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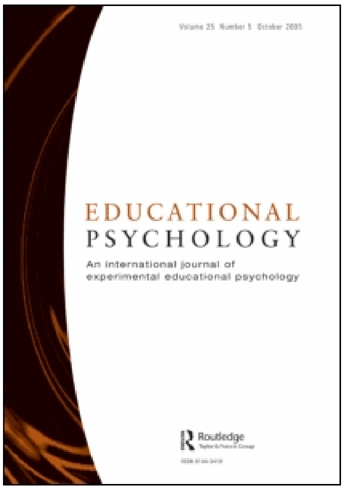

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Worked example effects in individual and group work settings

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Worked example effects in individual and group work settings

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This study compared the effects of worked example and problem-solving approaches in individual or group work settings on learning to solve geometry problems. One hundred and one seventh graders from Indonesia were randomly allocated to four experimental groups using a 2 (problem-solving vs. worked examples) × 2 (individual vs. group study) design. Performance measures on numeric and reasoning abilities using both similar and transfer tasks were collected. The results indicated a significant superiority of the worked example approach in both the individual and group work settings. Supporting data revealed that students could understand the material more easily using worked examples than when solving problems. The experiment provided evidence that the advantage of using worked examples over solving problems extends to a group work context.

Keywords: cognitive load theory; worked examples; group work

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Introduction

Solving problems is a major activity when studying mathematics. Nevertheless, despite the popularity of problem-solving as a teaching and learning device, there are both theoretical and empirical grounds for suggesting that students, particularly novices in the domain, learn more by studying worked examples than by solving problems (Kalyuga, Ayres, Chandler, & Sweller, 2003). Cognitive load theory, for example, argues that solving conventional problems imposes a heavy, extraneous cognitive load that interferes with learning. Detailed theoretical reasons for this argument are provided below.

Empirically, there is considerable evidence for the superiority of worked examples to problem-solving in various domains for novice learners (for some examples of this ‘worked example’ effect in mathematics see: Carroll, 1994; Mwangi & Sweller, 1998; Paas, 1992; Paas & Van Merrienboer, 1994; Sweller & Cooper, 1985; Tarmizi & Sweller, 1988; Ward & Sweller, 1990). In contrast, problem-solving has been found to be superior to worked examples only when learners have significant expertise (prior knowledge) in the domain (see Kalyuga, Chandler, Sweller, & Tuovinen, 2001; Kalyuga et al., 2003).

Most research that has compared studying worked examples with solving problems has studied learners dealing with problems on an individual basis (see Atkinson, Derry, Renkl, & Wortham, 2000; Sweller, 1999). It can be hypothesised that whereas

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individual problem-solving is inferior to individual studying of worked examples, group problem-solving may be superior to group studying of worked examples. Learning from others while solving a problem may have unique benefits. Accordingly, the present work compares studying worked examples versus solving problems under both individual and group learning conditions. We will begin by indicating the cognitive architecture used by cognitive load theory to explain the worked example effect.

Human cognitive architecture

Cognitive load theory (see Sweller, 1999; Sweller, van Merrienboer, & Paas, 1998; van Merrienboer & Ayres, 2005) assumes that subject areas such as mathematics constitute biologically secondary rather than biologically primary knowledge (Geary, 2007, 2008; Sweller, 2007, 2008). Biologically primary knowledge is the knowledge that we have evolved to acquire over many generations. Examples are listening to and speaking our first language, recognising faces and general problem-solving strategies such as means-ends analysis (Newell & Simon, 1972). Biologically primary knowledge is acquired easily and effortlessly simply as a consequence of interacting with other people. It does not have to be explicitly taught. In contrast, biologically secondary knowledge, though it relies on biologically primary knowledge, is the knowledge that has become culturally important relatively recently, and so, we have not evolved to acquire such knowledge simply by immersion in a functioning society. Such knowledge can be difficult to acquire and requires explicit instruction. Educational institutions were invented to teach biologically secondary information. Mathematics provides an example, although it should be noted that there is evidence that young children have an innate capacity (primary knowledge) to acquire arithmetical skills (see Butterworth, 2005).

The manner in which we acquire biologically secondary information mimics the manner in which evolution by natural selection acquires information (Sweller, 2003, 2004; Sweller & Sweller, 2006). Human cognitive architecture is a natural information processing system that can be summarised by the following five principles.

The information store principle

This principle indicates that a natural information processing system requires a large store of information in order to function (Sweller & Sweller, 2006). Long-term memory provides that store. It has an unlimited capacity to store organised information that allows us to deal with familiar information.

The borrowing and reorganising principle

Almost all information stored in long-term memory is borrowed from the long-term memory of others (Sweller & Sweller, 2006). We imitate what other people do, listen to what they say and read what they write.

The randomness as genesis principle

While information can be borrowed from others, it must be initially generated. The initial source of all information in our long-term memory is produced by random generation followed by tests of effectiveness during problem-solving.

