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Expertise reversal effect and its instructional implications: introduction to the special issue

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The formulation of robust and empirically-funded instructional principles is one of the major goals of instructional science. Research on aptitude-treatment interactions (ATIs) have, however, shown that instructional principles usually do not apply to any type of learner. As learners' prior knowledge is the most important learning pre-requisite, it is clear that instructional principles should take prior knowledge into account: What could be beneficial for beginning learners might get detrimental for advanced learners. In recent years, the concept of the expertise reversal effect—developed within the framework of cognitive load theory—has inspired a renewed interest on the interactions between levels of learner prior knowledge and effectiveness of different instructional techniques and procedures.

The expertise reversal is a reversal in the relative effectiveness of instructional methods as levels of learner knowledge in a domain change. The effect has been investigated since mid-1990s (see Kalyuga 2005, 2007; Kalyuga et al. 2003, for available overviews). It has been replicated in many studies with a large range of instructional materials and participants either as a full reversal (a disordinal interaction with significant differences for both novices and experts) or, more often, as a partial reversal (with non-significant differences for novices or experts, but with a significant interaction). The major instructional design implication of these studies is the need to adjust instructional methods and procedures as learners acquire more experience in a specific domain.

The expertise reversal effect fits well some empirical findings obtained in ATIs studies initiated in mid-1960s (Cronbach and Snow 1977). However, although learners' prior knowledge was recognized as an essential aptitude within the ATI approach (e.g., see Tobias 1976, 1989 for overviews), aptitudes and instructional treatments were investigated without taking into account underlying cognitive processes, and psychometric measurement tools used in ATI studies were not suitable for realistic instructional systems that could tailor instructional methods to individual learners.

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Cognitive load theory is based on an established model of human cognitive architecture that includes working memory with very limited duration, as well as storage and processing capacities for novel information, and effectively unlimited long-term memory as a knowledge base (see Sweller 2004; van Merriënboer and Sweller 2005, for recent overviews of the theory). The limitations of working memory lead to the necessity to avoid cognitive overload, for example, by excessive amounts of interacting elements of information that have to be processed by the learners. The theory distinguishes between productive (intrinsic, germane) cognitive load that makes learning possible and wasteful (extraneous) cognitive load that interferes with learning. For example, cognitive effort involved in comprehending novel information in text and pictures is required for successful learning as learners need to make connections between associated elements of presented information and their knowledge base (productive load). However, when related text and pictures are separated in space or time, the additional effort required for visual search processes and their co-referencing is expected to increase extraneous cognitive load. Physically integrating verbal and pictorial representations (placing them next to each other or synchronizing them in time) may reduce or eliminate this load (split-attention effect in cognitive load theory). A similar effect could be achieved by narrating the text rather than presenting it in a visual form (modality effect).

It was demonstrated that procedures and techniques designed to reduce extraneous cognitive load such as integrating textual explanations into diagrams to minimize split-attention, replacing visual text with auditory narration, or using worked examples to increase levels of instructional guidance and reduce unproductive search processes, were more effective for novice learners (see Sweller et al. 1998 for a review of original studies of major cognitive load effects). However, further studies with more advanced learners indicated that with the development of learner knowledge in a domain, such procedures and techniques often became unnecessary or even detrimental (Kalyuga et al. 1998, 2000, 2001; Renkl 1997; Renkl and Atkinson 2003; Renkl et al. 2002). For example, for more advanced learners, eliminating redundant representations or detailed worked-out steps was more effective than providing them. For these learners, processing redundant material could induce unnecessary working memory load and may distract from the central concepts and principles yet to be learned (see Renkl and Atkinson 2007; Wittwer and Renkl 2008). Especially, if more knowledgeable learners could not avoid or ignore redundant sources of information, those sources might impose an additional cognitive load resulting in negative rather than positive or neutral effects. A cognitive load interpretation of the effect was supported by measures of mental load (using subjective rating scales). Knowledgeable learners found it more difficult to process instructional formats and procedures involving redundant components because of additional, unnecessary information that they had to attend to and integrate with their available knowledge structures to find congruity between prior knowledge and incoming instruction.

