Individual versus group learning as a function of task complexity

DOI:
10.1007/978-1-4020-8827-8_4

Document status and date:
Published: 01/01/2008

Document Version:
Peer reviewed version

1Running head: Individual versus Group Learning

This is a pre-print of the article that was published as

Kirschner, F., Paas, F., & Kirschner, P. A. (2008). Individual versus group learning as a function of task complexity: An exploration into the measurement of group cognitive load. In J. Zumbach, N. Schwartz, T. Seufert, & L. Kester (Eds.), *Beyond knowledge: The legacy of competence* (pp. 21-28). Springer.

Individual versus Group Learning as a Function of Task Complexity: An Exploration into the Measurement of Group Cognitive Load

Femke Kirschner[1], Fred Paas[1] and, Paul A. Kirschner[2]

[1]Educational Technology Expertise Center, Open University of the Netherlands

P.O. Box 2960

6401 DL Heerlen, the Netherlands

femke.kirschner@ou.nl/fred.paas@ou.nl

[2]Research Centre Learning in Interaction

Utrecht University

Abstract

The target of this study is twofold, on the one hand it is an empirical study into the learning effectiveness of group versus individual learning as a function of task complexity, on the other hand it is an exploration into the measurement of group cognitive load as a function of task complexity. The effects of individual versus group learning on retention and transfer test performance and mental effort were investigated among 52 high school students performing mathematical tasks. Applying cognitive load theory groups were considered as information processing systems in which group members, by communication and coordination of information (i.e., transaction costs), can make use of each others WM capacity. It was hypothesized that with low complexity tasks, group members would achieve the same test performance, but with higher learning effort than individuals because of the transaction costs. With high complexity tasks, group members were expected to achieve a higher test performance with lower learning effort than individuals, because the transaction costs are minimal compared to the gain afforded by a division of cognitive load. On an exploratory basis, it was investigated how individual-level models can be used as a basis to understand group-level load.

Individual versus Group Learning as a Function of Task Complexity: An Exploration into the Measurement of Group Cognitive Load

The target of this study is twofold, on the one had it is aimed at studying group versus individual learning as a function of task complexity, on the other hand it is aimed at taking a closer look at the development of a method to calculate the cognitive load of a group of collaborative learners by examining the amount of mental effort invested by the individual group members and by the group as a whole.

This study considers groups as information processing systems consisting of multiple working memories (WM). Consequently, it can be argued that groups have effectively more processing capacity available than an individual with one WM. In a group, the cognitive load can be shared among group members enabling them to deal with more complex problems than individuals. Although the cognitive load caused by communication and coordination within the group, the so called transaction costs, have to be taken into account, in case of complex cognitive tasks these costs are minimal compared to the advantage of being able to share the high cognitive load among group members. This distribution advantage was found in a previous experiment comparing the effects of group and individual learning of complex cognitive tasks on transfer efficiency (Kirscher, Paas, & Kirschner, in press). By making use of each others processing capacity through sharing of cognitive load imposed by a task, it was possible for group members to more deeply process information elements, and construct higher quality schemata in their long term memory than learners working individually. Another situation occurs with low complexity tasks in which a learner has sufficient capacity to solve the problem individually. In that case, solving the problem in collaboration, in terms of experienced cognitive load, does not have an advantage for the group member or could even be disadvantageous, because of the relatively high load caused by the transaction costs within the group. Indeed, research comparing groups to individuals when performing relatively simple recall tasks shows that working in a group can be detrimental (Weldon & Bellinger, 1997). Although groups in all cases outperform individuals in the amount of items recalled, comparing the amount of recalled items by each group member to the amount of items recalled by the individual shows that working in a group hampers performance for the group member because the individual performance is now higher. It was therefore hypothesized that with low complexity tasks, group members would have to invest more mental effort in learning to achieve the same test performance than individual learners, because of the relatively transaction costs. With high complexity tasks, it was hypothesized that group members could achieve a higher test performance with lower learning mental effort investment than individuals, because the transaction costs are minimal compared to the gain afforded by a division of cognitive load.

