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Can the isolated-elements strategy be improved by targeting points of high cognitive load for additional practice?

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A B S T R A C T

Reducing problem complexity by isolating elements has been shown to be an effective instructional strategy. Novices, in particular, benefit from learning from worked examples that contain partially interacting elements rather than worked examples that provide full interacting elements. This study investigated whether the isolating-elements strategy could be improved further by targeting points of high cognitive load for additional practice. In learning to solve algebraic problems, fifty-four 13–14 year-old students were randomly assigned to one of three learning strategies: (a) an isolated-elements strategy with targeted extra practice on key components, (b) an isolated-elements strategy with an equal amount of practice on each component, and (c) a full-worked example strategy without isolating elements. Results showed that the targeted strategy was superior to the full-worked example strategy on a number of measures, but not to the equal practice strategy. For low prior-knowledge learners the equal practice isolated format was superior.

1. Introduction

Some materials are difficult to learn because of intrinsic complexity. Cognitive load theory identifies element interactivity as the major construct underpinning the learning of complex materials (see Sweller, Ayres, & Kalyuga, 2011; Sweller & Chandler, 1994). Materials low in element interactivity require few working memory resources and are relatively easy to learn. In contrast, materials high in element interactivity require considerably more working memory resources and are harder to learn. In order to deal with high cognitive load caused by problem complexity, specific instructional methods are required. Isolating elements is one such strategy, as it reduces element interactivity by initially presenting part-tasks before progressing to whole tasks (Ayres, 2006a; Pollock, Chandler, & Sweller, 2002). Learners initially develop partial schemas, which they then build on to construct full schemas at a later time. The main aim of this study was to investigate whether the isolated-elements strategy can be improved further by providing additional practice within problems where cognitive load is highest.

1.1. Cognitive load theory

Cognitive load theory (CLT) is an instructional theory based on the knowledge of human cognitive architecture. The theory is grounded in the findings of memory research, in that long-term memory is assumed to be extremely large (De Groot, 1965), whereas working memory is very limited in both capacity (Cowan, 2001; Miller, 1956) and duration (Peterson & Peterson, 1959). Critical to CLT are the interactions between working memory and long-term memory. It is argued that humans are only able to handle and process large amounts of information in working memory by accessing schematic knowledge stored in long-term memory (Ericsson & Kintsch, 1995; Sweller, Van Merriënboer, & Paas, 1998). Schemas chunk information together, which compensates for the shortcomings of working memory (Chi, Glaser, & Rees, 1982). Instead of having to process multiple bits (elements) of information at the same time, working memory has to deal with fewer elements, because they are grouped together into meaningful chunks. In CLT it is argued that for successful learning to occur the total demands on working memory (total cognitive load) should not exceed the working memory capacity of the learner. For novice learners, with little prior knowledge, chunked information is not readily available and therefore cognitive capacity is easily challenged.

Three types of cognitive load have been defined (Sweller et al., 1998). *Intrinsic* cognitive load is generated by the materials to be learned and is independent of the instructional procedures followed. It is created by the interactions between elements of information that must be considered simultaneously for learning to occur. If elements interact and must be processed simultaneously more information processing must take place in working memory for learning to occur. If there are many interacting elements that are

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intrinsic to the task, intrinsic cognitive load is high because *element interactivity* is high and that material is difficult to learn. On the other hand, instructional material that is low in element interactivity requires few working memory resources because the constituent elements do not interact and can be understood and learned in isolation. Hence learning is easier. The level of intrinsic cognitive load experienced depends upon the prior knowledge of the learner – what is complex for one learner is not necessarily complex for another.

Extraneous cognitive load is generated by the instructional procedures that guide the learning process. Poorly designed learning materials, where learners spend considerable effort in trying to follow or understand the procedures, are high in extraneous load, which in turn is a significant impediment to learning. Unlike intrinsic load, which naturally occurs, instructional designers create extraneous cognitive load by constructing poor learning environments. In addition to these two categories of cognitive load, *germane* cognitive load refers to the effort that needs to be directly invested for schema formation to occur (Sweller, 2010; Sweller et al., 2011).

1.2. Strategies to overcome problem complexity

CLT research has identified a number instructional design flaws that create extraneous cognitive load and found strategies to overcome such impediments to learning. For example, one highly researched instructional strategy has been worked examples (see Atkinson, Derry, Renkl, & Wortham, 2000; Kirschner, Paas, Kirschner, & Janssen, 2011; Renkl & Atkinson, 2003; Sweller & Cooper, 1985). Worked examples were proposed as an alternative to problem-solving methodologies and have been shown to reduce extraneous cognitive load compared with more inefficient problem-solving methods. Asking novice learners to solve problems creates extraneous cognitive load, because much of the learner's working memory resources are taken up by solving the problem rather than learning about the key features of the problem (see Kirschner, Sweller, & Clark, 2006). In contrast, studying solutions to problems reduces problem-solving search and frees up more working memory resources for schema acquisition (germane cognitive load).

Reducing poorly designed instructional materials is highly desirable, however it does not necessarily help learners deal with complex materials. Reducing extraneous load makes available more working memory resources to attend to intrinsic cognitive load; however, the intrinsic load of some materials may be so high for some learners that working memory capacity is insufficient to deal with such demands. In such scenarios, learning will be ineffective. A number of methods have been successfully employed to lower intrinsic cognitive load. One method is to increase the knowledge of the learner. Greater knowledge allows more elements to be chunked together in working memory, thus reducing intrinsic load. A second method is to change the task itself. Instead of exposing students initially to a complex task, containing many interacting elements, students are given related tasks that contain fewer interacting elements. Such a strategy is consistent with a simple-to-complex sequencing approach. In the following sections, some of the different methods for reducing intrinsic cognitive are described.