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The narrow limits of change principle

This principle flows from the randomness as genesis principle. Due to the random generating process indicated in the third principle, working memory is severely limited in capacity (Miller, 1956) and duration (Peterson & Peterson, 1959) when processing novel information (Sweller et al., 1998). For example, if working memory must deal with three elements of novel information, there are six possible permutations. If it must deal with 10 elements, there are 3,628,800 permutations rendering problem-solving essentially impossible. Accordingly, working memory must be severely limited when dealing with novel information.

The environmental organising and linking principle

This principle suggests that an unlimited amount of organised, familiar information from long-term memory can be transferred to working memory (Ericsson & Kintsch, 2005) while imposing a relatively light working memory load. The consequent freeing of working memory capacity can be employed to generate new information. Thus, the function of learning is to store large amounts of information in long-term memory in order to reduce working memory load and guide activity.

This cognitive architecture can be used to suggest that when dealing with the biologically secondary information found in mathematics courses, instruction should be detailed and explicit (Kirschner, Sweller, & Clark, 2006). Students need to learn to recognise problem states and the best moves associated with each state. They should be shown the best moves via the borrowing and reorganising principle in order to facilitate the construction of knowledge in long-term memory that can be subsequently used by the environmental organising and linking principle to allow rapid problem-solving. Worked examples make use of the borrowing and reorganising principle. In contrast, when learners (novices, in particular) are required to solve the problem, extraneous cognitive load (load unnecessary for learning) is created because attention is mostly directed towards solving the problem, looking for solution steps using the randomness as genesis principle, rather than learning about the solution steps (Sweller et al., 1998).

Cooperating with others during problem-solving may be a biologically primary task. It is plausible to speculate that such cooperation may eliminate the worked example effect by improving learning during problem-solving. Of course, such cooperation may similarly improve studying worked examples. Group work settings will be discussed in the next section.

Group work settings

Group work may be defined as a small group of students who learn collaboratively to accomplish desired tasks. It is thought to have social and economical advantages, as well as purely academic ones (Kirschner, Paas, & Kirschner, 2009a). Webb (1991) suggested that the giving of explanations to group members by other group members not only promotes the exchange of ideas but also encourages the discovery of underlying principles. The process of giving explanations may encourage explainers to recognise, clarify, reorganise and resolve the material and develop new perspectives (Webb, 1991; Webb & Mastergeorge, 2003). As well, the process of receiving explanations may help learners in gathering and clarifying the information. Webb (1991) and Cohen (1994) called the effect of giving explanation as *cognitive facilitation.* By

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generating explanations for others, students may reorganise their cognitive structures, and by elaborating the material, they may facilitate their cognitive development.

However, exchanging explanations in a small group to promote active learning should meet certain requirements. There should be conditions to ensure that the interactions occur positively with all students having an equal opportunity to mutually help each other and to ensure that explanatory help is consistently shared. Consequently, students who know more should be able to share their explanations, whereas students who do not know should be encouraged to ask and benefit from explanations. However, as Kirschner, Paas, and Kirschner (2009b) point out, collaboration may be most effective when the learning environment has highly scripted rules enforcing a high degree of meaningful collaboration. Furthermore, Schmidt, Loyens, Van Gog, and Paas (2007) recommended training of collaborative skills in two steps. The first step requires a mastering of the learning materials by individuals while the second requires learning the various roles required for maximum group performance, such as the role of a chairperson or scribe. Johnson and Johnson (1994) argued that the most important cue for successful cooperative learning is cooperative skill development. On the other hand, Webb and Cullian (1982) found that over a three month period, students' interaction frequency remained stable in their group.

In terms of grouping arrangements, Webb (1991) suggested that students with medium ability should be homogenously grouped, rather than mixed with high- and low-ability students, because heterogeneous groups are more likely to be dominated by high-ability students (who do more explaining) and low-ability students (who do more requesting). Peterson and Swing (1982) found that heterogeneous groups did not facilitate medium-ability students. Nevertheless, a homogenous male group of high-ability or low-ability students was not significantly related to better achievement (Saleh, Lazonder, & de Jong, 2007). Heterogeneous ability grouping, consisting of a balanced number of high, medium and low-ability students, is favoured by many researchers (Johnson & Johnson, 1994; Webb, 1991).

There is little definitive research concerning ideal group sizes and interactions. Indeed, most research applies to a group size of four or five in an educational setting (Johnson & Johnson, 1994; Mevarech, 1985; Webb, 1991). It is widely accepted that the smaller the group size, the higher the chance for each member to actively participate. Conversely, large sizes result in less individual accountability.

Recently, the cognitive load consequences of group work were addressed by Kirschner et al. (2009b). In a review of the literature, they pointed out that few studies have been conducted that directly compared individual learning with group learning using performance measures. Although results from those studies making direct comparisons are fairly mixed, some evidence has emerged that collaboration seems to be most effective when problem-solving tasks are used as a test rather than simpler recall tasks – a finding confirmed by their own study when testing transfer performance.