Whereas valid and reliable instruments have been developed in the context of individual learning (Paas, Tuovinen, Tabbers, & Van Gerven, 2003) there are no standard methods to determine the cognitive load experienced by groups of collaborating learners. It is not clear if and how these individual measurements can be used to get a reliable estimate of the group's cognitive load, in other words whether an individual-level model can be used as a basis to understand group-level load. Individual cognitive load measurements represent the load that a specific instructional method imposes on the limited cognitive system of a learner. This load can be anywhere between very high or very low depending on the characteristics of the learner (e.g., age and expertise) and the characteristics of the instructional method (e.g., task format and task complexity). Determining individual cognitive load can be done using a variety of psychological, task- and performance based, and subjective measurements, which have been tested on reliability and validity (see Paas et al., 2003). For measuring group cognitive load, such instruments are not available. It is therefore the question how individually based measurements can be used to determine the cognitive load of a group of collaborative learners. The individual subjective rating scale developed by Paas (1992) is based on the assumption that students are able to introspect on their cognitive processes and can report how much effort it took them to solve a problem. This rating scale has been shown to be valid, reliable, and non intrusive, and has been used in a lot of studies dealing with cognitive load, which provides the possibility to compare results between studies. In this study, this rating scale was used to obtain an indication of group cognitive load by looking at the average of individual group member effort scores, individual group member scores of the effort it took the group as a whole, and by looking at one effort score decided on by the group. The goal of this part of the study was to explore the impact of task complexity on the amount of cognitive load people experience in a group and how different measurements can be used to measure group cognitive load.

Method

Participants

Participants were 52 second year Dutch high school students with an average age of 14 years. They participated in the experiment as part of their math curriculum and did not receive any academic or financial compensation. Prior knowledge on math related subjects was assumed to be the same for all participants, for they all had followed exactly the same math courses during the last two years. The students were assumed to be novices on the topic of surface calculation for they were only instructed on how to calculate rectangle surface areas but did not have any prior knowledge concerning the calculation of surface areas of triangles and circles.

Materials

All materials were in the domain of mathematics that is concerned with the calculation of geometrical surface areas; namely that of the triangle and the circle. An introduction on how to calculate geometrical surface areas, learning tasks in which solving geometrical surface calculation problems was the goal, and retention and transfer test tasks on geometrical surface calculation, were designed. All materials were paper based.

Introduction. The introduction was based on three subjects or geometrical figures: rectangles, circles and triangles. For every geometrical figure the theory behind calculating the surface area, as well as a worked out example of how to use this theory when solving a surface calculation problem were the core of the introduction. The theory, in all three instructions, consisted of an insight in the relevant formulas and shapes of the geometrical figures. The three geometrical figures were treated separately in the order of rectangle, triangle, and circle. This way students started with known information to activate their prior knowledge, to subsequently extend their knowledge by studying unknown information. The introduction was paper based but also discussed in class by the math teacher.

Learning tasks. Learning tasks were of low medium and high complexity. For each of these three levels of task complexity, two tasks in the domain of mathematics were developed. This way three tasks focused on the calculation of surface areas of triangles and three tasks on the calculation of surface areas of circles. Task complexity or intrinsic cognitive load was determined by using Sweller and Chandler's (1994) method based on the number of interactive elements in a task and the insight necessary for solving the problem. The tasks were structured in such a way that transaction costs of communication and coordination were kept to a minimum and the information elements could be divided among the members of the group.

Test tasks. Eight test tasks were designed to determine how much students had learned. Half of these tasks were based on surface calculation of circles and half on triangles. There was a distinction in retention and transfer test tasks meaning that four of the tasks (two circle and two triangle) were identical in structure to the ones performed in the learning phase, these were the retention tasks. Four of the tasks (two circle and two triangle) were structurally different from the ones performed in the learning phase but to solve these problems the same underlying theory on surface calculation had to be used.

Cognitive-load measurement. To measure the participants cognitive load after each task in the learning and test phase, the subjective 9-point cognitive-load rating scale developed by Paas (1992) was used.

