the visual-spatial pad and once from the phonological loop. As the two elements contain similar information, they do not interact to a high degree with each other in the central executive processor. However, the "duplicate" items of information can have twice as many interactions with other elements in working memory. This high degree of element interactivity allows the new item of information to be more efficiently integrated into existing schemata.

The modality effect, while a powerful tool for instructors to use to facilitate learning, is not without its shortcomings. In many research studies examining the modality effect, it has failed to materialize and, in some cases, even been reversed. The cause of the modality effect and its periodic failure to materialize is rooted in cognitive architecture (Leahy & Sweller, 2011) and understanding the limitations of the modality effect is of critical importance to classroom teachers.

The transient information effect, first proposed by Leahy and Sweller (2011), seeks to explain the limits of the modality effect. The transient information effect illustrates that, far from being the ideal method to present information, simultaneously presenting visual and auditory pieces of information can easily overwhelm the working memory. The transient information effect can only be understood by examining the three different processors in working memory.

Imagine a teacher presenting a multi-step assessment task to a room full of students. With the aim of increasing student knowledge retention, the teacher has written the required steps on a whiteboard and is verbally describing what is expected to the class. This seems like an ideal situation for learning for each student. Within the working memory of each student as the visual-spatial sketchpad processes the information written on the slides, the phonological loop processes auditory information, and the central executive processor co-ordinates information from both processors.

However, the transient information effect reverses the benefits of the modality effect when the auditory information becomes too complex. As the phonological loop does not have a permanent source of information to refer back to, the information (i.e., the teacher's verbal instructions) must be held in working memory by the central executive processor therefore limiting information from other sources. To maintain the benefits of the modality effect, the teacher must present verbal information in drastically simplified manner and should focus on duplicating visual information in an auditory manner to reduce elemental interactivity. If this is not done, the central executive processor will likely be overwhelmed and learning during an assessment may not occur (Leahy & Sweller, 2011).

Long-Term Memory

All knowledge that a learner can draw upon exists within long-term memory in the form of schemata that organizes knowledge by its expected use. New items of information are integrated into existing schemata within the working memory before the modified schema is sent back to long-term memory. The complexity of one's schema for a given domain of knowledge illustrates the depth of knowledge the one can draw upon (Paas, Renkl, & Sweller, 2004; Sweller, van Merrienboer, & Paas, 1998).

Organizing knowledge into schemata has several important consequences for educators. The first is that an entire schema, with all of its associated knowledge, can be brought into working memory as a single element. The higher the degree of complexity a schema has, the more information that can be actively drawn from it while it is being held in working memory. As mentioned previously, working memory is limited to two or three interacting elements so being able to draw upon a complex schema, which accounts for only a single element, is a tremendous advantage (Sweller, van Merrienboer, & Paas, 1998). One of the defining characteristics that separate an expert from a novice is not in their working memory, but the degree of schema complexity available to each person.

The advantages of utilizing complex schemata can best be understood through problem-solving tasks. An expert can bring a complex and rich schema into their working memory as a single element while a novice has either a less complex schema to draw from or worse, fragmented schemata that must be brought into working memory as independent elements. Consequently, an expert would be able to draw upon more developed schemata and still have less cognitive strain than a novice learner (Sweller, van Merrienboer, & Paas, 1998).

Another advantage an expert learner has over a novice learner is in the large number of general problem schemata that can be brought into working memory during an assessment task. While both experts and novice learners may be equally able to develop long, complex chains of reasoning that may be needed to solve a multi-step problem, an expert can circumvent this cognitively demanding task by drawing upon their experience with similar problems. Consequently, a novice may be highly cognitively engaged with simply understanding the required steps of a problem while an expert can bring problem schemata into their working memory as a single element and not become cognitively overwhelmed (Paas, Renkl, & Sweller, 2004).

Cognitive Load Theory

CLT posits that cognitive processing ability is divided among three forms cognitive load: intrinsic, extraneous, and germane (Sweller, 1984). If the sum of the intrinsic and extraneous cognitive loads exceeds the working memory of an individual, there will be no cognitive processing power available for the germane cognitive load and no information could be transferred into long-term memory (i.e., learning could not take place). Intrinsic cognitive load is derived from the learner's relationship with the material. As a consequence, this form of cognitive load cannot be directly lessened through instruction alone. Only through schema automization or a reduction in the number of interacting elements held in working memory during learning can the intrinsic cognitive load be reduced (Paas, Renkl, & Sweller, 2003; Paas, Renkl, & Sweller, 2004).

