“Not a Theory of Everything”: Debating the Limits of Cognitive Load Theory

Michael Pershan

Cognitive Load Theory (CLT) is a theory of learning that has played an important role in recent debates about teaching math.[1] At the core of CLT is an attempt to show how learning is constrained by the limits of the human mind. CLT researchers have argued that these limits doom many instructional approaches to failure. The doomed pedagogies often include discovery math, problem-based learning and progressive education more broadly.

None of this has happened without controversy. In educational circles, attention is mostly commonly directed at disagreements between CLT researchers and advocates of these “doomed pedagogies.” While those debates are important, too often we neglect the differences of opinion within the circle of scientists who fully accept CLT’s premises. From the substance of their debates, we can learn about the challenges scientists face when studying teaching and learning. From the fact of their disagreements, we can learn how the direction of a scientific theory is impacted by individual human judgement.

In recent years, CLT theorists have disagreed as to the amount of complexity their work should encompass. Learning depends on so many factors -- everything from a student’s home

[1] Kirschner, Sweller & Clark, 2006.

life to their personal interests -- that no theory can encompass it all. To do their work, scientists need to find the proper balance between careful control (limit the factors) and relevance (embrace messiness). There is no recipe for finding this balance, and some of the most fascinating disagreements in educational research come down to this one issue: what complexities need to be included in research if the results are to be relevant for teaching?

Some researchers want to include student motivation in the work of CLT. Other researchers disagree, instead arguing that motivation falls outside the scope of the theory. A fascinating aspect of these internal struggles is that the inventor of CLT, John Sweller, has at different times advocated for both sides. This essay is about how John Sweller came to invent CLT, how he expanded the theory to embrace more complexity, and eventually restricted the boundaries of CLT to exclude this complexity.

Problem Solving and Learning

"Problem solving must be the focus of school mathematics." This call opened the National Council of Teachers of Math (NCTM)'s *Agenda for Action: Recommendations for School Mathematics of the 1980s.* The *Agenda* helped launch math educators into a decade of intense interest in problem solving. Researchers could also claim credit for this growing excitement. In the years leading up to NCTM's *Agenda*, problem solving had emerged as a vibrant area of research in cognitive science and experimental psychology.[2]

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[2] NCTM, 1980, Schoenfeld, 1992.

In the early 1970s, John Sweller found himself needing a change. After finishing graduate school he had accepted a position as a psychology lecturer for a teacher training program. The first problem was the location -- a small town, far away from Sweller's family. Second, Sweller was unused to teaching, and the time it took away from his research activities. Finally, his research was on learning in rats, and he was finding this work unproductive. After just one year, Sweller left for Sydney, where he reinvented himself as a researcher in the emerging field of human problem solving.[3]

In one of his early problem-solving studies, Sweller tasked his undergraduates with a number puzzle.[4] "I am going to give you one or more problems to solve," he told participants. "You will be given an initial number and asked to transform it into a final number by multiplying 3 and/or subtracting 69 as many times as is required." The game, however, was rigged. The numbers were carefully chosen so that each initial number could easily be transformed into the final number by alternating multiplication with subtraction. For example, the first problem asked participants to get from 60 to 111 – simply multiply by 3 and subtract 69. The second problem went from 31 to 3 – multiply, subtract, multiply, and finally subtract once more. The third problem could again be solved by alternating between multiplication and subtraction. Would the players of this game discover this winning strategy all on their own?

Sweller found that most participants never discovered this rule. Instead, they used a different technique to attack the puzzle – at each turn they performed whichever move would

[3] Sweller, 2016.
[4] Sweller, et al., 1982.

make their number closer to the goal. Suppose a participant was tasked with turning 54 into 210. 54 is less than 210, so they would multiply to get closer to 210. That gave 162 -- still too small. OK, multiply again. That gives 486, which is too large! Subtract, then subtract and subtract again until you are below 210. Continue this process – “means-ends search” in Sweller’s parlance – until the puzzle is solved. (In contrast, alternating between multiplication and subtraction would solve the puzzle in four moves.)

Sweller hypothesized that this wasn’t just a bad strategy for solving the puzzle, but that it would be *awful* for ever discovering a better approach. After all, if you’re always comparing the number you have to the number you want, you’re completely ignoring all of your prior moves. This ignorance of past moves eliminated any chance that a participant might notice patterns that would lead to the successful strategy. The means-ends search is not only slow, but it directs all of one’s attention away from what matters for learning.