1.2.1. Increasing prior knowledge (pre-training)

One method of reducing intrinsic cognitive load is often referred to as pre-training, as specific prior knowledge is developed before the key materials are presented. Mayer, Mathias, and Wetzell (2002) demonstrated this effect with students learning about how piston brakes worked. Using an animation, information on a component model (how the brake piston moves) and a causal model (relations between the piston movement and what happens to the brake fluid) were presented. Both models needed to be built simultaneously for full understanding to occur. Mayer et al. (2002) showed that superior learning (problem solving) could be obtained by pre-training on the component model in contrast to learning the component and causal models simultaneously. In this case, pre-training was simply learning the names and behaviours of the component parts, but enabled more attention to be paid later to causal effects. A further study by Mayer, Mautone, and Prothero (2002) demonstrated that students who received pre-training on illustrations of key geological features showed superior problem-solving performance than students who did not receive such training in a game-based geology lesson. In a different context Clarke, Ayres, and Sweller (2005) found a pre-training effect when a secondary skill (spreadsheet knowledge) was required for learning primary concepts (mathematical graphs). Students with little spreadsheet knowledge who received initial spreadsheet training before applying this knowledge to learning the mathematics benefited more than students who received a concurrent approach of learning about mathematics and spreadsheets at the same time. In contrast, students who had more knowledge of spreadsheets benefited from the concurrent approach.

The results of these studies can all be explained in terms of a reduction in element interactivity. Pre-training on key aspects builds vital schematic knowledge. So when full tasks are presented, the number of interacting elements is reduced accordingly because of chunking capabilities provided by the prior knowledge. In the Mayer studies, the prior learning of key aspects of the component model or geological information allowed a smooth transition to the more complex final tasks. In the Clarke et al. (2005) study, many students found dealing with elements associated with both spreadsheets and mathematics simultaneously problematical. However, the more knowledgeable learners already had many of the elements associated with spreadsheets incorporated into schemas and so were able to handle the concurrent approach because for them, there were fewer interacting elements.

1.2.2. Altering solution complexity

In a similar fashion to pre-training other studies have focused on particular sub-components of the tasks to be learned. Consistent with the idea of a reduction in intrinsic load Chi, de Leeuw, Chiu, and LaVancher (1994) argued that a learner is more likely to integrate new knowledge with old if tasks are completed in smaller sections. Catrambone (1998) found supporting evidence for this argument by showing that learners achieved significant transfer of knowledge if solutions were structured in terms of subgoals. In this study, where students had to learn about statistical concepts, students were cued to notice that certain solution steps could be grouped together into subgoals. There was no practice on pre-defined subgoals as might be expected from a pre-training strategy, but the method was effective. Catrambone argued that once students noticed these subgoals, self-explanation strategies would be activated that would ultimately lead to better learning outcomes (see Chi, Bassok, Lewis, Reimann, & Glaser, 1989). However, this approach is also consistent with intrinsic load reduction. By focussing on subgoals, element interactivity is lowered because only the elements within a subgoal are considered at any one time rather than all of the elements in the task.

Focussing on specific aspects of a solution, rather than the deconstructing the task, has been further researched by Gerjets, Scheiter, and Catrambone (2004). Gerjets et al. distinguished between molar and modular presentation of solutions. In a molar presentation, students learn all about the category-defining structural features of a problem and the appropriate general formula needed for its solution. For a modular solution emphasis is placed on partly independent modules that contribute towards the overall formula. In a study that involved learning about probability theory, a molar approach (an explanation on how to categorise was given followed by a general formula) with a modular approach (key features were identified and partial calculations completed). The modular approach led to better learning outcomes, and has much in common with a subgoal approach. Each module could be considered meaningfully in isolation and therefore element interactivity and intrinsic cognitive load was reduced. A study by Nadolski, Kirschner, and Van Merriënboer (2005) also investigated the reduction of information in model answers. In a complex learning environment (how to conduct a law plea) learners were given identical worked examples, except for variations in the number of solution steps provided. Students who received an intermediary number of worked-example steps outperformed students who received the maximum number of steps. Again this is consistent with reduced element interactivity. Fewer solution steps equates to fewer interacting elements that need to be considered.

1.2.3. Isolated-elements strategy

The strategies described above have reduced intrinsic cognitive load using quite different methods without necessarily directly referring to reducing element interactivity. Other researchers have taken a more direct approach to element interactivity by initially removing from the to-be-learned task a number of interacting elements. This strategy is known as *isolating elements*. Pollock et al. (2002) conducted the first study of this nature within the CLT framework. In this study, trade apprentices were required to learn about electrical safety-tests. To isolate elements, initial instruction for one group of learners focused on explaining only basic procedural steps. In contrast, a second group received this same instruction but also with other relevant explanatory information geared to understanding all aspects of the task, and hence containing full element interactivity. In a second phase both groups received instructional materials with full interacting elements. On subsequent test problems, the isolated-elements group significantly outperformed the full element-interactivity group. In a second experiment, Pollock et al. replaced the initial focus on procedural knowledge with a greater emphasis on conceptual knowledge with the same findings. The results from both experiments were consistent, regardless of whether procedures or concepts were emphasised, learners who were provided with initial materials containing reduced element interactivity (isolated-elements group) outperformed students who were provided fully interacting elements throughout.

Along similar lines Kester, Kirschner, and van Merriënboer (2006) separated declarative and procedural information. Using an electronics domain, Kester et al. found that a strategy that sequenced information in the order of declarative (pre-practice) followed by procedural (during practice) was superior to a strategy that presented both declarative and procedural information together before practice or during practice. It was also found that the order could be reversed (procedural followed by declarative) with the same learning advantages. By separating the two forms of information intrinsic cognitive load was reduced and learners benefited.