Extraneous cognitive load is the demand placed upon the learner through the presentation of information or in how the student interacts with that information during a learning activity. Extraneous cognitive load is most commonly envisioned by classroom teachers as the cognitive strain placed upon students through understanding teacher instructions or in understanding multi-step assessment tasks. In both cases, students may be required to hold pieces of information in their working memory to be used at a later stage (i.e., the first few steps described by either the teacher or in the problem). These elements are held in working memory and reduce the cognitive resources available for solving the problem.

While many cognitive psychologists and educators are rightly concerned with decreasing extraneous cognitive demand in students to improve learning, it is important to note that there is an additive relationship between the intrinsic and extraneous cognitive load. Consequently, reducing extraneous cognitive load is only a worthwhile endeavour if the intrinsic cognitive load associated with that learning activity is also high (Paas, Renkl, & Sweller, 2003). For tasks with minimal intrinsic cognitive load (i.e., answering the question: What does 2+2 equal?), a reduction of high extrinsic cognitive load (i.e., standing in front of class of 40 strangers compared to a group of 5 peers) would not significantly impact your ability to complete the task.

The third aspect of CLT is germane cognitive load. Germane cognitive load is the effort required to transfer elements held in one's working memory into existing schemata. Unlike intrinsic and extraneous cognitive load, an increase in germane cognitive load increases the efficiency of learning as more working memory resources could be devoted to schema acquisition and automation. Germane cognitive load is where motivation, dedication, and effort play a significant role in learning (Paas, Renkl, & Sweller, 2003). If a learner were able to devote more working memory resources to a learning task through increased attention, there would be a greater total amount of working memory resources available. Since the intrinsic or extraneous cognitive load is independent of the degree of attention given to an assessment task, the extra cognitive resources could be directed to the germane cognitive load.

Cognitive Architecture and Classroom Assessment

POWERSOURCE

As mentioned previously, schema complexity is a key characteristic that separates an expert and a novice learner in a particular domain of knowledge. Although slight differences in working memory (i.e., the relative strength of each processor, the degree of elemental interactivity working memory can hold, attentive focus) may exist between individuals, they are dwarfed in importance by differences in schema complexity by experts and novices. Using classroom assessment strategies to exploit this knowledge of cognitive architecture has been shown to have a large impact upon student achievement.

Developed by the Center for Research on Evaluation, Standards, and Student Testing (CRESST), POWERSOURCE (PS) is a mathematics curriculum for Grades 6-8. Using primarily a formative assessment strategy, PS seeks to provide teachers with the capacity to appropriately integrate assessment practices into the core of the mathematics curriculum (Phelan, Vendlinski, Choi, Dai, Herman & Baker, 2011). This focus on formative assessment has been shown to be a powerful strategy to enhance student learning (Black & Wiliam, 1998), particularly for lower achieving students within the classroom (Volante, 2010).

A direct consequence of a formative assessment approach is in the focus of PS on the development of, and between, student schemata. The design of PS is based heavily on schema acquisition and begins initially with analyzing the cognitive demands in relation to the intellectual skills and content knowledge of the student (Baker, 2007; Phelan, Vendlinski, Choi, Dai, Herman, & Baker, 2011). Teachers then build upon previous knowledge and actively foster connections between existing schemata. The development of rich, interconnected schemata allows an individual to draw upon a large volume of knowledge as a single element in the working memory, allowing cognitive space to be afforded to integrate new elements into existing schemata (Kirschner, 2002). As previously mentioned, a single schema can hold a large amount of information, yet it is processed in working memory as a single element (Kirschner, 2002). As working memory is limited to seven elements of information (Baddeley, 1992; Miller, 1956), or even as little as two or three elements if they are being actively processed (Kirschner, 2002), any reduction in cognitive load will be of great benefit to the learner.

The transfer of student learning to novel contexts is a hallmark of understanding (Kirschner, 2002) and is used by PS throughout assessment tasks as a measure of student learning (Phelan et al., 2011). PS facilitates knowledge transfer in a variety of manners. One method is through a self-evaluative (i.e., assessment as learning) process during problem solving. This metacognitive strategy is used for the self-identification of knowledge deficiencies, a trait that may cause the learner to invest more deeply in learning through example problems (Kirschner, 2002). By focusing on this formative assessment strategy, research has shown that problem-solving strategies can be more easily transferred to novel situations (Moreno & Mayer, 2005; Palincsar & Brown, 1984). PS also aims to develop problem schemata that can be easily transferred to novel contexts by presenting learners with worked out examples before attempting similar problems on their own (Phelan et al, 2011).

PS has had a tremendous impact upon student achievement (Phelan, et al., 2011). Although longitudinal research is still in its infancy, it appears that students that were involved in PS have maintained high achievement in mathematics in later years. PS provides strong evidence that developing and implementing a curriculum deeply rooted in research cognitive psychology is an excellent strategy to ensure long-term academic success for students (Phelan, et al., 2011). The success of PS has not gone unnoticed as other educational institutions within and outside North America, in particular South Korea, have begun implementing programs similar to PS (Baker, 2007).