To explain these results, Kirschner et al. (2009b) argued that group work has two countervailing consequences for cognitive load. First, if individuals in groups share the cognitive load by sharing the task, then the intrinsic cognitive load, due to the intrinsic complexity of the material (see Ayres, 2006; Sweller et al., 1998), can be reduced, although at the cost of each individual not necessarily being familiar with the entire task. Second, working in a group results in transaction costs because working memory resources must be allocated to communicating with other group members, a cost not associated with individual work. The importance of transaction costs depends

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on intrinsic cognitive load. If intrinsic cognitive load is exceptionally high due to the complexity of the material, then transaction costs may be relatively trivial and group work may be important. In contrast, if intrinsic cognitive load is low, then transaction costs may exceed any benefit of being able to share the intrinsic cognitive load among group members, and so, individual learning may be preferable. In this last scenario, transaction costs are a form of extraneous load and are redundant to learning.

The main aim of this study was to extend the research that applies principles of cognitive load theory to collaborative learning environments and, in particular, to conduct fairly novel research that combines worked examples with group work (for a computer-based example, see Rummel & Spader, 2005). As argued above, we expect that individual learners will benefit from worked examples compared with problem-solving. In contrast, students working in groups may not need worked examples, as the cognitive load may be reduced if it is shared amongst group members. Under such circumstances, we expect a problem-solving strategy to be more effective. On the other hand, if collaboration has extra transaction costs created through communication, then the advantages of sharing the load may reduce the effects of problem-solving. To test these hypotheses, a 2×2 randomised, controlled experimental design was used. To ensure that the effects of collaboration could be best assessed, transfer tests were included.

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Methods

Experimental design

The study used a 2×2 factorial design varying in learning approaches (problem-solving or worked examples) and student settings (individual learning or group work). The two dichotomous variables generated four experimental groups: (1) problem-solving in an individual setting; (2) worked examples in an individual setting; (3) problem-solving in a group setting; and (4) worked examples in a group setting.

Participants

The participants were 108 Year 7 students in three mathematics classes in one Indonesian junior high school. Each class consisted of 36 students (18 males and 18 females). The students had graduated from primary schools that used a National Curriculum, and therefore, it can be assumed that all students had fairly similar mathematical experiences. The participant school used a competency-based curriculum (Depdiknas, 2004) that was part of the Indonesian National Curriculum for junior high schools. The learning material and competencies required were outlined in the curriculum and compulsory for all students. Problem-solving was a stated focus of classroom activity, and communication skills developed through small group learning, such as the ability to demonstrate and interpret mathematical ideas in written or oral form, were one of the outcomes. Because of the extended nature of the experiment, absenteeism led to seven students not completing all tasks. These students were excluded from the study. One hundred and one participants remained (mean age in years = 12.80, SD = 0.26), unequally distributed in the four groups as shown in Table 1.

At the time the research was carried out, students had been taught mostly by the same mathematics teacher using a class presentation followed by an individual

Table 1. Number of participants in each group.

	Individual	Group work
Problem-solving	29 (16 M, 13 F)	23 (12 M, 11 F)
Worked example	26 (11 M, 15 F)	23 (12 M, 11 F)
Total	55 (27 M, 28 F)	46 (24 M, 22 F)

Note: M = male, F = female.

practice procedure. Nevertheless, the teacher indicated that students had obtained some experience by learning in small groups, as this setting was used in at least one (of six) lesson per week.

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Materials and procedures

The experiment included five phases: a revision phase, a group skills induction phase, an acquisition phase, a test phase and a questionnaire phase, which were conducted during three consecutive daily mathematics lessons lasting 70 minutes each. The revision phase and the group skills induction stage were conducted on the first two days. On the third day, the acquisition phase was completed followed by the test and questionnaire phases. The whole experiment took 3.5 hours.

The subject matter to be learned was multi-step geometry theorems, which were part of the regular school curriculum followed by the school. However, when the experiment was run, the material had not been previously studied. The relevant geometry theorems (see Table 2) were all related to calculating angles and included intersecting line properties (Theorem numbers 1, 2, 3 and 4) and parallel line properties (Theorem numbers 5, 6 and 7).

The revision phase

The experiment began with all students studying the first four theorems listed in Table 2. This lesson included a 15-minute presentation by the teacher and also a description of each theorem and one worked example using the theorem. Every student was then provided a booklet consisting of 16 pairs of worked examples and problems. For each problem pair, students were required to study a worked example and then solve a similar problem themselves. All worked examples and problems required only a single step consisting of the application of one theorem for solution.

Table 2. Geometry theorems used in the study.

