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Commentary

The worked example effect and human cognition

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The worked example effect is the best known and most widely studied of the cognitive load effects. The field's relative emphasis on this effect is justified. Worked examples not only provide us with an effective instructional procedure that contradicts some instructional movements that arose in the 1960s and 1970s and that still have some currency, the worked example effect throws light on the very foundations of human cognition. In this discussion, I will briefly outline some of the cognitive principles that underlie cognitive load theory and indicate the relation between those principles and the worked example effect. I will then discuss the individual papers of this special issue.

1. Natural information processing systems

Human cognition is an example of a natural information processing system and as such, should not be considered in isolation from the rest of nature. There are multiple ways in which natural information processing systems can be represented (see Sweller, 2003, for one representation). In this discussion, I will use five foundational principles.

1.1. Information store principle

Human cognition is dominated by the contents of long-term memory in the same way as biological activity is dominated by the contents of a genome. What we perceive, how we think and how we solve problems are heavily determined by what has been learned and stored in long-term memory. Your ability to comprehend the prose you are currently reading depends on a huge store of information held in long-term memory that permits you to identify letters, words and combinations of words and relate that information to the external world. It takes decades to acquire this knowledge. The borrowing principle, summarised next is the principal mechanism.

1.2. Borrowing principle

Almost all of the knowledge held in long-term memory is borrowed from the long-term memory of other individuals by imitating what they do, listening to what they say or reading what they have written. The process is a constructive one involving a combination of information from someone else's long-term memory and information from one's own long-term memory resulting in a schematic construction that differs from both sources of information. Combining information from someone else's long-term memory with information from one's own long-term memory has inevitable random components. When attempting to assimilate new information we usually engage in a quest for meaning and that process requires us to randomly assign meaning to new information and test whether that meaning is viable. Assigning meaning to new information means attempting to combine the new information with old information in long-term memory. In the same way, during sexual reproduction, the genomes of offspring are

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a "construction" of the genetic material obtained from both parents during a process intended to ensure that offspring inevitably differ from both parents.

1.3. Randomness as genesis principle

The borrowing principle does not create new information other than by combining two sources of information. New information is created during problem solving using a random generation and effectiveness testing procedure. During problem solving, most moves are likely to be generated by using information from one's own long-term memory in a special example of the borrowing principle but if that information is unavailable, the only other possible procedure is to randomly generate a move and test it for effectiveness with effective moves retained and ineffective moves jettisoned. Effective moves may subsequently be incorporated into long-term memory. All knowledge held in long-term memory ultimately can be sourced back to this process. Knowledge acquired via the borrowing principle at some stage had to be generated by this process. Similarly, in biology, mutation randomly generates new information that is tested for effectiveness where effectiveness is defined as reproductive fitness via the borrowing principle.

1.4. Narrow limits of change principle

Long-term memory acquires information via the borrowing and randomness as genesis principles. As indicated above, there is a heavy random component driving both principles. Because of the centrality of randomness in generating new information, all change must be small. Human cognitive architecture ensures limited change by the presence of a working memory that is very limited when dealing with new information. Successful genetic mutations are similarly small and incremental over long periods.

1.5. The environment organising and linking principle

While working memory can only process very limited amounts of new information it can handle unlimited amounts of previously organised information from long-term memory. That information is used to organise and interact with the environment. Thus, information in long-term memory changes the characteristics of working memory. Analogously, while substantial changes to a genome may require many generations, massive amounts of previously organised genetic material may be used to create protein, which is the immediate purpose of a genome.

2. Worked examples

I have expressed human cognitive architecture in the above terminology in order to link human cognition to the rest of the natural world, where it surely belongs, and to more closely identify which instructional procedures are likely to be effective and which are likely to be ineffective. Change is most efficiently effected via the borrowing principle and the vast bulk of human learning occurs through this principle with the aim being to increase the size of the information store and so increase the effectiveness of the environment organising and linking principle. The randomness as genesis principle is only used when the borrowing principle cannot be used because relevant information in someone else's long-term memory is either inaccessible or does not exist. Worked examples are the ultimate instantiation of the borrowing principle while problem solving is equally the ultimate instantiation of the randomness as genesis principle.