To Sweller, these results underscored the huge difference between solving a problem and learning something useful from that experience: “After an enormous amount of problem-solving practice, subjects could remain oblivious of a simple solution rule.”[5]

If problem solving was ineffective for learning to win a simple game, then it would likewise be trouble for learning something more complex, such as an algebraic procedure. Sweller designed experiments that allowed him to observe novices attempting to solve mathematics problems. He saw the same thing: beginners chose “search” strategies that drew

[5] Sweller & Cooper, 1985.

attention away from the sorts of observations that might lead to obtaining a more powerful strategy. If teachers wanted to foster expertise, they would need techniques to circumvent these learning-killing search strategies.[6]

The first alternative to problem solving Sweller championed was "goal-free problems." Despite their name, Sweller's goal-free problems do have goals, but those goals are nonspecific ("find as many angles as you can") rather than specific ("find angle x"). Sweller pitted goal-free and conventional problems against each other and compared the learning that resulted. The winner: goal-free problems.[7]

The advantage of problems with nonspecific goals is that they allowed novices to avoid fixating on those goals. When Sweller asked participants to find the value of a particular angle in a diagram, novices were more likely to work backwards from the "goal" angle, constantly checking their progress towards the goal and how they might get closer to it. (This is the same means-end search that Sweller observed with his number puzzle.) Too much of a novice's attention was consequently devoted to the goal angle and how close they were to deriving its value. As in his number puzzle experiments, even when participants successfully solved these goal-specific problems, little learning resulted.

To discover a pattern or a rule, one needs to look away from the goals and their present progress, and instead turn to work in the past. What moves have you already tried? Which combinations of moves work particularly well together? Which angles in a diagram, when

[6] Sweller, et al., 1983, Sweller & Cooper, 1985.
[7] Sweller & Levine, 1982, Sweller, et al., 1983, Owen & Sweller, 1985.

derived, help you calculate other angles? By eliminating a single, clear goal for participants to fixate on, participants were free to notice patterns in their past moves. (And if there was a gap between their current status and a goal? They could discard the goal and choose another, instead of working backwards to derive it.) This freedom to think about the past is precisely what is needed for discovering useful, expert-like shortcuts. Sweller's results showed that these discoveries did, in fact, take place more frequently when problems were given with nonspecific goals. Therefore, nonspecific goals were better for learning than conventional problems.

These results were important for Sweller, but he was interested in a more fundamental result. Goal-free problems were still problems, if unconventional ones.[8] What if problems were totally unnecessary for learning?

Worked examples are not problems – they are explanations of how a problem is correctly solved. Goal-free problems function by eliminating means-end search, instead drawing participants' attention to their past successes. Was there any reason why the participants had to generate these past successes themselves? Sweller hypothesized that this was unnecessary. If people learned from studying and generalizing from their own examples of problem-solving success, it would be equally effective if these problems were presented by an instructor instead of generated by the learner.

In another series of experiments, Sweller carefully tested this idea. His results confirmed the hypothesis: the quality of learning was the same whether students learned via worked

[8] Or were they? "Problem" and "problem solving" have historically been fantastically tricky terms to pin down.

examples or self-discovered solutions. The major difference was time – problem solving took a lot of it! Worked examples took far less time. In this sense, explanations were more efficient than discovery.[9]

With these results in hand, Sweller began to take his results to the math education world. A 1989 piece in the Journal for Research in Mathematics Education asked, "Should Problem Solving Be Used as a Learning Device in Mathematics?" Their answer was unambiguously, "no":

> Students may learn more by solving goal-free problems or by studying their problem solutions than by solving the problems in the first place. This of course begs the question: Why solve the problem in the first instance?[10]

This wholesale skepticism of the value of problem solving put Sweller at odds with many in the educational establishment.

Given how slippery the term "problem" has proven, it's worth checking-in to see what Sweller means in his usage. After all, he does advocate for goal-free *problems*. If a student solves a goal-free problem, what should we call that? Apparently, not "problem solving." What sort of teaching is he opposed to, then?

[9] Sweller & Cooper, 1985, Cooper & Sweller, 1987.
[10] Owen & Sweller, 1989.

Sweller never defines “problem” in his 1989 paper, but he does give an example of the sort of mathematics instruction he is railing against at this stage of his thinking:

> The conventional mode of mathematics teaching is stereotyped. New material is presented and one or two worked examples using the new materials are demonstrated, followed by a reasonably large number of problems or exercises…Solving many conventional problems may not be the best way of acquiring this knowledge.