Theorem no.	Theorem
1.	Angles formed by lines running to the same point sum to 360°
2.	Adjacent angles in a right angle sum to 90°
3.	Adjacent angles on a straight line sum to 180°
4.	Vertically opposite angles made by straight lines are equal
5.	Co-interior angles between parallel lines sum to 180°
6.	Alternate angles made by parallel lines are equal
7.	Corresponding angles made by parallel lines are equal

Students were instructed to state the appropriate theorems used when solving the problems. Appendix 1 provides an example of the type of problem presented in this phase and the format of the worked example. The goal of this problem was to find the value of *x*. It can be solved by one application of *Theorem 3* (see Table 2). The initial problem state was written in black text, with the single solution step written in faded grey and in italic form. The final numerical answer for *x* was underlined. It should be noted that the solution was written on the diagram rather than below it, ensuring an *integrated* form of diagram and explanatory text, thus avoiding increasing cognitive load due to the split-attention effect (see Ayres & Sweller, 2005; Sweller, 2004; Tarmizi & Sweller, 1988). The second problem in Appendix 1 represents the paired problem with similar features to the first problem to be solved by the students themselves. Final numerical answers were only given on the last page of the booklet. At the end of this stage, the teacher read out the answers to each of the 16 problems, including both numerical and reasoning (the required geometry theorem) answers, and the students assessed their own work. If a question concerning a problem solution was raised, the teacher directed the student to study again the solution provided in the relevant worked example. No further questions were allowed.

The group skills induction stage

This stage aimed to foster collaborative skills by having students solve problems in small groups. This activity was designed to ensure that all students had some fundamental knowledge of working in groups regardless of the experimental strategy, to which they would be assigned later, and previous school experiences. Students were randomly assigned to a group of four, where each group had an equal number of males and females and had one low-, two medium- and one high-ability students. Ability levels were identified from mathematics assessments conducted by the school in the previous semester. In each of the three participating classes, there were nine groups.

During this phase, three new geometry theorems (Numbers 5, 6 and 7 as listed in Table 2) were also to be learned. Initially, the teacher gave a 15-minute presentation on these theorems, including a description of each theorem and one worked example. Booklets were then provided to the students containing 16 pairs of worked examples designed according to the same principles described in the previous section. Students were expected to study one worked solution and then solve a similar problem. Final numerical answers were again provided on the last page of the booklet.

Each group was instructed to work collaboratively in answering the problems in the booklet. To promote collaboration, the teacher instructed students to interact, to externalise their understanding, to elicit solution planning, to ask/answer questions and to reach a consensus of the solutions to the problems in their group work. The teacher described initially how to follow these interaction tasks by giving examples of cooperative behaviour, such as working together by indicating what was required from each problem pair, communicating with each other with respect, sharing time fairly, supporting each other and attempting to minimise social conflict. To ensure that students followed the correct procedures, the teacher indicated that she would observe group activities and take note of cooperative and non-cooperative students. Students were also told that they would be marked both as individuals and groups. The teacher did not interrupt group activities, and students were told not to ask

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questions of the teacher during problem-solving. Thirty minutes were given to this activity.

At the end of the activity, the teacher read out the correct answers, including numerical and reasoning answers, and the students marked their own answers to obtain feedback. If a question concerning a problem solution was raised, the teacher directed the student to study the solution provided in the relevant worked example or to discuss the issue with their group. The teacher also provided general commentaries of group work activities, including giving examples of students who were cooperative and non-cooperative.

Acquisition phase

At the start of this phase, students were randomly allocated to the four experimental conditions. To use the experience gained in the previous group work activity, 14 groups were chosen at random to belong to the experimental Group work learning setting, with the remaining students assigned to the Individual learning setting. Furthermore, Group work students and Individual group students were randomly assigned to either the worked example or problem-solving learning approach.

For the learning material, two different booklets were constructed: one for the worked example groups and a second for the problem-solving groups. The worked example approach used a paired problem strategy as described above. The problem-solving booklet included the same problems as the worked example booklet, except that all paired problems were to be solved and no worked solutions were given. Final numerical answers to the problems not presented as worked examples were provided to both groups on the last page of the booklets. Appendix 2 provides an example of the type of problems used and details of a worked example.

The goal of the problem was to find the value of x, and that goal could be attained in two steps. As described previously, the initial given information was in black text, whereas the solution steps were written in faded (grey) and italic form. Circled numbers showed the sequence of the solution steps with the final answer underlined. Each booklet contained 10 pairs of problems, whose solutions required a combination of two or three applications of the theorems presented in Table 2, with at least one use of a theorem on parallel lines (Theorems 5, 6 or 7).

At the start of the lesson, the teacher gave a description of the materials and one example of the problem, presented during a 15-minute period. Next, students who were allocated to group work conditions were asked to move into a discussion room in the school library, and those who were allocated to individual learning conditions remained in the classroom. The groups were separated to avoid noise from the interaction of group members that might distract students in the individual setting. A teacher's assistant stayed in the classroom supervising the individual settings, and the usual classroom teacher supervised the group work settings. These students were also told that their group activity would be observed. All students were given 35 minutes to solve as many problems as possible during the acquisition stage. In addition, students were allowed to access any notes on the learning material they might have written during the material presentation in all stages of the learning phase. To eliminate the possibility of any bias, teachers did not assist the learning process in any stages, and students did not receive any feedback from teachers after practice.