Ayres (2006a) extended research into isolating elements further by using algebraic problems of the form $4(3x - 6) - 5(7 - 2x)$. To simplify these expressions, the brackets have to be multiplied out first using four consecutive calculations. For novice students in the domain, there is a high level of element interactivity because a number of operators, signs, and variables need to be considered simultaneously. Ayres reduced element-interactivity by providing worked examples to one group of students (isolated-elements group) where only one of the calculations (e.g. $4 * -6$) was demonstrated each time in a worked example. In contrast, a second group of students (fully interacting elements group) received worked examples showing all four calculations in each worked example. On subsequent tests, which required students to solve fully interacting problems there was an expertise reversal effect (Kalyuga, Ayres, Chandler, & Sweller, 2003). Students with low levels of prior knowledge, benefited from the isolated-elements approach (partial worked examples), whereas students with higher levels of prior knowledge benefited most from fully interacting elements (full-worked examples). A later study by Blayney, Kalyuga, and Sweller (2010) into isolating-elements strategies for students required to construct spreadsheet formulae also found a similar expertise reversal effect. These studies (Ayres; Blayney et al.) confirmed that the isolated-elements strategy is most effective for students with low prior knowledge. Reducing intrinsic load initially helps develop partial schemas, which enable working memory limitations to be overcome. In contrast, high-prior knowledge learners have sufficiently developed schemas that allow them to deal with high levels of element interactivity immediately without such a need for scaffolding.

1.3. Focus of the present study

The evidence described above (Section 1.2.3) suggests that isolating elements is an effective strategy to help novices in particular, to learn complex materials. However, research has also shown that element interactivity can vary within tasks. On multi-step geometry problems Ayres and Sweller (1990) found that problem solvers made specific error patterns matching fluctuations with cognitive load. Where cognitive load was highest (caused by high element interactivity), more errors were made. Ayres (2001) found similar error profiles on algebraic expansion tasks previously described (Section 1.2.3). When expanding brackets such as $4(3x - 6) - 5(7 - 2x)$ problem solvers made more errors during the second calculation ($4 * -6$) compared with the first calculation ($4 * 3x$), and the fourth calculation ($-5 * -2x$) compared with the third calculation ($-5 * 7$). Independent measures of cognitive load using a dual-task methodology (Ayres, 2001) and a self-rating difficulty scale (Ayres, 2006b) correlated highly with errors, indicating that the error differences in this domain were caused by variations in cognitive load.

To explain why such variations exist, Ayres (2001) argued that novices have to learn to not only carry out four separate calculations, but also decide which terms (numbers, signs, operators, and variables) need to be combined for each calculation. For students in the early development of algebraic skills this is not a trivial matter. Verbal protocols collected by Ayres (2001) found that during the second and forth calculations more decision making had to be made and this led to lapses in working memory loss of information at these locations. This finding may have important implications for designing isolated-elements materials, because it suggests that such fluctuations in element interactivity should also be taken into account.

The previous strategy used by Ayres (2006a) in this domain was to isolate each calculation supported by paired worked examples (see Trafton & Reiser, 1993). Learners were required to study a worked example of an individual calculation and then solve a similar one. The amount of practice spent on each calculation was identical. For learners with low levels of prior knowledge this strategy was more effective than providing full-worked examples, where all computations had to be completed at the same time. However, even though overall element interactivity was reduced, error profiles still indicated that some calculations (1st & 3rd) were easier to complete than others (2nd & 4th). Hence, the main motivation of this article was to investigate whether the effectiveness of the isolated-elements strategy in this domain can be improved by directly targeting the main cause of errors.

It is difficult to meaningfully isolate elements any further than single calculations. However, the amount of practice completed on each component can be varied. It is hypothesized that error rates could be reduced further if learners spent more learning time on component parts (individual calculations) of the problems that evoked the highest cognitive loads. By targeting such points for extra practice, schemas may become sufficiently automated to decrease error rates for these computations. Extended practice is a well-known technique to strengthen automation of procedures (Cooper & Sweller, 1987; Logan & Klapp, 1991; Shiffrin & Schneider, 1977; Van Galen & Reitsma, 2010). In order to master bracket-expansion tasks learners must become highly proficient in all aspects of the task, including individual components that are high in element interactivity. Consequently extended practice on calculations 2 and 4 was expected to help automation and calculation proficiency.

In the current study, which used the same bracket-expansion tasks as Ayres (2006a) the second and forth calculations were targeted for extra practice. It was expected that by spending more time practicing the most cognitively demanding components, error rates would decrease due to this extended practice. Therefore it was predicted that a strategy that combines both an isolated-elements approach with extended practice at key locations (referred to as a *Targeted-isolated* approach) would lead to greater learning than both an *Equal-isolated* approach where equal practice is spent on all four calculations, and a *Full-worked example* approach where no elements are isolated.

In comparison to full-worked examples, the targeted approach has potentially two main advantages. Firstly, the isolated format reduces intrinsic cognitive load compared with full-worked examples, where no elements are isolated. Secondly, the targeted practice can help mastery of the most demanding calculations. In comparison to an equal-isolated approach, the targeted approach has only has one predicted advantage (targeted practice) as both formats isolate elements. However, there are some potential dangers to a targeted approach. Novice learners in particular may need sufficient practice on all calculations to master them and fully understand the domain. Reducing the amount of practice on the first and third calculations may interfere with the automation of these calculations. Hence, it was also predicted that the impact of a targeted strategy would be moderated by domain specific knowledge. To test the potential of a targeted approach and to develop appropriate materials a pilot study was first run.

1.3.1. Pilot study

In the pilot study the two isolated strategies were compared with each other. The *Equal-isolated* strategy isolated the elements by breaking down the brackets into four separate calculations. Learners were provided an equal amount of practice on each calculation. The *Targeted-isolated* strategy also isolated the elements by breaking down the brackets into four separate calculations. However, learners spent three times the amount of time studying the second and fourth calculations compared with the first and third calculations. To isolate elements the strategy of explicitly indicating the calculation with an arrow was used (see Ayres, 2006a), as shown in Appendix A (described in more detail in the method section of the study).