Performance measurement. Solving learning and test tasks meant correctly calculating the surface area of a geometrical figure. One point was awarded for a correct answer and zero points for an incorrect answer. In the learning phase this meant that a minimum score of zero and a maximum score of three points could be earned, in the test phase the minimum score was again zero and the maximum eight points. For the statistical analysis, the performance scores on retention and transfer were transformed into proportions.

Design and procedure

All students received a written instruction on how to calculate the surface areas of rectangles, circles and triangles two days prior to the learning tasks. During this instruction phase participants had seven minutes to study each geometrical figure by themselves after which the teacher had seven minutes to discuss the theory and a worked-out example in class and give clarification answers to questions asked by the students. The total instruction took 50 minutes after which the participants had to hand in the written instructions to the teacher. In the learning phase, because of the within subject design of this study, every participant, at one point, worked on the learning tasks individually as well as in a group. For each participant the order of individual and group work was counterbalanced, as was the task subject with which a participant started (i.e., circles or triangles). At the beginning of the learning phase participants were randomly assigned to the individual or group condition which meant that twenty-one participants started to work individually on three tasks of three different complexity levels and then work in triads on three other tasks at these three complexity levels. Twenty-one other participants started to work in triads on these problems and then worked individually. If a participant first, individually or in a group, worked on the calculation of the surface area of a triangle, the second time, being in the individual or group condition, the geometrical figure was a circle. If a participant, individually or in a group, worked on the calculation of the surface area of a circle, the second time, being in the individual or group condition, the geometrical figure was a triangle. The participants had to study and solve each problem and rate their cognitive load on the mental effort rating scale: the individual scale (Paas, 1992). On the same scale, group members additionally had to rate the amount of mental effort they invested to arrive at the solution together: the group member scale, and the group additionally had to give one score of their joint mental effort that was needed to come to the solution: the group scale. The test phase in which all participants had to individually work on four retention and four transfer tasks, was held one day after the learning phase and took 50 minutes in total. Again, after each test task, the participants had to rate their mental effort on the mental effort rating scale.

Results

Because analyzing the data is in progress the results are still preliminary.

Learning phase. A 2 (learning condition: individual vs. group) x 3 (task complexity: low, medium, high) ANOVA with repeated measures on both factors was used to analyze the data obtained during the learning phase. With regard to performance, the ANOVA revealed main effects of learning condition, $F(1, 48) = 4.811$, $MSE = 1.253$, $p < .05$ and task complexity, $F(2, 48) = 18.606$, $MSE = 3.055$, $p < .001$, as well as a significant interaction between learning condition and task complexity, $F(2, 48) = 3.792$, $MSE = .610$, $p < .05$. The interaction indicated that groups particularly performed better than individuals on the medium complexity tasks. With regard to mental effort, the ANOVA revealed main effects of learning condition, $F(1, 49) = 12.810$, $MSE = 40.412$, $p < .001$ and task complexity, $F(2, 49) = 63.384$, $MSE = 175.847$, $p < .001$, but did not reveal a significant interaction between learning condition and type of test, $F(2, 49) = 6.790$, *ns.* These results indicate that at all three complexity levels group members rated a lower mean mental effort than individuals.

Test phase. No significant effects were found in the test phase with regard to performance and mental effort. Performance efficiency was calculated for the transfer tests using Paas and van Merriënboer’s (1993; see Van Gog & Paas, 2008) computational approach by standardizing each of the participants’ scores for test performance, and mental effort invested in the learning phase. For this purpose, the grand mean was subtracted from each score and the result was divided by the overall standard deviation, which yielded *z*-scores for effort (*R)* and performance (*P)*. Finally, a performance efficiency score, *E*, was computed for each participant using the formula: $E = [(P – R)/2^{1/2}]$. High efficiency was indicated by a relatively high test performance in combination with a relatively low mental-effort rating. In contrast, low efficiency was indicated by a relatively low test performance in combination with a relatively high mental-effort rating. With regard to efficiency the analysis revealed a significant effect of condition, $F(1, 44) = 11.106$, $MSE = 6.744$, $p < .005$. Group learning was more efficient than individual learning, as indicated by a more favorable relationship between learning mental effort and test performance.