It’s easy to imagine advocates of problem solving nodding along with Sweller. They too were opposed to unnecessarily long sets of conventional problems students are often tasked with in math classes. Alan Schoenfeld -- researcher, educator and chamption of problem solving -- advocated for work with genuinely difficult, perplexing problems, not conventional work. Further, Schoenfeld later declared the movement of the 1980s “superficial,” adding that it had failed to incorporate the “deeper findings about the nature of thinking or problem solving.”[11] Sweller and his opponents could find common ground in their dissatisfaction with the way math was conventionally being taught.

The Invention of Cognitive Load Theory

Up until this point, the leading actor in Sweller’s theory was *attention*. Starting in 1988, attention would abruptly disappear from Sweller’s work. Taking its place was cognitive load,

[11] Schoenfeld, 2004.

which Sweller increasingly used to explain his experimental results. This shift marked the creation of Cognitive Load Theory.[12]

The fundamental idea of cognitive load is that humans have a limited capacity for holding information in our "mind's eye," i.e. our working memory. How many meaningless digits can you hold in your head at once? This is a test of your capacity for working memory, and most people struggle when asked to retain seven or more digits at once. This felt mental strain indicates that the cognitive load is high. Just as we might let an apple drop if the basket is too heavy, we're likely to forget things when our mind is over-burdened.

We've all experienced the frustration of a teacher who says too much, too quickly. *Slow down! I can't hold on to all of this at once.* Put another way, some teachers overload our working memory in ways that makes learning impossible.

Cognitive overload, for Sweller, became the main enemy of learning. Returning to his number puzzle, most participants attempted a means-end search. This, however, was a strategy that imposed a *high cognitive load.* To use the approach, there is a lot of information that you need to hold in your head: the goal number (210), the current number (54), how the current number compares to the goal (smaller), the rules of the puzzle (subtract by 69 or multiply by 3). That's a lot of information to hold on to at once, leaving precious little room for anything else! The cognitive load of that strategy was too high, and so learning could not happen.

[12] Sweller, 1988.

Why did Sweller make the move from attention to cognitive load? It wasn't because he had to. Sweller mentions no flaw or contradiction with his earlier theoretical explanations. He even points out that, in many ways, selective attention and limited cognitive load are two sides of the same coin: "Rather than using cognitive processing capacity terms, we could just as easily describe these circumstances in attentional terms."

Part of Sweller's shift might have to do with his interest in computational models of the mind. While his past results could be cast in terms of attention, it's unusual to talk about a computer as having limited attention. It's more natural to talk about a computer's limited processing load, and perhaps Sweller thought it more appropriate to use explicitly computational language.

Could there be a literary element to Sweller's choice of language? The image of a teacher burdening (crushing!) a student with problem solving is quite different than that of distraction. The shift from attention to cognitive load came as Sweller was sharpening his attack. No longer content to implicate the *strategy* used by students, he now placed the blame at the feet of the problems themselves:

> If, as suggested here, conventional problems impose a heavy cognitive load which does not assist in learning, they may be better replaced by nonspecific goal problems or worked examples (see Sweller & Cooper, 1985). The use of conventional problems should be reserved for tests and perhaps as a motivational device.

The language of load is sharper than attention might have been.

The new cognitive load framework yielded a flurry of new language. There were different *types* of cognitive load. Put in CLT terminology, the thinking generated by search strategies in the number puzzle was “extraneous,” unrelated to learning. But problem solving wasn’t only an extraneous distraction – it was an all-consuming one. The search strategy used up all the mind’s attentional resources, i.e. it had a high cognitive load. This high load made it impossible to pay attention to anything else that might lead to learning. Put together, it goes like this: conventional problems impose a *high extraneous load* on students.

Sweller’s experiments were simple and robust, and they provided Sweller (and other researchers) a foundation on which to build. That building happened in two directions: confirming that CLT held for traditional school topics, and discovering new techniques for reducing load during teaching. For example, Sweller found that it hurt learning to place geometric diagrams and supporting text in physically different places on the page. (They called this the “split-attention effect.”) This extraneous load could be reduced by weaving the supporting text into the diagram, a finding with implications for textbook design.

By Sweller’s own account, the research community did not line up behind CLT. “The research on worked examples was treated either with hostility or more commonly, ignored,” he wrote.[13] Some of these criticisms of CLT happened in the pages of academic journals. In 1991, psychologist Susan Goldman published a critique (“a commentary”) of CLT that asked whether

[13] Sweller, 2016.

“cognitive load theory [provides] an adequate general theory of learning?”[14] Her view was that it didn’t, and that the experiments that Sweller had designed failed to establish CLT’s theoretical stance as distinct from that of other, preferable theories.