While developing curriculum and assessments based upon cognitive psychology research is a laudable goal, the time, expertise, and financial resources required are currently beyond the limits of what the majority of school boards, schools, and teachers in Canada can afford. For example, in 2005 CRESST was awarded a $10 million grant from the research and development of PS (Phelan et al., 2011). Instead, existing classroom assessments commonly used by teachers could be adjusted to better align with current research in cognitive psychology.

Modification of Classroom Assessments

The creation of classroom assessments aligned with CLT does not have to be a large-scale endeavor as seen with PS. Basak and Verhaeghen (2011), were able to provide evidence that not all elements in working memory are given equal cognitive focus. Switching attention between elements in working memory represents an increase in cognitive demand. Even a working memory, in which all conscious processing occurs, is limited to a total of two or three interacting elements (Paas, Renkl, & Sweller, 2003) which is further restricted by the cognitive strain that can occur in changing the focus of attention between elements (Basak & Verhaeghen, 2011). In line with these findings, it appears that assessments that seek to address a wide field of knowledge puts students with poorly linked schemata, even if each is well developed, at an inherent disadvantage. While this may represent only a slight increase in cognitive load for a minority of students, with a focus on fair assessment practices in Canadian classrooms (Klinger et al, 2015) every effort needs to be made to level the assessment playing field. In addition, if the cognitive demand of switching between schemata surpasses the limits of working memory during an assessment, tasks such as balance control (Barra, Bray, Sahni, Golding, & Gretsy, 2006), reaction times (Britton, Glynn, Meyer, Penland, 1982), and long-term memory creation can no longer attended be addressed (Fisk & Schneider, 1984).

As discussed earlier, audio instructions provided to students should be much simpler than written instructions for the same task. This difference in information processing is inherent to the model of working memory proposed by Baddeley (1992). However, even written tasks that involve multiple steps can still induce high levels of extraneous cognitive load in the learner. An excellent method employed by PS is to divide multi-step problems into multiple problems. The effectiveness of this approach can be seen in its widespread use in mathematics, a subject commonly exerts high levels of intrinsic and/or extraneous cognitive load in students. Classroom teachers should adapt this strategy as common practice both during instruction and for multi-step, non-mathematical problems to ensure students are able to demonstrate their knowledge without being hindered by extraneous cognitive load.

Schemata exist in a part-whole organization: activating a piece of knowledge in a schema brings the entire schema into working memory (Hinton, 1998). A seldom utilized assessment strategy used to access how specific items of knowledge are integrated into schemata is for students to respond, either verbally or by writing, with the first thing they associate with a particular topic. This could be used as a diagnostic assessment to see what the general background knowledge of a student is on a particular topic. Words such as “unionized,” “ sewer,” “lead,” and “number” have very different meanings depending on how they are interpreted. How students interpret these words to themselves will lead to activation of different schemata, and with words associated with different domains of knowledge (i.e., “unionized” could lead to responses of “workers,” “bosses,” “atoms,” or “electricity”) possibly illustrating to an observing teacher the familiarity the student has in a particular domain of knowledge.

A traditional approach to build problem-solving proficiency in students would be to identify behaviours present in experts but lacking in novices and specifically design assessment tasks to proceduralize those skills (Sweller, van Merrienboer, & Paas, 1998). However, recent cognitive psychology research has determined that there is no linear acquisition of skills that distinguish a novice learner from an expert (Smith, diSessa, & Roschelle, 1993). Consequently, classroom teachers shouldn't seek to give every student a similar set of "tools" to solve a problem, but instead focus on differentiating the assessment tasks so that each student can use the tools they have to solve the problem.

Educational Implications

Classroom teachers are the frontline of our education system and proper classroom assessment practices have been shown to be one of the most efficient means to promote student learning (Black & Wiliam, 2006; Luckett, & Sutherland, 2000). CLT has had a tremendous impact on classroom instruction in the past few decades (Leahy & Sweller, 2011; Paas, Renkl, & Sweller, 2003) but appears to have been largely overlooked in the improvement of classroom assessments. While the design and implementation of curriculum and assessments based upon current research in cognitive psychology is beneficial for student achievement, large-scale changes of classroom assessment practices may be hindered due to financial constraints. Instead, classroom teachers should alter and adapt existing classroom assessment commonly practiced to better align with current research. While this approach may only provide small changes to assessment practices, it hopefully represents a shift in thinking of teachers towards research-guided practices in the classroom.

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