Ninety-one year 8 students (mean age of 13.8 years) from a Sydney high school were divided into high or low prior-knowledge groups using school placements based on general mathematical tests, and randomly assigned to one of the two learning groups. All students worked through a learning phase, according to their designated strategy, and then were tested on the same set of conventional bracket-expansion tasks. The results indicated that on acquisition and test problems no significant differences were found between the two isolated strategies. However, on both measures there were significant performance-prior knowledge interactions. Simple effects tests found there was a close to significant effect ($p = .06$) on both tests for the lower prior-knowledge group, who had higher scores following the Equal-isolated strategy, but no significant difference was found for the higher prior-knowledge group. However, it was noticeable that overall success rates were very high 95% (acquisition) and 89% (test), potentially reducing the impact of the strategies.

1.3.2. Introduction to the main study

In this study three strategies were compared in learning how to expand bracket-expansion tasks. One strategy, called the *Equal-isolated* strategy, isolated the elements by breaking down the brackets into four separate calculations. Learners were provided an equal amount of practice on each calculation. The second strategy, called the *Targeted-isolated* strategy, also isolated the elements by breaking down the brackets into four separate calculations. However, learners spent three times the amount of time studying the second and fourth calculations compared with the first and third calculations. Both these isolated-elements strategies ensured that only one calculation at a time was presented. In contrast, the third strategy, The *Full-worked example* strategy, provided full-worked example where all four calculations were presented each time. To provide adequate instruction, all three strategies were embedded within worked examples (Cooper & Sweller, 1987).

Following evaluation of the pilot study a set of transfer problems were included to avoid potential ceiling effects during testing. In the pilot study school-based assessments of general mathematical knowledge was used to form two different prior-knowledge groups. In this experiment a pre-test of basic algebraic skills was conducted. As a result a much more fine-grained relevant measure of prior knowledge was collected, which enabled multiple regression analysis using a continuous variable.

1.4. Hypotheses

In the present study three different strategies were compared in learning how to complete algebraic expansion tasks. As argued above it was expected that a targeted approach would have an advantage over full-worked examples because it would both reduce intrinsic cognitive load and provide additional practice at key points. Hence, it was hypothesised that learners following a targeted approach would have higher learning outcomes than those following a full-worked example approach (Hypothesis 1a), and experience lower cognitive load (Hypothesis 1b). Because of expected increases in learning outcomes and lowered cognitive load, it was also predicted that the targeted format would be more instructionally efficient than the full-worked example format (Hypothesis 1c). Efficiency measures have been used extensively in cognitive load theory research to indicate the effectiveness of instructional strategies. Instructional efficiency combines the cognitive load experienced during learning with test performance. If one instructional strategy produces the same performance as another strategy but with fewer cognitive resources expended during learning than the first strategy is more efficient (for further discussion see Hoffman, 2011; Sweller et al., 2011; Van Gog & Paas, 2008). The findings from the pilot study, as well as theoretical considerations suggested that students with low prior knowledge could be harmed by the targeted approach, and therefore it was hypothesised that the advantages of a targeted strategy would be moderated by prior knowledge (Hypothesis 1d).

Both a Targeted-isolated strategy and an Equal-isolated strategy use an isolated-elements approach, the only difference being the frequency of practice at key locations. Hence it was predicted that the targeted approach would lead to higher learning outcomes (Hypothesis 2a), but not with reduced cognitive load (Hypothesis 2b), nor the associated instructional efficiency (Hypothesis 2c). Again it can be hypothesised that all predictions will be moderated by prior knowledge (Hypothesis 2d). Finally as the main rationale for the targeted approach is to remove fundamental systematic errors in this domain it was also predicted that the targeted approach would generate fewer occurrences of the systematic errors profiles found in this domain (Hypothesis 3).

2. Method

2.1. Participants

Fifty-four year 8 (mean age of 13.9 years) students from a Sydney high school participated, and were randomly assigned to a group receiving the full-worked strategy ($N = 20$), or the equal-isolated strategy ($N = 18$) or the targeted-isolated strategy ($N = 16$). All students had some prior knowledge of the tasks presented.

2.2. Materials

The experiment consisted of a prior-knowledge test, an acquisition phase and two test phases.

2.2.1. Prior-knowledge test

To successfully complete bracket-expansion tasks a certain level of basic algebraic competence is required. A 15-question test was constructed that assessed these types of mathematical skills. For example, multiplying algebraic terms together (e.g. $4x * 5$) or solving linear equations (e.g. solve $5x - 4 = -3x$).

The acquisition phase for the three groups was based on a paired worked-example strategy (see Trafton & Reiser, 1993). Learners were asked to study a worked example and then solve a similar type of problem. To isolate elements the same strategy adopted by Ayres (2006a) in this domain was used. As shown in Appendix A an arrow was used to indicate which calculation (-5×3) was to be calculated at any given time by drawing it under the specified term. In this example, only the third calculation was to be completed. Altogether a set of 32 bracket problems similar to the one demonstrated was constructed. According to the paired strategy, 16 were used for studying and 16 were used for solving. When given a problem to study, learners where immediately given a similar one to solve. For example the problem shown in Appendix A, would be followed by a problem that also required only the third calculation to be calculated, as indicated by an arrow, involving the same characteristics (e.g. -4×2). The Equal-isolated group completed exactly 4 pairs of problems for each of the four calculation locations.

The Equal-isolated group studied and solved 16 calculations evenly spread over the brackets. In contrast, the Targeted-isolated group were presented three times as many problem pairs corresponding to the second and fourth locations in the brackets. They studied and solved two problem pairs each for locations 1 and 3, and six problem pairs for locations 2 and 4. At no stage during acquisition were students in these two groups required to study or complete more than one calculation.