Thus, in cognitive load theory, the effect is generally explained by imbalances between learner organized knowledge base and provided instructional guidance. Such imbalances could be caused by an insufficient learner knowledge base that is not compensated by appropriate instructional guidance (especially at the initial stages of learning) or by overlaps between available knowledge of more advanced learners and provided instructional guidance. In the first case (knowledge gaps), novice learners have to engage into unsupported search processes that may cause excessive levels of extraneous cognitive load. On the other hand, the need for higher knowledge learners to integrate and cross-reference redundant instructional guidance with available knowledge structures may also consume additional cognitive resources. A minimal instructional guidance would allow these learners to take advantage of their knowledge base in the most efficient way.

Thus, instructional guidance that is essential for novices may inhibit learning for more experienced learners by interfering with retrieval and application of their available knowledge structures, especially if these learners cannot ignore or otherwise avoid processing the redundant explanations. In order to optimize cognitive load, appropriate instructional support should be provided to novice learners, while unnecessary guidance removed as the learners acquire higher levels of proficiency in a specific domain. Adaptive learning environments that dynamically tailor levels of instructional support to changing individual levels of learner expertise in a domain have the best potential for optimizing cognitive load.

Issues of managing cognitive load by adapting instructions to individual learners are generally difficult to tackle because of the involvement of many learner characteristics. Studies of expert-novice differences in cognitive science have clearly demonstrated that learner knowledge base is the most important and fundamental cognitive characteristic that influences learning and performance (e.g., Bransford et al. 1999). A focus on the learner knowledge base may provide evidence-based procedures for the design of efficient adaptive learning environments.

The papers in this special issue present recent significant advances in research on the expertise reversal effect. The single contributions will be introduced in the next section. Nevertheless, some examples for new insights should be shortly mentioned at this point. It is shown in this special issue that the expertise reversal effect (a) holds not only in well-structured domains such as mathematics but also in such ill-structured domains as literary interpretation (Oksa et al., this issue); (b) it holds not only for learning results but also if the outcome variables refer to the employment of learning strategies and to motivation for learning (Nückles et al., this issue); (c) it interacts also with the developmental level of the learners (Homer and Plass, this issue); (d) it can be applied to “real-life” learning settings (Blayney et al., this issue); (e) it can be used to fruitfully inform adaptation schedules in intelligent tutoring systems (Salden et al., this issue).

Two commentaries conclude the issue. The first discussion paper is authored by a prominent researcher in the area of Aptitude Treatment Interactions and their instructional implications (Tobias 1976, 1989). The second discussion paper is authored by one of the leaders in the field of cognitive load theory and multimedia learning (Schnotz 2002; Schnotz and Kürschner 2007).

Structure of the special issue

Recent reviews of the expertise reversal studies (e.g., Kalyuga 2007) identified some directions for further research in this area. The effect needs to be extended from well-defined technical areas in which most of the studies have been conducted, to relatively poorly defined tasks and domains. Identifying a broader range of instructional methods and procedures that are optimal for learners with different levels of expertise also remains an essential direction for research, as well as determining effective approaches to dynamic tailoring of instruction to individual learners. Accordingly, the sequence of papers in the current special issue follows these research directions. The issue includes five empirical papers. The first two papers report on experimental studies of the expertise reversal effect in two non-technical areas of reading classical Shakespearean texts and writing journals in psychology courses. The following two papers present recent results demonstrating the expertise reversal effect with different instructional techniques using instructional visualizations in science education and spreadsheets in training accountants. The fifth and (partially) second papers investigate issues related to applying the effect to the design of learner-tailored environments based on adaptive fading techniques. The discussion papers focus on relations between the expertise reversal effect and ATI studies, theoretical problems related to the effect, instructional implications, and directions for future research.