Sweller’s response was telling. While he quibbled with many of Goldman’s claims, one major difference became clear: Sweller wasn’t after a general theory of learning at all. “A better understanding of various phenomena is probably the most common justification for a theory,” but improving our understanding was an insufficient goal for a theory of learning. “There can be only one ultimate goal,” he wrote, “the generation of new, useful instructional techniques.” Goldman may be right -- CLT can not explain learning, in general -- but that’s not its purpose. The purpose of CLT, for Sweller, was inventing new teaching techniques.

Sweller claimed that CLT had already successfully invented a handful of instructional techniques -- goal-free problems, worked examples, and texts that integrated words with diagrams. While this might be claiming a bit too much credit (did CLT invent worked examples?) it was true that Sweller had been led to these results via his theoretical work. The future of CLT, then, seemed as clear as its past. CLT would continue to discover new ways that students’ minds became over-taxed by instruction. Researchers would then invent ways to reduce this extraneous load. In time, these methods would make their way into schools and curricular materials, and learning would become more efficient.

[14] Goldman, 1991.

To a large extent, this would prove to be the work of CLT. But, inspired by the theory's successes, a new crop of researchers would push the theory in new directions that would test Sweller's standards of scientific worth.

Taking on Complex Learning

Jeroen van Merriënboer's doctoral work was on teaching computer programming.[15] He championed a style of teaching centered on "completion tasks." van Merrienboer would present students with a partially-complete program. Then, he tasked his students with filling in the missing pieces to make the program functional. At first, the gaps were quite small, but with time he would leave larger and larger sections of the program for his students to complete.

van Merriënboer found that these completion tasks were often very effective, more effective than worked examples. Why?

> "...students will often skip over the examples, not study them at all, or only start searching for examples that fit in with their solution when they experience serious difficulties in solving a programming problem. ... [In completion problems] students are required to study the examples carefully because there is a direct, natural bond between examples and practice."[16]

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[15] van Merriënboer, 1990.
[16] van Merrienboer, 1990.

Studying worked examples could help students learn to write software, but they had to be properly motivated to do so. Just presenting students with an explanation was not enough, in practice.

While van Merriënboer's early work does not mention CLT, he soon came to embrace Sweller's theory. In 1994 van Merriënboer published another study ("Variability of Worked Examples and Transfer of Geometrical Problem-Solving Skills: A Cognitive-Load Approach").[17] This new paper was firmly within the CLT framework, and its findings supported Sweller's ideas about extraneous cognitive load. At the same time, the paper challenged the idea that, when it comes to cognitive load, the lower the better.

In his study, van Merriënboer had heeded Sweller's warnings and taken care not to unduly burden his students. Following Sweller, again, he had tasked his students with studying a series of worked examples. The use of worked examples had ensured that participants in the study had mental fuel to spare. What do you do with that spare mental fuel, though? In Sweller's earlier experiments, that leftover capacity had been ignored. van Merriënboer, in contrast, realized that if "bad" cognitive load was reduced, there was an opportunity to increase students' load in a more productive way. Rather than discarding this spare capacity, he could reinvest it into learning.

For some of his students, van Merriënboer increased the cognitive load by increasing the *variability* of their worked examples. In the low-variability condition, each worked example

[17] Paas & van Merrienboer, 1994.

was followed by another that was identical except for the numbers. If one example showed how to find the distance between two points, the next one did too. In the high-variability condition, the second problem was changed. “Find the X-Coordinate of P2 given the distance between P1 and P2 and all the other coordinates.” While the mathematics of this second problem overlaps significantly with the first, the problem was entirely new.

On the one hand, the high-variability learning activity was significantly harder for students. It took them longer to finish the activity, and the students reported a higher degree of mental effort. At the same time, these students significantly outperformed their low-variability counterparts in a follow-up test. Unlike the effort that Sweller had studied, this cognitive load seemed to be good for learning. Along with his results showing the advantages completion tasks had over worked examples, van Merriënboer had pushed CLT into new territory.

van Merriënboer’s research didn’t contradict any of Sweller’s results, but they were challenging to the direction of his work. Their was summarized several years later in a joint paper by Sweller and van Merriënboer:

> “Until now, cognitive load theory research almost exclusively has studied instructional designs intended to decrease extraneous cognitive load. Recently, some studies have been conducted in which [cognitive load] was increased for processes considered to be directly relevant to schema construction.”[18]

[18] Sweller, van Merrienboer & Paas, 1998.

Why hadn't Sweller come up with completion tasks or high-variability examples in his own work? van Merriënboer and Sweller came from different traditions of research. Sweller's work involved "basic" learning, in the sense that the learning he studied involved acquiring isolated skills in a laboratory setting. As van Merriënboer's doctoral work shows, he came from a world of "complex" learning. The learning that van Merriënboer studied was the acquisition of competence in an entire domain of inter-related skills (computer programming) and took place in a classroom, not a laboratory.