This architecture, when incorporated into cognitive load theory, can be used to predict that for novices, learning via worked examples should be superior to learning via problem solving because of the reduction of random processes. While the use of worked examples does not and should not eliminate randomness because all novelty derives from randomness, the probability of successful learning following a worked example is dramatically increased compared to learning following problem solving. Working memory cannot be expected to handle the amount of processing required by the random components of problems solving in a timely manner. The worked example effect provides an empirical demonstration of the relative effectiveness of the borrowing principle. On this reading, attempts over the last few decades to encourage learning through problem solving are likely to continue to fail (Kirschner, Sweller, & Clark, in press).

The papers of this special issue provide the latest research on the worked example effect and will be discussed next.

Catrambone and Yuasa (this issue) investigated the effects of solving problems (labelled active learning) or studying examples (labelled passive learning) with an emphasis on either the conditions of a condition–action pair or on both the conditions and actions. The procedure differed from most worked examples experiments in that under worked example conditions, one example only was provided for each of the 11 lessons and that example was not followed by an equivalent problem or fading procedure.

The results indicated that solving problems took longer than studying examples but resulted in less time to solve test problems. Adding study and test times resulted in no differences between problem solving and worked example groups. Emphasising both conditions and actions in examples or problems facilitated learning compared to emphasising conditions only.

There are several important conclusions that I feel should be derived from this study. First, a single worked example per instructional area is not likely to result in the worked example effect. Second, after studying a worked example, learners require a procedure, normally a problem, to provide them with feedback on whether they have learned. Third, a problem following a worked example provides an incentive for learners to actively process the worked example, an important consideration when using participants for whom the material does not constitute relevant curriculum information. Fourth, learners not only need to learn the conditions under which particular problem-solving moves are appropriate but also need to learn the consequences of those moves. As far as I am aware, this combination of factors has not been studied previously and it is important to have the data generated.

Reisslein, Atkinson, Seeling, and Reisslein (this issue) looked at three instructional procedures: worked examples followed immediately by a similar problem; problems followed immediately by a similar worked example and a fading technique in which worked examples were incrementally altered to problems by fading out solution steps. On problems similar to the training problems, the example–problem sequence was superior to the problem–example sequence for lower knowledge learners but the problem–example sequence was superior to the example–problem sequence for higher knowledge learners, providing a clear instance of the expertise reversal effect. There were no significant effects on far transfer problems nor, in contrast to previous findings, was the fading technique superior to using example/problem pairs.

This demonstration of the expertise reversal effect is novel and interesting. I do not know of any other work that has tested the effects of providing learners with problem–example pairs and compared that sequence to example–problem pairs. The fact that the problem–example sequence was better than the example–problem sequence for high knowledge learners is, as far as I am aware, a unique result that invites further investigation.

The expertise reversal and guidance fading effects rely heavily on instructors picking the right point at which to alter instructional techniques. If the wrong point is picked, the effects are unlikely to be obtained. Until recently, instructors had to use knowledge of their students or guesswork to determine when to alter instructions. A metric allowing rapid determination of levels of learner expertise is required to provide more solid grounds for instructor decisions. Kalyuga and Sweller (2004, 2005) commenced work on this goal.

Große and Renkl (this issue) in their first experiment found that providing learners with multiple solutions to a problem facilitated learning compared to a single solution. They failed to replicate that effect in their second experiment using more complex materials that probably had a higher intrinsic cognitive load. That high intrinsic cognitive load, according to Große and Renkl, may have left insufficient working memory capacity to allow adequate processing of the multiple solutions leading to no differences between groups. This explanation is plausible and, indeed, leaves open the interesting possibility that with materials that impose an even higher intrinsic cognitive load, a reverse effect with single solution instruction proving superior to multiple solutions may be obtained.

Große and Renkl (this issue) also studied the effects of self-explanations versus instructional explanations and in the first experiment found that both instructional explanations and even no explanations were superior to self-explanations on conceptual learning. A failure to find positive effects following self-explanations is not unusual for experiments using learning time controls (e.g. see Mwangi & Sweller, 1998). Many of the early experiments demonstrating the superiority of self-explanations used (a) quasi-correlational studies in which learners who spontaneously self-explained performed better than learners who did not self-explain; (b) experimental studies that did not strictly control learning times; or (c) such lengthy learning times that learning time was essentially uncontrolled.