Whereas the Equal-isolated and Targeted-isolated groups received 16 pairs of worked examples requiring single calculations to be completed, the Full-worked example group received only 4 pairs of worked examples, each requiring all 4 calculations to be completed. However, consistent with the other two groups this group studied 16 worked calculations and completed 16 calculations. Furthermore, to avoid any computational bias, these 4 pairs of brackets were constructed from the exact same computations used by the other two groups in the identical locations. All groups studied and solved exactly the same 16 numeric and algebraic pairs but not necessarily positioned in the same locations. Hence, equivalence was achieved for all three groups.

All problem sets were presented in booklets consisting of A4 sheets of paper with enough spaces after each task for students to write their answers. In order to ensure that the participants understood the acquisition task and to provide a limited review on the topic, all students were given four matched partially worked examples consisting of single computations only, indicated by arrows before the acquisition phase. These worked examples were presented on the first pages of the answer booklets. Problem pairs were presented in booklets consisting of A4 sheets of paper with enough spaces after each task for students to write their answers.

2.2.2. Similar test phase

For the Similar test phase, a problem set of eight bracket-expansion tasks was developed similar to those studies during acquisition. Students from all three groups were required to complete the set by completing all four calculations per problem (fully integrated) as is usual in this domain. To ensure that the task was understood, a worked practice example was positioned on the first page before the problem set was commenced. All test information was presented in a second A4 booklet where students also wrote answers.

2.2.3. Transfer test phase

5 Transfer problems, called the Transfer test, were added. A degree of novelty was introduced by including more than one algebraic variable (only x had been used previously) and a different number of brackets (only two had been used previously). The five questions are shown in Appendix B.

2.2.4. Cognitive load measures

To obtain an indication of cognitive load during learning, a self-rating scale of difficulty was used, consisting of a nine-point scale: 1 (extremely easy), 2 (very easy), 3 (easy), 4 (quite easy), 5 (neither easy or difficult), 6 (quite difficult), 7 (difficult), 8 (very difficult), and 9 (extremely difficult). Each of these choices was presented at the end of the Acquisition phase answer booklet and students were required to "tick" one choice. In CLT research, two subjective scales (difficulty and mental effort) have been used extensively as an indication of cognitive load (see Sweller et al., 2011; Van Gog & Paas, 2008). In this study the difficulty scale was chosen because Ayres (2001, 2006a, 2006b) had previously used it successfully in the same learning domain, and also the difficulty scale is particularly sensitive to fluctuations in intrinsic cognitive load (see Ayres, 2006b; Marcus, Cooper, & Sweller, 1996). The main benefit of an isolating-elements strategy is to reduce intrinsic cognitive load. By reducing intrinsic load overall cognitive load is also reduced because of the additive nature of the different loads (see Sweller et al., 1998). This cognitive load scale was also used to calculate *instructional efficiency* based on a modification of the original formula developed by Paas and Van Merriënboer (1993). Instructional efficiency combines the cognitive load experienced during learning with test performance. If one instructional strategy produces the same performance as another strategy, but with fewer cognitive resources expended during learning, then the first strategy is more efficient (for further discussion see Hoffman, 2011; Sweller et al., 2011; Van Gog & Paas, 2008). Efficiency scores were calculated for both the Similar test and Transfer test.

2.3. Procedure

All students were given the booklets one at a time and given sufficient time to finish all the tasks. The prior-knowledge test was conducted on the day before the main study was completed, which was completed all on one day. Students were given the booklets one at a time and in the order of acquisition phase, Similar test phase, and Transfer test phase.

2.4. Scoring of tests

For the prior-knowledge test, 2 marks were assigned to each question. If one error was made, the mark was reduced to 1, if two errors were made no marks were given. A maximum score of 30 was possible, and the combined sample had a mean score of 20.6. For the acquisition problems a mark of 1 was assigned for every correct individual calculation. If an error was made, either arithmetical or in multiplying the signs together, no marks were assigned. During acquisition each group completed 16 calculations regardless of the strategy followed. Consequently a maximum score of 16 was possible. For the two post acquisition tests (Similar and Transfer) a mark was given for every correct individual calculation made (Zero if incorrect). However, as total scores across problems varied, the marks for each problem were standardised to give a maximum mark of 2. Hence, maximum marks for acquisition, test and transfer were 16, 16 and 10 respectively. For the cognitive load measure the difficulty rating score (1–9) was the only measure collected.

3. Results

Group means for each test and cognitive load related measures are shown in Table 1. To prepare the data for entry into a regression program a number of transformations of the data was necessary. The continuous variable prior knowledge was *centred* (called *Prior Knowledge-centred*) by subtracting the overall mean from each raw score, as recommended by West, Aiken, and Krull (1996) to provide more meaningful interaction interpretations. To test all the hypotheses a number of comparisons were required. For the main strategy effects the variables were coded to enable pair-wise comparisons between the three groups. To test for prior knowledge-strategy interactions, three new variables were calculated representing each pair-wise comparison interaction. All seven variables were entered into the regression program. Preliminary analyses revealed that Prior Knowledge-centred was a significant predictor for each dependent variable, as might be expected. However, only one pair-wise comparison between strategies (Full-worked example vs. Targeted-isolated) was found to be significant (for 4 of the 6 dependent variables) and one interaction (Prior knowledge × Equal-isolated vs. Targeted-isolated comparison) for only 1 of the 6 dependent variables. In view of the lack of significance of the other variables, stepwise regression was completed by entering Prior Knowledge-centred into the model first (step 1), followed by the Full-worked example vs. Targeted-isolated pair-wise comparison. The only exception being for the dependent variable Transfer, where the significant interaction was entered for step 2 (see Table 3). In all cases, the non-significant variables added extremely small levels of additional variance, and therefore were excluded from the final models and not reported. Regression results for tests of performance are reported in Table 2, while those based on the difficulty scale are reported in Table 3.