Results on the measurement of group cognitive load as a function of task complexity in the learning phase using only the group condition data were analyzed using a 3 (type of mental effort scale: individual scale, group member scale, group scale) x 3 (task complexity: low, medium, high) ANOVA with repeated measures on both factors. With regard to mental effort score, the ANOVA revealed a main effect of task complexity, $F(2, 48) = 56.132$, $MSE = 438.177$, $p < .001$, but not for type of mental effort scale, $F(2, 48) = 2.513$, *ns*. It also did not reveal a significant interaction between task complexity and type of mental effort score, F(2, 49) = 1.432, *ns.* These results indicate that the higher the complexity level, the higher the mental effort score for all three mental effort measurements. Comparing the group member scale with the group scale in a 2 (type of mental effort scale: group member scale, group scale) x 3 (task complexity: low, medium, high) ANOVA with repeated measures on both factors only revealed a main effect for task complexity $F(2, 49) = 58.313$, $MSE = 314.678$, $p < .001$. Comparing the individual scale with the group member scale in a 2 (type of mental effort scale: individual scale, group member scale) x 3 (task complexity: low, medium, high) ANOVA with repeated measures on both factors revealed a main effect for task complexity $F(2, 48) = 44.930$, $MSE = 253.503$, $p < .001$, as well as for type of mental effort scale, $F(1, 48) = 4.047$, $MSE = 2.920$, $p = .05$. Indicating that the higher the complexity level the higher the mental effort score, and that the mental effort score is significantly higher on the individual scale than on the group member scale. The task complexity x mental effort scale interaction is not significant but shows a trend, $F(2, 48) = 2.692$, $MSE = 1.299$, $p = .075$.

Discussion

The goal of this study was twofold first of all it was hypothesized that with low complexity tasks, group members would achieve the same test performance, but with higher learning effort than individuals because of the transaction costs. With high complexity tasks, group members were expected to achieve a higher test performance with lower learning effort than individuals, because the transaction costs are minimal compared to the gain afforded by a division of cognitive load. Secondly it was investigated how individual-level models of measuring cognitive load can be used as a basis to understand group-level load.

The hypothesis that group members would achieve the same test performance with low complexity tasks, and higher test performance with high complexity tasks than individuals was confirmed with a significant interaction between condition and task complexity. Performance on tasks of medium complexity were particularly enhanced. That reason for the highest complexity task not to enhance performance as much as we expected could be explained by a ceiling effect. The highest complexity task was just to difficult for both groups en individuals the complete. The hypothesis that group members would rate a higher mental effort when working on low complexity tasks and a lower mental effort when working on high complexity task than individuals was not confirmed. The results show that independent of the complexity of the task group members rate a lower mental effort.

The exploratory part of the study which was concerned with a way to measure a group cognitive load shows that the mental effort rating scale that is used at the individual level could be transformed in such a way that it measures group cognitive load. The three scales: the individual scale, the group member scale, and the group scale, are sensible to complexity. The higher the complexity of the task, the higher the rated cognitive load. When comparing the individual scale to the group member scale, the results show that for the individual scale the mental effort scores are higher on all complexity tasks.

References

Kirschner, F. C. , Paas, F., & Kirschner, P. A. (in press). Individual and group-based learning from complex cognitive tasks: effects on retention and transfer efficiency. *Computers in Human Behavior.*

Paas, F. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive load approach. *Journal of Educational Psychology, 84*, 429-434.

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist, 38*, 63-71.

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. *Cognition & Instruction, 12*, 185-233.

Van Gog, T., & Paas, F. (2008). Instructional efficiency: Revisiting the original construct in educational research. *Educational Psychologist, 43*, 1-11.

Weldon, M. S., & Bellinger, K. D. (1997). Collective memory: Collaborative and individual processes in remembering. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 1160-1175.