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Test phase

The test phase was intended to assess students' mathematical learning and was given directly after the acquisition phase. There were two tests, with each test measuring both numeric (procedural and arithmetical accuracy) and reasoning (knowledge of the theorems) performance. Numeric ability was indicated by the number of correct angle sizes calculated, whereas reasoning ability was indicated by the extent to which a logical explanation of the derived solution was provided such as stating the appropriate theorems.

The first test presented included problems similar to the practice problems in the acquisition phase and was called the 'Similar' test. There were 10 questions given, and students had a maximum time of 15 minutes to complete them. A transfer test followed that was intended to measure the students' ability to apply the learned material to problems different from those in the acquisition phase and which were more complex. The problems had unusual figures, required more than three steps to obtain the solution or consisted of a combination of theorems that included other angle theorems learned before but not previously included in the experiment. Such problems have been found in a previous study by Ayres and Sweller (1990) as difficult to solve. Two problems required geometric proofs rather than numerical answers. The first problem in Appendix 3 is an example of a problem with an unusual configuration, and the second problem depicts a proof problem. For this phase, the students were brought back together into the same classroom, and all students answered the questions as individuals under closely supervised conditions.

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Questionnaire phase

In the previous part of the study, all students gained some experience by studying worked examples (Phases 1 and 2) and working in groups (Phase 2). To obtain their opinions about these experiences, a paper questionnaire, consisting of five questions, was distributed after the test phase. To gain information about students' preferences for the different learning conditions, the following questions were asked (translated from the Indonesian): 'Which learning condition do you prefer – individual or group work?' and 'During learning, do you prefer to have worked examples provided or not provided by only being given problems to solve?'. Before completing these questions, the teacher read through the questions and options, and informed the students that they must choose an option and write reasons for their preferences on the provided space in the questionnaire.

To obtain information about the students' reactions to the learning conditions during the first two phases, the following two questions were asked: 'Do you think the worked examples in Stage 1 were helpful?' and 'Do you think the group work setting in Stage 2 was helpful?'. The teacher read out these questions and explained that Stage 1 was the first practice revision stage and Stage 2 was the second practice revision stage in which all students worked in groups. For these questions, students completed a five-point Likert scale: 1 = very unhelpful; 2 = unhelpful; 3 = moderately helpful; 4 = helpful; 5 = very helpful. The teacher read out these labels and asked students to circle only one value according to their opinions.

To assess the extent to which the students thought that they actively participated in group work, the following question was asked: 'This question is only for students who were in the group work condition during Stage 3. During the group work activities, did you: 1 = always work individually? 2 = mostly work individually? 3 = sometimes work individually/with discussion? 4 = mostly work with discussion? 5 = always work with discussion?'. The teacher explained what was meant by Stage 3 and asked students to circle one value only. This question was called the 'Interaction intensity' item, and again, students were asked to write a reason for their answer in the space provided.

Before starting the questionnaire, the students were told that the questionnaire was anonymous and would not influence their mark. To minimise misunderstanding of the questions, the teacher provided some guidance to students while they completed the questionnaire. However, this took the form of explaining what the questions were about and did not guide answers. About 10–15 minutes were required to complete this questionnaire.

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Results

The similar and transfer tests consisted of multi-step solutions. Numerical and reasoning answers were scored separately. A score of 0 was given for an incorrect solution, a score of 0.5 was given if the solution was partially correct and a score of 1 was given for a full correct solution. Group scores are reported for the Similar and Transfer tests in Table 3.

Similar test results

A 2 × 2 analysis of variance (ANOVA) was conducted on both the numeric and reasoning scores. A significant main effect was found for numeric scores, $F(1, 97) = 7.74$, $MSE = 2.21$, $p < 0.01$, partial $\eta^2 = 0.07$, and for reasoning scores, $F(1, 97) = 39.14$, $MSE = 2.57$, $p < 0.001$, partial $\eta^2 = 0.29$. There was no significant effect for learning setting, $F < 1$, or an interaction, $F < 1$, on either. These results showed that students were more procedurally accurate and able to reason in the worked example groups compared with the problem-solving groups in both individual and group settings.

Transfer test results

A 2 × 2 ANOVA was also conducted on both the numeric and reasoning scores. There was no significant main effect for the numeric scores for the learning approach, $F(1, 97) = 1.40$, or setting, $F < 1$, nor an interaction, $F < 1$. However, for the reasoning scores, a significant main effect for the learning approach was found: $F(1, 97) = 21.56$, $MSE = 1.49$, $p < 0.001$, partial $\eta^2 = 0.18$, close to significant interaction (just failing

Table 3. Group means (and standard deviations) on similar and transfer test scores.