3.1. Hypotheses 1: targeted-isolated vs. full-worked example comparison

The regression analysis revealed (see Table 2) that the Targeted-isolated approach led to significantly higher test results only on the set of acquisition problems indicating weak support for Hypothesis 1a. Hypothesis 1b was supported, as cognitive load, as measured through the difficulty scale, was significantly lower for the Targeted-isolated approach in comparison to the Full-worked example approach (see Table 3). Hypothesis 1c was supported as the Targeted-isolated approach was found to be significantly more instructionally efficient in completing both Similar and Transfer test problems (see Table 3). No interactions were found for this comparison for any of the six measures indicating that the results were not moderated by prior knowledge.

3.2. Hypotheses 2: targeted-isolated vs. equal-isolated comparison

For the test measures no significant main effects were found for this comparison, indicating no support for Hypotheses 2a, where it was predicted that the targeted approach would lead to higher learning outcomes. Both the null hypotheses (2b & 2c) were supported as no significant differences were found for the cognitive load and associated instructional efficiency measures. However, a significant interaction was found (see Table 2) in support of Hypothesis 2d. To identify the cause of this interaction a pair-wise comparison (Least Significance Difference Test) were conducted at 3 points on the prior knowledge (Prior Knowledge-centred) continuous variable at 1 standard deviation (SD) above the mean, at the mean, and 1 SD below the mean. These locations represent points of high, average, and low prior knowledge respectively (see Fig. 1). At both 1 SD above the mean and at the mean, no significant differences were found. However at 1 SD below the mean, scores for the Equal-Isolated group was significantly higher than the Targeted-isolated group ($p < .05$). Hence, when prior knowledge was low students benefited most from the same amount of practice on each isolated component of the problem (Equal-isolated strategy) compared with the Targeted-isolated strategy.

3.3. Hypothesis 3: the targeted approach would reduce systematic errors

The theoretical development of the targeted strategy was based on the error profiles previously identified by Ayres (2001, 2006b). In the domain of double-bracket expansion tasks, systematic error patterns occur, in that problem solvers make more errors on Calculation 2 compared with Calculation 1, Calculation 4 compared with Calculation 3, and Bracket 2 compared with Bracket 1. To examine if the different experimental conditions had alleviated this error pattern, the total number of errors made on each of the four calculations was counted for each participant on the Similar Test. From this data it was possible to calculate three new variables. The

Table 1
Means (standard deviations) for each test and cognitive load related measures.

Instructional method	Acquisition scores	Test scores	Transfer scores	Difficulty rating	Test efficiency	Transfer efficiency
Full-worked	13.4 (2.5)	13.3 (3.1)	7.9 (4.5)	3.2 (1.9)	−0.37 (1.4)	−0.28 (1.2)
Equal-isolated	14.9 (2.2)	13.5 (2.5)	7.8 (4.1)	2.2 (0.9)	0.13 (1.0)	0.17 (0.9)
Targeted-isolated	15.6 (0.6)	14.1 (2.2)	7.7 (4.4)	1.8 (1.1)	0.46 (0.9)	0.27 (1.1)

Table 2
Summary of hierarchical regression analysis for variables predicting test performance.

	Acquisition test			Similar test			Transfer test		
	B	SE *B*	*β*	*B*	SE *B*	*β*	*B*	SE *B*	*β*
Step 1									
PK-centred	0.08	0.04	0.28*	0.19	0.04	0.55**	0.39	0.06	0.66**
Step 2									
PK-centred	0.10	0.04	0.34**	0.20	0.04	0.56**	0.52	0.07	0.89**
(Worked − targeted)	−1.20	0.32	−0.45**	−0.51	0.37	−0.16	–	–	–
PK-centred × (equal − targeted)	–	–	–	–	–	–	−0.34	0.12	−0.36**
	$R^2 = 0.08$ for step 1			$R^2 = 0.30$ for step 1			$R^2 = 0.44$ for step 1		
	$\Delta R^2 = 0.20$ for step 2			$\Delta R^2 = 0.03$ for step 2			$\Delta R^2 = 0.08$ for step 2		

Note. PK-centred = prior-knowledge scores, (worked − targeted) = pair-wise comparison between full-worked example and targeted-isolated strategies, PK-centred × (equal − targeted) = interaction between prior knowledge and the pair-wise comparison between equal-isolated and targeted-isolated strategies. *Significance at $p < .05$, **significance at $p < .01$.

first variable ($C2 - C1$) was generated by subtracting the total number of errors made at Calculation 1 ($C1$) from the total numbers errors made at Calculation 2 ($C2$). For the second variable ($C4 - C3$) the total number of errors made at Calculation 3 ($C3$) was subtracted from the errors at Calculation 4 ($C4$). To calculate the third variable, the difference in errors made between the second and first brackets ($B2 - B1$), the total number of errors made in Bracket 1 were added together ($C1 + C2$) and were subtracted from the total number of errors made in Bracket 2 ($C3 + C4$). Mean error rates for each group were then calculated for each of these variables (see Table 4). A positive difference, which is consistent with the expected error pattern, was found throughout except on two of the three measures for the Targeted group ($C4 - C3$, $B2 - B1$).