The first paper "Expertise reversal effect in using explanatory notes for readers of Shakespearean text" by Oksa et al. (this issue) investigates the effects of explanatory notes on reader comprehension of Shakespearean text. Such texts are usually filled with classical references communicated through a language that is different from Modern English. Traditional methods of learning such texts may impose high levels of cognitive load. The design of instructional materials that assist in comprehending Shakespearean plays was based on interpretations of play extracts in Modern English that were physically integrated line by line with Shakespeare's original text. Experiment 1 presented an extract from a play to a novice group of Grade 10 students who had no prior knowledge of the text. The results demonstrated that the explanatory condition group reported a lower cognitive load and performed better in a comprehension test than the control group that studied the original extract. In Experiment 2, the same material was presented to a group of Shakespearean experts, and a reverse effect occurred: the control group outperformed the experimental group. The test performance data along with verbal protocols indicated that the explanations became redundant for these high-knowledge readers. Experiment 3 investigated whether the results of Experiment 1 could be replicated using a different Shakespearean text, with a group of Grade 10 high school novice-level students. In addition to test performance data, verbal protocols were also recorded. Similar to Experiment 1, results indicated advantages of explanatory text. The experiments showed that the relative effectiveness of instructions depended on learner levels of prior knowledge, thus demonstrating an expertise reversal effect in the literary comprehension area. Embedded explanatory text benefits low-level knowledge readers. However, for learners with more advanced and automated knowledge structures, needlessly processing redundant information may overload working memory and impede its processing capacity. The benefits of guided instruction may reverse and become detrimental for individuals with high prior knowledge levels.

The second paper "Expertise reversal effects in writing-to-learn" by Nückles et al. (this issue) provides evidence for the expertise reversal effect in another non-technical area related to journal writing in developmental psychology courses. Journal writing is an effective follow-up coursework that is used after a lecture or seminar session by asking students to write down a text in which they reflect on the previously studied contents. Previously conducted laboratory studies indicated that to fully exploit the potentials of writing learning journals and to maximize productive (germane) cognitive load, instructional support could be required in the form of prompts for applying appropriate cognitive and metacognitive strategies. Two longitudinal field studies reported in the current paper investigated the long-term effects of prompts on strategy use and learning outcomes. In Experiment 1, students wrote a journal entry about each weekly seminar session over a whole term. The experimental group received a combination of cognitive and metacognitive prompts, while the control group received no prompts. In the first half of the term, the experimental group applied more strategies in their learning journals and showed a higher learning success than the control group. Towards the end of the term, the amount of cognitive and metacognitive strategies elicited by the experimental group decreased while the number of cognitive strategies applied by the control group increased. Accordingly, when learning success was measured again at the end of the term, the experimental group performed worse than the control group and it showed also less favorable motivation for learning. In order to avoid these negative long-term effects of prompts, a gradual and adaptive fading-out of the prompts was introduced in Experiment 2. In the experimental group, each of the presented prompts was faded out as soon as a student applied the prompted strategy to a satisfactory degree. In the control group, the prompts were presented permanently. The results showed that, over the course of the term, the fading group applied increasingly more cognitive strategies while the permanent prompts group applied increasingly less cognitive strategies. At the end of the term, the permanent prompts group showed substantially lower learning outcomes than the fading group. Together, these results provide evidence for an expertise reversal effect in writing-to-learn. In the beginning of the term, the prompts successfully facilitated the application of beneficial strategies. However, as the students became more skilled in journal writing and internalized the desired strategies, the external guidance by prompts became a redundant stimulus that interfered with the students' internal tendency to apply the strategies and, thus, induced extraneous load. Accordingly, a gradual fading-out of the prompts in line with the learner's growing competencies was effective in mitigating the negative side-effects of the provided instructional support.