		Similar test numeric reasoning				Transfer test numeric reasoning			
Strategy	Group	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Problem	Individual	3.74	1.54	2.38	1.92	2.81	1.15	1.91	1.18
	Group	4.24	1.62	2.33	0.97	3.09	1.61	1.50	0.88
	Total	3.96	1.58	2.36	1.56	2.93	1.36	1.73	1.07
Worked	Individual	4.81	1.62	4.33	1.73	3.15	1.26	2.60	1.32
	Group	4.83	1.04	4.39	1.51	3.35	1.06	3.09	1.44
	Total	4.82	1.36	4.36	1.62	3.25	1.16	2.83	1.38

the $p = 0.05$ test) between the learning approach and the setting, $F(1, 97) = 3.43$, $MSE = 1.49$, $p = 0.07$, partial $\eta^2 = 0.03$. As can be seen from Table 3, the interaction trend was due to a larger difference between the worked example and problem-solving approaches under the group work condition (1.59) compared with the individual settings (0.69). It is notable that for the problem-solving groups, students who studied as individuals had a higher mean (1.91) than those who studied as part of a group (1.50). In contrast, this trend was reversed for the worked example groups, in which group scores (3.09) were higher than individual scores (2.60).

The results show that the worked example approach strongly improved reasoning scores on transfer tasks compared with a problem-solving approach for both individual and group settings. This effect was strongest for students who worked collaboratively. Although no significant differences were found for the numeric scores, the combined means for the worked examples groups (3.25) were higher than for the problem-solving groups (2.93).

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Questionnaire

Learning approach preferences

For both learning conditions, students indicated a strong preference for worked examples (see Table 4). Sign tests indicated that for both the problem-solving ($Z = 7.66$, $p < 0.001$) and worked example groups ($Z = 7.62$, $p < 0.001$), there was a significant preference for worked examples. The reasons why students preferred worked examples were examined, and similar statements were grouped together. Two categories emerged: first, students reported that worked examples helped them understand the material more easily (84.4%), and second, worked examples assisted them in knowing how to solve the problems accurately (15.6%).

Learning setting preferences

Frequency data for the learning setting preferences are shown in Table 5. For the individual setting conditions, a sign test indicated no significant preference for either individual or group settings, $Z = 0.27$, $p > 0.05$; however, for the group work setting conditions, there was a significant preference for group work, $Z = 3.16$, $p < 0.001$. The main reason given (91.38%) for preferring a group work setting was that 'students could discuss the solution with group-mates making learning easier and feeling more confident'. Two other less frequent reasons given were: (1) working in a group could help in remembering how to solve the problem (1.72%), and (2) it was more enjoyable (6.9%). Students who preferred an individual setting reported that they felt more comfortable and independent and were better able to concentrate (63.64%). In

Table 4. Group frequencies for learning approach preferences.

	Learning preference		
Actual learning approach	Problem-solving	Worked example	Total
Problem-solving	6	46	52
Worked example	5	44	49
Total	11	90	101

Table 5. Group frequencies for learning setting preferences.

	Setting preference		
Actual learning setting	Individual	Group work	Total
Individual	29	26	55
Group work	12	34	46
Total	41	60	101

contrast, when in a group work setting, these students found that they tended to imitate group-mates' work (7.27%), found obstacles when communicating with group-mates because they liked working individually, and had had experience with uncooperative group-mates (10.91%).

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Helpfulness of worked examples

Students were asked to rate how helpful they found worked examples during the first two phases (learning new geometry theorems). Group mean scores data for this question are shown in Table 6. A 2 × 2 ANOVA indicated a significant main effect for the learning approach, $F(1, 97) = 15.87$, $MSE = 0.41$, $p < 0.001$, partial $\eta^2 = 0.14$; however, there was neither a significant main effect for the learning setting, $F < 1$, nor an interaction, $F(1, 97) = 1.18$, $MSE = 0.41$, $p > 0.05$. Regardless of which learning approach students were ultimately assigned to, students preferred worked examples to problem-solving.

Helpfulness of group work

Students were asked to rate how helpful they found group work during the second phase (group work skills induction). Mean scores are shown in Table 6. A 2 × 2 ANOVA indicated a non-significant main effect for the learning approach, $F < 1$; but a significant main effect for the learning setting, $F(1, 97) = 14.98$, $MSE = 0.66$, $p < 0.001$, partial $\eta^2 = 0.13$. No significant interaction was found, $F < 1$. As indicated

Table 6. Group ratings of helpfulness of worked examples and group work.

		Helpfulness of worked examples (1–5)		Helpfulness of group work (1–5)	
Strategy	Student setting	Mean	SD	Mean	SD
Problem-solving	Individual	4.10	0.62	3.03	0.82
	Group work	4.13	0.55	3.74	0.81
	Total	4.12	0.58	3.35	0.88
Worked example	Individual	3.73	0.67	3.23	0.82
	Group work	3.48	0.73	3.78	0.80
	Total	3.61	0.70	3.49	0.85
Total	Individual	3.93	0.66	3.13	0.82
	Group work	3.80	0.72	3.76	0.79
	Total	3.87	0.69	3.42	0.86

above (see Table 6), more students who completed the final learning phase in groups preferred group work than those who eventually worked as individuals.