Regression analysis was conducted on these three new variables, using the same predictors as described previously. Initial analyses revealed that only Prior Knowledge-centred and one pair-wise comparison between strategies (Equal-isolated example vs. Targeted-isolated) were found to be significant. Hence, stepwise regression was completed by entering Prior Knowledge-centred into the model first (step 1) followed by the comparison between the Equal-isolated and Targeted-isolated groups (step 2). Results (see Table 5) indicated that prior knowledge was a significant predictor (negative) for two measures ($C2 - C1$, $B2 - B1$), and the pair-wise comparison for two measures also ($C4 - C3$, $B2 - B1$). The latter result indicated that in comparison to the Equal-isolated strategy, the Targeted-isolated strategy eliminated the error patterns usually found in this domain for two of the three statistics calculated, thus providing some support for Hypothesis 3, even though no significant different was found between the Full-worked example and the Targeted-isolated strategies. It can be concluded from this analysis, that the error profiles observed in this domain are very robust. Nevertheless, the targeted extra practice has achieved some reductions in its occurrence.

3.4. *Additional analysis: full-worked example vs. equal-isolated comparison*

Because of the 3-group design of the study it was also possible to compare an Equal-isolated strategy with a Full-worked example strategy, which was previously investigated by Ayres (2006a). The regression analysis found no significant differences for this comparison.

4. Discussion

The overall aim of this study was to investigate the effectiveness of using a targeted approach to locations within problems where cognitive load was greatest. This strategy was based on the isolated-elements approach of de-constructing problems requiring consecutive calculations into single calculation practice problems. In the given learning domain of double expansion brackets, an Equal-isolated learning strategy was created by requiring learners to practice an equal number of times on each of the four calculations, individually presented within a worked-example framework. The Targeted-isolated strategy modified this strategy by providing more practice (three times the amount) on locations where cognitive load was greatest (Calculations 2 and 4).

The results found in the study indicated that the Targeted-isolated strategy was most effective when compared with the Full-worked example strategy (Hypotheses 1). A significant advantage was found in completing the acquisition problem-solving tasks. Students in the Targeted-isolated group also rated the learning phase easier than those in the Full-worked example group. The self-rating scale of difficulty/easy has been used extensively as a measure of cognitive load (see Sweller et al., 2011) and is particularly sensitive to changes in intrinsic cognitive load (see Ayres, 2006b). The main aim of an isolated strategy is to reduce

Table 3
Summary of hierarchical regression analysis for variables predicting difficulty scores and efficiency results.

	Difficulty measure			Test efficiency			Transfer test efficiency		
	B	SE *B*	*β*	*B*	SE *B*	*β*	*B*	SE *B*	*β*
Step 1									
PK-centred	−0.05	0.03	−0.27	0.08	0.02	0.51**	0.09	0.02	0.58**
Step 2									
PK-centred	−0.06	0.03	−0.28*	0.08	0.02	0.54**	0.09	0.02	0.59**
(Worked − targeted)	0.86	0.39	0.47**	−0.45	0.16	−0.32**	−0.32	0.15	−0.24*
	$R^2 = 0.07$ for step 1			$R^2 = 0.26$ for step 1			$R^2 = 0.34$ for step 1		
	$\Delta R^2 = 0.15$ for step 2			$\Delta R^2 = 0.10$ for step 2			$\Delta R^2 = 0.06$ for step 2		

Note. PK-centred = prior-knowledge scores, (worked − targeted) = pair-wise comparison between full-worked example and targeted-isolated strategies. *Significance at $p < .05$, **significance at $p < .01$.

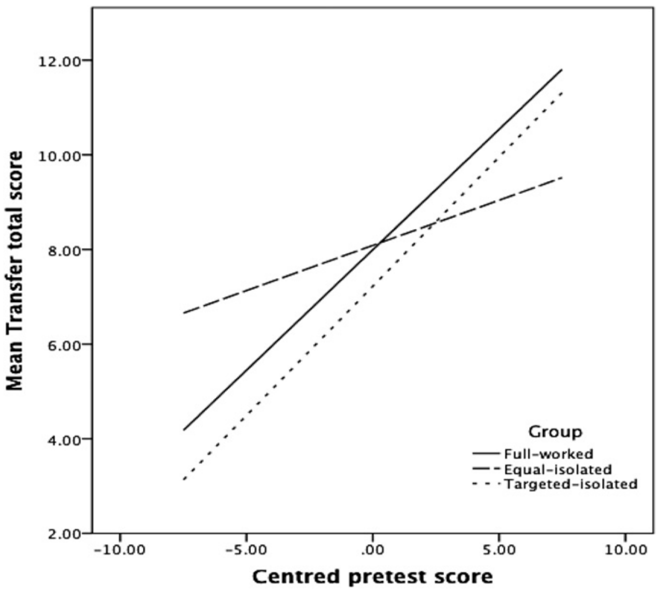

Fig. 1. Group regression lines for transfer scores graphed against prior-knowledge pretest scores.

Table 4
Means (standard deviations) per group for differences between calculations.

	Calculations (2 − 1)	Calculations (4 − 3)	Brackets (2 − 1)
Full-worked	0.70 (1.6)	0.30 (1.0)	0.90 (1.7)
Equal-isolated	1.06 (0.4)	0.41 (0.7)	1.6 (1.2)
Targeted-isolated	0.94 (1.8)	−0.31 (0.8)	−0.13 (2.1)

problem complexity by reducing element interactivity and the subsequent intrinsic cognitive load. The lower difficulty rating by the Targeted-isolated group suggests that this strategy did reduce intrinsic cognitive load, and therefore cognitive load overall.

A derivative of the formula developed by Paas and Van Merriënboer (1993) was used to combine cognitive load (difficulty rating) with performance on the Similar and Transfer tests to obtain two measures of instructional efficiency. Instructional efficiency (see Van Gog & Paas, 2008) measures the cognitive load experienced by the learner during instruction relative to how the learner performed on a test. On both measures, the Targeted-isolated group was more efficient than the Full-worked example group, suggesting that test performance was achieved at a lower cost of dealing with cognitive load during acquisition. In the theoretical argument underpinning this study, it was predicted that the targeted approach would have two potential advantages over the full-worked example approach, as it provided both an isolated format and additional practice on specific areas. The results provide support for this argument. It was also notable that in comparing these two groups, prior knowledge was not found to be a moderating factor on any measure.