CLT had been created out of Sweller's work with basic learning. For acquiring these sorts of skills, a more limited instructional toolkit was sufficient. There is usually just one skill being taught -- it's unsurprising that Sweller hadn't introduced high-variability conditions. Sweller was also working with highly-motivated participants in a laboratory, not students in a classroom. He didn't need to worry about them not being properly motivated to study his worked examples with care. This issue came up for van Merriënboer, though, because he was working with students in a classroom. van Merriënboer was taking CLT into newer, more complex learning.

In 1996, Sweller spent a sabbatical at van Merriënboer's university and the two tried to bring their approaches together. In a later reflection on this collaboration, van Merriënboer (characteristically) suggested that their work was difficult, but in a good way:

John and I encountered many problems in bringing cognitive load theory and models for complex learning together, because they are rooted in very different traditions. But problems are there to be solved and we always have a lot of fun doing so.[19]

Their collaboration resulted in an article, "Cognitive Architecture and Instructional Design."[20]

In their joint work, they introduced a new type of cognitive load, which they called *germane load*. Germane load was -- like the effort introduced by completion tasks or high-variability -- an addition mental burden that was good for learning. It's opposite was extraneous learning, that load which was bad for learning. Following van Merriënboer's lead, the goal for CLT was no longer merely to reduce extraneous load, but to then use that newly available mental capacity to good effect. "Learners' attention must be withdrawn from processes not relevant to learning and directed toward processes that are relevant to learning," they wrote.

The collaboration with van Merriënboer finds Sweller working with a larger palette of learning factors. Echoing van Merriënboer's earlier work, their joint paper points out the benefits completion tasks can have over worked examples:

> A lack of training with genuine problem-solving tasks may have negative effects on learners' motivation. A heavy use of worked examples can provide learners with stereotyped solution patterns that may inhibit the generation of new, creative solutions

[19] http://archive.sciencewatch.com/dr/erf/2009/09augerf/09augerfMerr/
[20] Sweller, van Merrienboer & Paas, 1998.

to problems…For this reason, goal-free problems and completion problems…may offer a good alternative to an excessive use of worked examples.

Before this collaboration, Sweller had not written about student motivation. Neither had he concerned himself with long-term learning issues resulting from "stereotyped" solution patterns. CLT was moving into complex learning, and it was changing in the process.

The Expertise-Reversal Effect

At the same time that CLT was moving into more complex learning, exciting developments were happening within CLT's core. Slava Kalyuga had done his doctoral work in Sweller's department, and was (and continues to be) a frequent co-author with Sweller. A series of papers they wrote would introduce a minor revolution into CLT, one that left room for even *conventional* problem solving as an efficient instructional technique.[21]

In his experiments, Kalyuga aimed to find teaching that would fit the needs of students with their different prior knowledge. (In education circles, this is usually called "differentiation" and is considered of high-importance, but it had never before been part of CLT's repertoire.)

Kalyuga showed that the entirety of CLT research had only considered the learning needs of novices, who were new to the material. Once a learner got past a certain degree of knowledge, however, these load-reducing techniques often became counter-productive.

[21] Kalyuga, et al., 2001; Kalyuga, et al., 2003.; Kalyuga, 2007.

Worked examples worked great for novices, but once enough knowledge had accrued they were no longer as helpful – problem solving led to greater gains for these participants.

These results might seem to go against the very principles of CLT, but Kalyuga and Sweller made the case that they actually follow from the theory's principles. CLT had previously had ascribed the failure of problem solving to lead to learning to the particular strategy that participants used -- a means-ends search. This, however, is a strategy that is employed by novices, who don't have anything better to use. A more knowledgeable student, though, is likely to have at least a partial grasp of more efficient strategies, and will be less likely to use the sorts of strategies that are damaging for learning.

At a certain point, a student would know enough that they would try to use more efficient strategies rather than the means-ends, even if they aren't *entirely* sure about how to use these more efficient strategies. (They might spend a lot of time thinking, for example, about whether they should subtract four from both sides, and this might help consolidate their knowledge.) Worked examples would be a waste of time for these more experienced students, drawing their attention to a lot of details they didn't need. Kalyuga and Sweller called this the "expertise reversal effect."

In 1988, Sweller had suggested that problem solving be practically eliminated from the mathematics curriculum. A decade later, his position had evolved significantly. While problem solving was unproductive for novices, with enough experience it would once again become the most efficient learning technique. Further, his work with van Merrienboer had showed the limits of worked examples for motivating students. It had also shown that increased mental effort could be a good thing. Thanks to van Merrienboer and Kalyuga, the palate of teaching methods was now larger than originally suggested. Challenging tasks -- and even conventional problems -- were back on the table.