Interaction intensity

Students in the group work conditions were asked to measure their interaction intensity during the acquisition stage, in which intensity is defined as the extent to which learners engaged with the group. There was no significant difference in interaction intensity between the problem-solving group (mean = 3.87, SD = 0.76) and the worked example group (mean = 3.91, SD = 0.79), $t(44) = -0.19$, $p > 0.05$.

Discussion

This study contrasted the influence of a worked example approach in either group work or individual settings. Four experimental groups were formed varying in learning approach (problem-solving or worked examples) and student setting (individual learning or group work) during acquisition of multi-step geometry problems. All students were then tested individually on problems that were very similar in nature to those provided during acquisition (Similar tasks) and some that were conceptually different (Transfer tasks). Both numerical and reasoning skills were assessed during these two tests. Results indicated that the worked example groups scored higher than the problem-solving groups, irrespective of the learning setting, on every performance measure. Significant differences were found in reasoning on both similar and transfer problems, whereas a significant difference for the numerical tasks was found only in the similar problem set.

The experiment provides further evidence that the use of worked examples is beneficial for students both procedurally and conceptually. This result is in accord with previous findings (e.g. Cooper & Sweller, 1987; Mwangi & Sweller, 1998; Sweller & Cooper, 1985), which have indicated that worked examples substantially reduce extraneous cognitive load compared with problem-solving. Furthermore, a similar result was obtained under both individual and group learning conditions in contrast to previous work that has studied the worked example effect under individual learning conditions.

The worked example effect has been shown to be very robust over 25 years of research. Most of the studies have been conducted with well-defined problems in areas such as mathematics and science; however, more recent research has found similar effects in more ill-defined problem domains such as language learning (Diao & Sweller, 2007), music instruction (Owens & Sweller, 2008), fine arts (Rourke & Sweller, 2009) and interpreting English literature (Oksa, Kalyuga, & Chandler, 2009). One past criticism of worked examples has suggested that the effects only occur when compared to poorly supported problem-solving environments (Koedinger & Aleven, 2007). However, Schwonke et al. (2009) found that the effect was still present in a well-supported domain using a cognitive tutor. In the present study, similar to previous studies, worked examples were shown to be superior to problem-solving.

As argued above, asking students to solve a problem, particularly those learning new concepts and procedures (novices in the domain), creates an extraneous cognitive load that is detrimental to learning. The very limited working memory resources of the learner are absorbed in attempting to find solution steps. Few resources are devoted to learning key features of the problem (germane cognitive load). In contrast, worked

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examples reduce extraneous load and allow learners to focus on learning about solutions steps and problem characteristics. In other words, worked examples allow more working memory resources to be applied directly to schema formation.

Consistent with two recent US Department of Education documents that advocate explicit instruction (National Mathematics Advisory Panel, 2008) and worked examples (Pashler et al., 2007), we recommend the widespread use of worked examples in mathematics instruction. Nevertheless, we do not reject the use of problem-solving as a methodology in learning mathematics or any other learning domain. As reported in the introduction, research on the expertise reversal effect (Kalyuga et al., 2003) has demonstrated that strategies that are highly effective for novices lose their effectiveness, and may even become harmful, when sufficient prior knowledge develops. Problem-solving can be effective when learners gain sufficient expertise (Kalyuga et al., 2001). Nevertheless, before such expertise develops, the use of worked examples is a highly effective procedure. Group work may offset the demands on working memory under some conditions, but this study has shown that worked examples can be beneficial in collaborative learning environments.

The questionnaire revealed that the worked example approach was preferred by the students in both the problem-solving and worked example conditions. The emphatic reason given was that they could understand the material more easily. All students in the initial learning stages were provided with worked examples, but during the acquisition stage, the problem-solving groups were not provided with worked examples. Their response that they preferred the worked example approach indicates that they expected better achievement on the tests if they had been provided worked examples in the acquisition stage. In summary, data support the hypothesis that an emphasis on worked examples is important when learning.

The hypothesis that the group work setting would be more beneficial for students than individual settings was not confirmed. The study included transfer problems specifically to give the collaborative groups the best opportunity to demonstrate an advantage. However, unlike Kirschner et al.'s (2009b) study, no significant benefits were found on transfer problems. This failure to find an effect has also been obtained by other researchers (Mevarech, 1985; Saleh et al., 2007; Webb, 1991).