In comparing the Targeted-isolated strategy with the Equal-isolated strategy (Hypotheses 2), no overall advantage was found for the targeted approach on test measures, the cognitive load measure, or the efficiency measures. However, there was a significant interaction found on the Transfer test. Students with low prior knowledge were disadvantaged by the targeted strategy. In contrast, students with higher levels of prior knowledge were not disadvantaged or advantaged. This interaction was predicted on the grounds that novice learners (low prior knowledge) may need to be exposed to sufficient practice on all four calculations initially to develop overall competency in the domain. The results support this prediction, as did the pilot study. Notably no differences in cognitive load measurements were found suggesting that differences in cognitive load did not cause the test score variations. As both strategies used an isolated format, cognitive load differences were not expected. Further research is required to tease out all the factors that might contribute to the disadvantage experienced by these low prior-knowledge learners.

The only advantage found in favour of the Targeted-isolated approach over the Equal-isolated concerned the error profiles. This study, like others (see Ayres, 2001, 2006b), found that the same systematic error patterns occurred. However, in comparison to Equal-isolated strategy the Targeted-isolated approach reduced its impact considerably.

Comparisons were also made between the Equal-isolated and Full-worked example groups. The previous study by Ayres (2006a) found a prior-knowledge-test performance interaction. Students with low prior knowledge were disadvantaged by the Full-worked example strategy, whereas students with higher prior knowledge were not. However, in this study, no support was found for these previous findings, but it is notable that test scores in the study were high. Even though a transfer test was included to combat potential ceiling effects, combined scores for each test were: 91% (acquisition), 85% (Test) and 77% (Transfer). It is feasible that overall prior-knowledge levels were too high to find significant differences for this comparison. It is also notable that the number of participants in the sample was not large, and therefore the study may have lacked power. Nevertheless, some of the changes in variance observed in the regression analyses are quite large, indicating that for some significant effects, sample size was quite adequate. Again further research is required to tease out such explanations.

In summary, the results of this study indicated that the Targeted-isolated strategy had a number of advantages over the

Table 5
Summary of hierarchical regression analysis for variables predicting error rate differences.

	Calculation 2 vs. Calculation 1 ($C2 - C1$)			Calculation 4 vs. Calculation 3 ($C4 - C3$)			Bracket 2 vs. Bracket 1 ($B2 - B1$)		
	B	SE B	β	B	SE B	β	B	SE B	β
Step 1									
PK-centred	−0.11	0.03	−0.46**	0.00	0.01	0.05	−0.07	0.03	−0.28*
Step 2									
PK-centred	−0.10	0.03	−0.46**	0.01	0.02	0.07	−0.06	0.03	−0.26*
Equal vs. targeted	0.06	0.26	0.03	0.36	0.15	0.33*	0.82	0.28	0.36**
	$R^2 = 0.21$ for step 1			$R^2 = 0.00$ for step 1			$R^2 = 0.08$ for step 1		
	$\Delta R^2 = 0.00$ for step 2			$\Delta R^2 = 0.11$ for step 2			$\Delta R^2 = 0.13$ for step 2		

Note. PK-centred = prior-knowledge scores, (equal − targeted) = pair-wise comparison between equal-isolated and targeted-isolated strategies. *Significance at $p < .05$, **significance at $p < .01$.

Full-worked example strategy, but not the Equal-isolated strategy. Learners with the lowest prior knowledge benefited most from the Equal-isolated strategy, consistent with previous research (see Ayres, 2006a; Blayney et al., 2010). These findings may have important implications for the use of worked examples. Research into worked examples has tended to focus on how they can be moderated to help the transition to expertise. Strategies such as variation (Paas & Van Merriënboer, 1994), completion problems (see Van Merriënboer, 1990; Van Merriënboer & de Croock, 1992), and fading (see Renkl & Atkinson, 2003) have all led to significant learning gains by building upon the standard worked-example model. This present study, as well as other studies into isolated-elements, has shown that full-worked examples may not necessarily be the best starting point for novices.

An ongoing aim of worked examples has been to reduce extraneous cognitive load especially when compared to learning through problem solving (Cooper & Sweller, 1987), whereas the isolating-elements strategy was formulated to reduce intrinsic cognitive load. Combining the two strategies may have significant advantages when carefully matched to the prior knowledge of the learner. Pollock et al. (2002) found a two-stage sequence to be effective: isolated-elements followed by full interacting elements. The findings of this study suggest that a targeted strategy, that provides extra practice on points of high cognitive load, might be effectively sequenced between the two stages. The optimum sequence for learners in the early stages of schema acquisition may be isolated elements, targeted elements and then fully worked examples. More research is required, especially in other learning domains, to test this hypothesis further. A limitation of the study was that no significant group differences were found for high-prior knowledge learners. Future experiments in more complex domains will provide greater understanding of the expertise continuum.

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Appendix

A) Strategy used to isolate elements during acquisition problems

$$3\,(2x\ +\ 4)\ -\ 5\,(3\ -\ 8x)$$

$$\downarrow$$

$$= -5 \times 3$$
$$= -15.$$

B) Transfer problems used in experiment 2

Expand the bracket the following brackets.

1. $-8\,(-7x - 5) - (2 + 4y)$
2. $-3\,(1 + 2x) - 5\,(3 + 2x) - 4\,(-2 - 3x)$
3. $-2\,(3x - 7x^2 + 5)$
4. $7x\,(-2 - 4x) - 4x\,(-5x + 8)$
5. $-9\,(2 - x) - 4\,(7y + 2) - x\,(-2 + y - 5x^2)$

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