In 2005, van Merriënboer and Sweller collaborated again on a piece titled "CLT and Complex Learning: Recent Developments and Future Directions."[22] The piece is brimming with promise and optimism about new corners of learning that CLT might shed light on. The piece concludes with three promising directions for future work with CLT. The second proposed line of inquiry calls for studying "instructional methods that motivate students to invest effort in processes that generate germane cognitive load." Motivation and germane load were relative newcomers to the CLT world, but they seemed crucial to the future of the theory.

There was no hint in this fundamentally optimistic piece that just five years later Sweller would renounce germane cognitive load and declare motivation outside of the scope of CLT. But who gets to decide what CLT should be? And what are those decisions based on? The troubled history of germane load within CLT raises questions of just how much complexity a theory of learning should be allowed to entertain.

A Theory of Everything?

In 2012, John Sweller was interviewed concerning the relationship of CLT to "constructivist" approaches to instruction. The interviewer asked Sweller to speak to the role of

[22] van Merrienboer & Sweller, 2005.

motivation with CLT. Sweller asserted the importance of motivation for learning, but placed its study outside the scope of his theory:

> "One of the issues I faced with Cognitive Load Theory is that there at least some people out there who would like to make Cognitive Load Theory a theory of everything. It isn't. […] It has nothing to say about important motivational factors…It's not part of CLT."[23]

Sweller, it seemed, now had clearer (and stricter) ideas about what the boundaries of CLT consisted of.

This interview was part of a broader shift in his thinking. In 2010, Sweller published a piece that effectively eliminated germane load from CLT.[24] Why the shift away from germane load? In a short comment online, Sweller explained:

> "Here is a brief history of germane cognitive load. The concept was introduced into CLT to indicate that we can devise instructional procedures that increase cognitive load by increasing what students learn. The problem was that the research literature immediately filled up with articles introducing new instructional procedures that worked and so were claimed to be due to germane cognitive load. That meant that all experimental results could be explained by CLT rendering the theory unfalsifiable. The

[23] *An Interview with John Sweller* https://www.youtube.com/watch?v=3bZOdZ8qBOk
[24] Sweller, 2010.

simple solution that I use now is to never explain a result as being due to factors unrelated to working memory."[25]

Just five years earlier, Sweller had co-authored a piece that concluded with a rousing call for researchers to pay closer attention to investigate motivation and germane load within the framework of CLT. Now these effects had no home within the theory.

Even as Sweller has moved away from germane load, many other researchers operating within the CLT framework continue to use the concept. Van Merriënboer and others who study complex learning give germane load, along with motivational factors, a significant place in their work. Whatever problems Sweller now sees with the notion of germane load, others prominent within the field do not share his concerns.

If germane load presents a significant threat to CLT, why haven't van Merriënboer and others eliminated it from their theories? The question is not addressed explicitly in the literature – at least, I couldn't find it – but I think the dynamic is clear. Germane load might muddy the experimental waters, but the waters are often muddier when complex learning is considered. For researchers on complex learning it is undesirable (impossible?) to eliminate good difficulties and motivational factors from consideration. To do so would, effectively, remove our capacity for grappling with the complexity in complex learning. This might be an option for Sweller, but it's not on the table for van Merriënboer.

[25] https://gregashman.wordpress.com/2016/02/09/example-problem-pairs/

During the five years between his collaboration with van Merriënboer and his elimination of germane load, Sweller saw confusion erupt in the CLT literature. This confusion was widely noticed. In a piece subtitled "The Good, The Bad and The Ugly," Sweller collaborators Kirschner, Ayres and Chandler decried the direction many CLT researchers were taking.[26] Too many were using sloppy techniques to measure various types of cognitive load. Other researchers were offering speculative explanations to make sense of their results, after the fact. While many sought to correct these issues in the field, Sweller reasoned that complex learning wasn't worth the trouble. This is my best reconstruction of what happened, at least.

Sweller had erected clear boundaries around CLT that excluded considerations of motivation and so-called "desirable difficulties." This protected CLT from the problems of post hoc speculation and sloppy measurement that had bloomed within the literature. Now, though, Sweller's theory had less to say about learning and problem solving in more complex settings. Now that a world of learning *outside* of CLT had been established, instructional techniques that had failed within CLT might be posited to thrive in more complex settings. Perhaps someone within CLT could now rethink the earlier, pessimistic research on problem solving.