The question remains, why was a group work setting not superior to individual learning? There are at least two possible explanations. First, as pointed out by Kirschner et al. (2009b), group work is most effective when a high degree of collaboration is enforced, and collaboration was not enforced in the current experiment. An alternative explanation may be redundancy. It has been indicated that problem-solving causes a heavy extraneous cognitive load for novice learners, and group interaction tasks were intended to lower the cognitive load using the shared knowledge among group members. The interaction task instructed the students to interact, to externalise understanding, to elicit solution planning, to ask/answer questions and to reach a consensus of the solutions to the problems in their group work. However, it can be speculated that some group members under the worked example approach might have found that the interaction task led to redundant information regarding the externalisation of problem strategy tasks because they could find the procedure from the worked examples provided. As proposed by cognitive load theory, multiple sources of information, which can be understood if they are given individually, cause redundancy effects (see Sweller, 2004). Students in this condition could receive the same information from two different sources, the worked examples and the externalisation of the worked examples by group members. Hence, the group interaction task might impose

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additional extraneous cognitive load due to the redundancy effect and, thus, interfere with learning. It could also be speculated that group members failed to produce interactions that led to beneficial help for schema acquisition. Consequently, the interaction task itself might impose a high extraneous cognitive load, instead of decreasing the cognitive load (Kirschner et al., 2009b).

Nevertheless, even though no superior effect was found for group work compared with individual study, no significant negative effects were found either. On performance measures, group work means tended to be higher than individual means, albeit not significantly higher. The only exception was on the transfer test of reasoning, where for problem-solving groups, the individual condition score was higher than the collaborative condition score, but not significantly higher. If interactive tasks did cause increases in extraneous load, they were not sufficient to have an overall impact.

Responses to the question about the preferred setting indicated that a group work setting was only preferred by those students who were actually instructed in group work during the acquisition stage, whereas students who were instructed in the individual settings during the acquisition stage showed no significant preference. Those in favour of group work reported that learning was easier through discussion and they felt more confident, whereas students who preferred individual study reported that they felt more independent and had better concentration. These results might be interpreted as indicating that either individual or group work settings could be enjoyable for learning, regardless of their influence on achievement.

With respective to problem-solving, students who were asked to learn through solving problems fared the worst; not even being able to collaborate improved test scores compared with worked examples. Many mathematics educators promote methods that combine problem-solving and collaboration. It is often argued that this combination leads to more conceptual understanding, particularly in more complex domains. However, in this study, it is notable that such assumptions cannot be supported. For the conceptual measure, reasoning scores on the transfer tasks, the worked example approach was significantly superior to the problem-solving approach.

This experiment adds to the already considerable amount of evidence that the use of appropriately designed worked examples is effective as a learning procedure. In addition, the use of worked examples in collaborative settings was found to be as effective as in individual settings for the Year 7 students in this study. Whether this result can be replicated under different conditions will, of course, require additional research.

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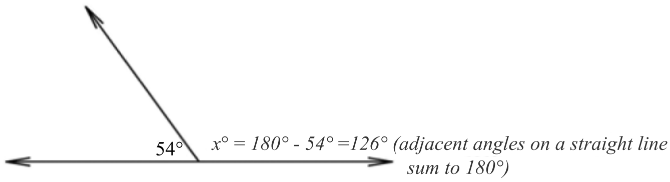
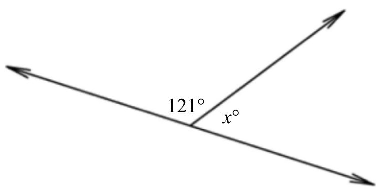
Appendix 1. Example of a one-step worked example problem pair.

Problem: Find the value of *x* and give reasons for each step.

Solution:





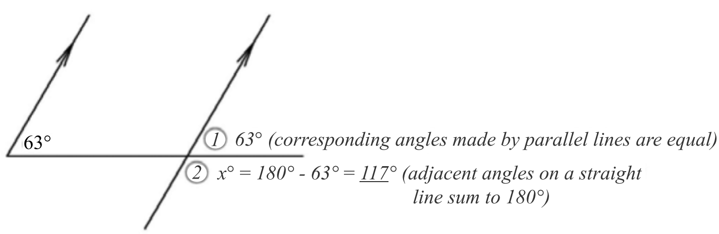
Problem: Find the value of *x* and give reasons for each step.

Solution:

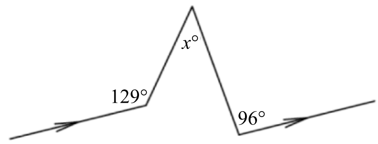
Appendix 2. Example of a two-step worked example.

Problem: Find the value of *x* and give reasons for each step.

Solution:

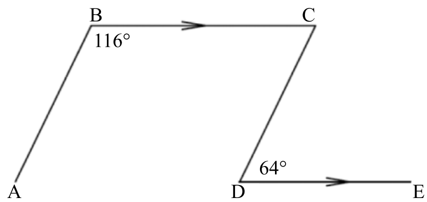


Appendix 3. Examples of two transfer problems.



Problem: Find the value of *x* and give reasons for each step.

Solution:



Problem: From the given angles, show that AB//DC.
Give reasons for each step.

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