As indicated by Große and Renkl (this issue), self-explanations impose a germane cognitive load that can be expected to facilitate learning. It may be reasonable to assume that all techniques that directly vary germane cognitive load but leave intrinsic and extraneous load constant run the risk of requiring additional learning time. In Experiment 1, the use of multiple solutions (also an example of germane cognitive load) may have taken cognitive load to the limits of working memory capacity. If working memory is fully extended dealing with all three forms of cognitive load increasing one form of load can presumably only be accommodated by increasing learning times or decreasing learning. Self-explanations may have taken cognitive load beyond working memory capacity. Experiment 1, by using a strictly and appropriately controlled experimental design with fixed and limited learning times, has obtained what I believe to be the expected (and important!) result of decreased learning.

It should be noted that most cognitive load effects do not vary germane cognitive load directly but rather, indirectly by reducing extraneous cognitive load and so freeing working memory capacity for an increase in germane cognitive load. If germane cognitive load is increased without working memory capacity being available, learning is likely to be interfered with rather than facilitated. In providing evidence for this point, this paper does us a considerable service.

Van Gog, Paas, and Van Merriënboer (this issue) investigated the effects of worked examples and of providing learners with additional process information using electrical engineering material. In an interesting finding, the standard worked example effect was obtained but additional process information was not beneficial.

The presentation of additional information to learners is a vitally important issue in instruction design that has been largely ignored and so this paper is timely. There are many relevant questions, some of which have been addressed in the discussion of this paper. Here are my views. When any additional information is added, issues of split attention may arise while the issue of redundancy also must be considered. Information presented in split-attention format is *never* effective as far as I am aware. The split-attention effect is one of the largest, most easily obtained cognitive load effects and information should never be presented in split-attention format unless it is quite unavoidable.

The issue of redundancy is much more difficult to deal with because it can be entangled with issues of expertise and the expertise reversal effect. When additional information is presented as in the present experiment, its purpose is to reduce cognitive load by reducing the need for learners to engage in inference processes that can make very heavy demands on working memory. If structured appropriately to eliminate split attention and if vital to learners by reducing unnecessary inferencing, process information should be beneficial, leading to positive effects. In contrast, if the additional information replaces inferences that learners can and do make easily and automatically, it will be redundant and lead to negative rather than positive effects. Whether learners need the additional information is likely to be a function of expertise and so the presence or absence of process information of the type used in this experiment could be used to demonstrate the expertise reversal effect. Less knowledgeable learners may need the additional information while more knowledgeable learners may find it interferes with learning the critical information. The value of this paper is in indicating the intricate relations between the worked example effect and several other cognitive load effects. Whether a particular effect is obtained is likely to depend on several interactions between effects.

I have one minor methodological point concerning the data of this experiment. Results indicated that learners from worked example groups spent more rather than the expected less time on task during the test phase than learners from the problem-solving group. This result can easily be obtained when learners with decreased knowledge make only cursory attempts to solve test problems that they do not understand. Using time to correct solution with non-solvers allocated the maximum allowable time eliminates this problem.

Gerjets, Scheiter, and Catrambone (this issue) in two experiments, looked at the effects of providing ‘‘molar’’ as opposed to ‘‘modular’’ worked examples and the effects of instructional explanations (Experiment 1) and self-explanations (Experiment 2). A molar example is one in which a largely formula based solution is provided and students need to learn how and when to use the formula. A modular example is one in which a verbal/logical solution is provided consisting of a series of steps that can be considered in isolation. The authors suggest, correctly, I believe that modular examples reduce intrinsic cognitive load. Results indicated that modular examples resulted in improved performance in both experiments despite requiring less study time. Experiment 1 yielded no effects due to instructor provided explanations while Experiment 2 indicated reduced performance on modular examples when associated with self-explanations but no effect on molar examples. The effect on modular examples was obtained despite the self-explanation condition requiring more instruction time.