Slava Kalyuga did just this. First, in 2011 Kalyuga had called for the elimination of germane load. First, because it was unncessary to CLT: "germane cognitive load was introduced not because there were unexplained empirical findings that demanded a new concept." (It wasn't?) Then, Kalyuga reasserted the mission of the theory: "CLT was originally developed to

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[26] Kirschner, et al. 2011.

suggest means for reducing extraneous cognitive load in learning," he wrote. Germane load, however, was distracting CLT from this mission. "The theoretical perspective of embracing all those methods [that benefit learning, but increase load] within a CLT framework based on the concept of germane load would potentially devalue CLT as a specific and constructive instructional theory."[27] To be useful -- to continue to develop techniques for reducing extraneous load -- the boundaries of CLT had to be protected.

Then, in 2015, Kalyuga argued for a further restriction of CLT's boundaries. The new issue was that researchers were amassing evidence showing that, in some situations, novices benefited from problem solving – a notion that clearly contradicted the dominant perspective of CLT. Kalyuga's solution looked a great deal like his solution to the threat of germane load: withdrawal. "The boundaries of cognitive load theory need to be narrowed down," he wrote.[28]

Kalyuga clarified that the only goal of interest within CLT was the direct development of knowledge during the duration of the experiment. But, he argued, complex learning calls for a much more diverse smattering of purposes. Consider, for example, a problem solving activity involving a simple equation, such as 2x = 10:

> Asking novice learners to solve the equation would most likely trigger applying a trial-and-error procedure by randomly testing different values for x, which would effectively demonstrate the dependencies between the elements of the equation and

[27] Kalyuga, 2011.
[28] Kalyuga & SIngh, 2015.

relations between both sides of it—exactly what is required to understand the nature of this problem situation and missing knowledge.

Problem solving might then be very helpful for learning, but in a way that is beyond the newly limited scope of CLT.

Sweller, for his part, is as yet unswayed by the contradictory research that so impressed Kalyuga. Sweller is particularly concerned about the methods these pro-problem solving researchers used. In a pointed back-and-forth with one of these research teams, Sweller suggests that their work breaks the "vary-one-thing-at-a-time rule essential to all randomized, controlled experiments."[29] Sweller seems to have unresolvable disagreements on methodology with these other teams that Kalyuga does not share.

At the end of all this, then, what does CLT have to say about problem solving? Sweller, Kalyuga and van Merriënboer all agree that problem solving and skill acquisition are largely separate processes. They also all agree that working memory needs to be carefully considered while designing instructional techniques. They also agree that, after gaining enough knowledge, problem solving once again becomes beneficial for learning.

Is there a place in CLT for problem solving past these fairly narrow confines? It depends who you ask. van Merriënboer approaches the question from a complex learning perspective. From his standpoint, teachers must take extreme care not to overwhelm the novice. This can be done in a variety of ways – using worked examples, goal-free problems, completion tasks, case

[29] Schwartz, et al. 2009.

studies and other, undiscovered techniques – that balance the needs of presenting the learner with tasks that are motivating, manageable, challenging and that build creative problem solving capacity.

Kalyuga, on the other hand, does not seem particularly interested in taking a stand on the larger role of problem solving within education. Maybe, as other researchers are finding, problem solving can help learning in some ways. But are problems helpful for motivation? Do they help prepare the student for skill acquisition? Maybe. CLT doesn't care. These results are beyond the confines of CLT, and CLT has nothing to say about them. CLT, for Kalyuga, focuses entirely on the way working memory supports or hinders the acquisition of a skill in those moments when skill acquisition is being attempted. Any larger picture of learning might be valuable, but is beyond CLT's scope.

If Sweller weren't skeptical of these new pro-problem solving results, he might sound a lot like Kalyuga. When it comes to the value of problem solving in the context of a test, Sweller *does* sound a lot like Kalyuga – fine results, but beyond the scope of CLT. CLT is not a theory of everything, Sweller is fond of pointing out. Germane load, motivation, testing, all these are things on which he his theory no longer has anything to say. All that he can say is that problem solving looks very bad from within CLT's narrow scope, and that he's skeptical of new pro-problem solving findings.

How Much Complexity Can One Theory Take?

van Merriënboer sometimes uses bicycle-riding to explain the difference between complex and simple skills. Riding a bicycle requires the rider to do many things at once – you must steer, pedal, and balance, at the very least. It would be a mistake, though, to attempt to teach a child to ride a bicycle by first teaching them to steer, then to pedal, to balance and finally to put all of these skills together at once. Why? These skills are so deeply connected that to practice them apart from each other is hardly to practice them at all. Steering a bicycle is, in fact, the skill of steering a bicycle *while* remaining balanced and pedaling. The skill is unrecognizable out of its context, and that is what makes learning to ride a bicycle a complex, rather than simple, skill.