The third paper "Developmental changes in expertise reversal for iconic representations in science visualizations" by Homer and Plass (this issue) investigates how the addition of visual scaffolds in computer-based narrated chemistry visualizations affects learning outcomes for middle- and high-school students with differing levels of prior knowledge. It was demonstrated that visual scaffolds created by adding iconic representations to the purely symbolic (text-based and numerical) representations improved learning outcomes for low-prior knowledge but not for higher-prior knowledge high-school students. The study also showed that cognitive developmental levels of learners might have influenced the expertise reversal effect. For younger middle-school children who presumably lacked more general symbolic competencies (even if they had content knowledge), the effect was eliminated: the icons helped the younger children, regardless of their level of prior knowledge. The results support the claim that iconic visual scaffolds can facilitate learning in visual learning environments, particularly for low prior knowledge learners at lower levels of cognitive development. The findings argue for the importance of considering variations of individual learners when designing dynamic science visualizations. To be cognitively efficient and effective, they should be tailored to developmental levels and prior knowledge of individual learners.

The fourth paper "Interactions between the isolated-interactive elements effect and levels of learner expertise: Experimental evidence from an accountancy class" by Blayney et al. (this issue) investigates interactions between the isolated-interactive element instructional formats and levels of learner expertise with first year undergraduate university accounting students. The isolated-interactive elements effect occurs when learning is facilitated by initially presenting elements of information sequentially in an isolated form (e.g., using several less complex intermediate working formulas in spreadsheet-based calculations) rather than in a fully interactive form (using a single complex formula). The results demonstrated that learner expertise interacted with instructional formats using isolated or interactive elements of information during the initial phase of instruction. Novice learners primarily benefited from studying isolated elements first by performing complex tasks in a sequential manner using intermediate spreadsheet cells and starting from simple procedural steps. In contrast, for more experienced learners, this method did not improve learning as compared to using single spreadsheet cells that allowed these learners to take advantage of their knowledge base. It was suggested that for more experienced learners, the need to integrate and cross-reference the sequence of redundant for them simplified intermediate formulas with their available knowledge of the complete formula might have consumed additional cognitive resources.

The fifth and final empirical paper, “The expertise reversal effect and worked examples in tutored problem solving: Benefits of adaptive instruction” by Salden et al. (this issue) describes an experimental study related to a major instructional implication of the expertise reversal effect, namely to tailoring instruction to levels of learner knowledge in a task domain. According to cognitive load theory, worked examples are more favorable than problem solving exercises for initiating cognitive skill acquisition (worked examples effect). However, problem solving could be more effective in later phases of skill acquisition. This switch in effectiveness of examples is an instance of the expertise reversal effect. Moreover, a “smooth” transition from worked examples to problems (i.e., gradually fading worked-out steps) particularly facilitates learning (e.g., Renkl and Atkinson 2003). Recently, Koedinger and Aleven (2007) have noted the assistance dilemma that addresses the balance between giving information to the students (e.g., by using worked examples) and deliberately withholding it (e.g., by asking students to solve problems). It is, however, unclear when exactly should the switch between these assistance conditions take place to optimize learning. The reported study was designed to investigate if the current skill levels in terms of self-explanation performance while studying examples and problem solving performance could be employed to determine the appropriate learning conditions. A fading approach adaptive to a learner’s current skill level was expected to be more effective than a predetermined fading approach to structuring the transition from studying examples to problem solving. One laboratory and one classroom experiments were conducted to test this assumption. An individualized fading procedure (adaptive fading) was compared to a fixed procedure (fixed fading), and to a standard tutored problem solving condition (problem solving) with high school students studying geometry lessons in the Cognitive Tutor. The results of the lab study showed that the adaptive fading of worked-out examples lead to higher performance scores on immediate and delayed (a week later) posttests. The classroom study replicated this effect on the delayed posttest but not on the immediate posttest. Despite only partially replicating lab results in the classroom, the study demonstrated benefits of the adaptive fading condition. Both experiments provided evidence of better learning outcomes resulting from adaptive fading than from fixed fading or problem solving.

We hope that we can convince the readers of this special issue that the expertise reversal effect is a powerful concept in instructional science (a) with respect to the more basic issue of explaining boundary conditions of instructional principles and (b) with regard to the applied issue of adapting learning environments to the individual learners. We see the findings of this Issue also as a strong plea for taking the learners’ prior-knowledge level into account when investigating and formulating instructional principles in future research.

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