There are several comments I wish to make concerning these very interesting experiments. My first comment concerns the possibility of varying intrinsic cognitive load. As the authors indicate, according to cognitive load theory, intrinsic cognitive load is intrinsic to a problem and contrary to the current work, should not be alterable. I believe that statement is true but only to the extent that the problem remains the same. If the problem changes, so can the intrinsic cognitive load (see, for example, Pollock, Chandler, & Sweller, 2002; Van Merriënboer & Sweller, 2005 for a review of this issue). Molar and modular problems are different problems, with students required to learn quite different procedures that are usable under different circumstances. Consider simple multiplication and repeated addition. Learning that $4 \times 3 = 12$ gives the same solution as learning that 4×3 means adding 4 three times or adding 3 four times. For a student who already has addition schemas, learning the second procedure may substantially reduce intrinsic cognitive load compared to learning how to multiply. There may be no new learning at all required for repeated addition and so intrinsic cognitive load is zero. Nevertheless, the reason intrinsic cognitive load has varied is because the task has changed. Evidence that the task has changed comes from the fact that learning how to multiply will allow one to do things that are effectively impossible by repeated addition. Similarly, the molar format for Gerjets et al. (this issue) probability problems allows problem solvers to solve problems that simply could not be contemplated by learners who merely learned the modular format. They are different tasks with a different intrinsic cognitive load.

The failure to obtain effects due to instructional explanations and the negative effects due to self-explanations also require comments. Both of these results are in accord with the findings of Van Gog et al. (this issue) and Große and Renkl (this issue), respectively. In light of these important findings from carefully run experiments, we may need to reconsider the advisability of providing learners with additional information or encouraging them to engage in additional activity while studying worked examples. It may be almost impossible to avoid the risks of split attention or redundancy. In light of the work reported in this special issue, my preference is to provide all detailed explanation during initial instruction and minimise explanations while studying worked examples.

3. Conclusions

The worked example effect has provided a rich source of information for instructional designers for two decades. It has also helped advance our knowledge of human cognition. The papers of this special issue demonstrate the continuing value of research into this important effect. They go well beyond the initial work simply comparing worked examples with equivalent problems and in the process provide us with valuable information concerning how to structure worked examples, the information that should be provided by worked examples and the activities in which learners should be encouraged to engage.

References

Catrambone, R., & Yuasa, M. (2006). Acquisition of procedures: The effects of example elaborations and active learning exercises. *Learning and Instruction*, *16*(2), 139–153.

Gerjets, P., Scheiter, K., & Catrambone, R. (2006). Can learning from molar and modular worked examples be enhanced by providing instructional explanations and prompting self-explanations? *Learning and Instruction*, *16*(2), 104–121.

Große, C. S., & Renkl, A. (2006). Effects of multiple solution methods in mathematics learning. *Learning and Instruction*, *16*(2), 122–138.

Kalyuga, S., & Sweller, J. (2004). Measuring knowledge to optimize cognitive load factors during instruction. *Journal of Educational Psychology*, *96*, 558–568.

Kalyuga, S., & Sweller, J. (2005). Rapid dynamic assessment of expertise to improve the efficiency of adaptive e-learning. *Educational Technology Research and Development*, *53*, 83–93.

Kirschner, P., Sweller, J., & Clark, R. (in press). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential and inquiry-based teaching. *Educational Psychologist*.

Mwangi, W., & Sweller, J. (1998). Learning to solve compare word problems: The effect of example format and generating self-explanations. *Cognition and Instruction*, *16*, 173–199.

Pollock, E., Chandler, P., & Sweller, J. (2002). Assimilating complex information. *Learning and Instruction*, *12*, 61–86.

Reisslein, J., Atkinson, R. K., Seeling, P., & Reisslein, M. (2006). Encountering the expertise reversal effect with a computer-based environment on electrical circuit analysis. *Learning and Instruction*, *16*(2), 92–103.

Sweller, J. (2003). Evolution of human cognitive architecture. In B. Ross (Ed.), *The psychology of learning and motivation*, *Vol. 43* (pp. 215–266). San Diego: Academic Press.

Van Gog, T., Paas, F., & Van Merriënboer, J. J. G. (2006). Effects of process-oriented worked examples on troubleshooting transfer performance. *Learning and Instruction*, *16*(2), 154–164.

Van Merriënboer, J., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review*, *17*, 147–177.