Much of the differences among researchers in the CLT community concern how much of this complexity they are willing to take on. Perhaps the future of CLT depends on incorporating more and more complexity into the theory. Maybe, instead, the exact opposite is true, and the future of CLT depends on erecting barriers that protect the theory from studying the learning of more complex skills.

Any scientific theory necessarily involves some simplification of reality – if the theory is no simpler than reality, then we have done nothing at all to make the world more comprehensible. Like Borges' map that perfectly copied the country's terrain in all its detail, a theory that captured all the complexity of learning would be useless.[30] Instead, science involves

[30] Jorge Luis Borges, "Of Exactitude in Science"

the hard work of “just enough.” The task of the researcher is to find an appropriate level at which to balance all the competing needs of science – relevance, rigor, elegance and sustainability.

As we’ve seen, scientists can reasonably disagree on the proper scope of a theory of learning. There are other researchers who would argue that, like riding a bicycle, the phenomenon of learning *itself* is too messy to be neatly divided into its component parts. Is it helpful to talk about the role of cognitive load without simultaneously considering motivation? What about other components of learning – a student’s feelings about the material, or how they see themselves, their home lives, the perceived usefulness of the material or the thousands of other factors that arise in classroom learning. Perhaps it is, ultimately, unhelpful to think of learning in the categories that Sweller, van Merriënboer and Kalyuga have argued for.

Recently, some scholars have leveled such criticisms at CLT. “CLT is remarkably silent about the relation among load, affect, and motivation,” writes Roxana Moreno. “This void is extremely problematic under the light of decades of empirical evidence showing the tight interconnectedness among these constructs.”[31] CLT’s self-sufficiency also deserves critique, for Moreno: “Cognitive load research often ignores the existence of earlier research and theories that may better account for the findings than CLT.” CLT should not, Moreno writes, make itself into a scientific island.

[31] Moreno, 2010.

Sweller, for one, would reply that the ultimate test of a theory is the instructional techniques that it generates. In research on teaching, Sweller wrote, “there can be one ultimate goal: the generation of new, useful instructional techniques. All other functions of a theory are surely subsidiary to this ultimate function.”[32] Sweller also frequently argues that, by this measure, CLT has been a success. If Sweller has constrained the boundaries of CLT, it is only to put it in a position to continue generating new instructional methods for reducing extraneous cognitive load.

How useful can CLT claim to be, though, if it ignores the teaching of complex skills? For a brief period, Sweller embraced complex learning in CLT. Presumably, he thought this would lead to the generation of new teaching techniques. When he became convinced that it wasn’t going to work out, he dismissed motivation and germane load and called for a focus on the traditional role of CLT: discovering novel ways to reduce extraneous load.

Sweller thinks that CLT should ignore motivation; van Merrienboer thinks that it shouldn’t. Which researcher’s perspective is most appropriate for helping us improve teaching and learning? Many hope that time will tell, but there is no experiment that could settle their debate. Learning and teaching in schools are enormously complex phenomena, and researchers will always have to choose: what is worth seeing and what is worth ignoring? Ultimately, it comes down to judgement, and reasonable people will disagree.

[32] Sweller & Chandler, 1991.

Researchers on learning have often looked towards the physical sciences for a picture of how their science should, ideally, develop. Many have argued that, in physics, theories march in a strict procession. First, Newton. Next, Einstein, and so on, down the line. Einstein himself thought this, claiming that "the development of physics has shown that of all the conceivable theoretical constructions a single one has, at any given time, proved itself unconditionally superior to all others."[33] In science, the idea goes, we ought to all agree on the best theory on any given time.

Some researchers don't think the science of learning doesn't work like this, though. "Theories in psychology are not like theories in, say, physics," writes Dylan Wiliam.

> "In psychology, the tendency is for each new theory to be very good at explaining what previous theories did not, but generally not so good at explaining what the previous theories explained well...each new theory does not replace the preceding theories but rather complements them."[34]

This raises the possibility that in the study of teaching and learning we will always have an ecology of theories that are complementary, each appropriate for their chosen perspective. This is true within CLT – the community of perspectives within the theory makes it, on the whole, more interesting and applicable than otherwise it would be. It's also might be true of

[33] http://plato.stanford.edu/entries/einstein-philscience/
[34] Wiliam, 2007.

learning research more broadly, where CLT is just a single possible perspective among many.

The degree of complexity a researcher chooses to take on is perhaps just that -- a choice.

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