

IMPROVING LEARNING OUTCOMES OF SMALL GROUPS WORKING ON AN ENGINEERING DESIGN-ASSIGNMENT DURING LECTURES

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ABSTRACT

In the past years, the interest in collaborative learning has increased substantially. However, despite the attention for collaborative learning and the existing body of knowledge on that topic, many lecturers experience problems when implementing collaborative learning. Consequently, the theoretical benefits of collaborative learning are not always achieved in practice. To address this gap, this research studied higher education students collaborating on an engineering design-assignment during lectures, as a form of collaborative learning. The specific research question was: how can lecturers improve learning outcomes of small groups working on an engineering design-assignment during lectures? The research is a design-based research, aimed at systematically investigating problems, and designing and evaluating solutions to improve lecturers' actions and education. Five groups were videotaped when working on an assignment and the learning outcomes of those groups were assessed. Then, problems were analysed and possible solutions to improve learning outcomes were developed. The solutions had the form of practical interventions that lecturers could apply straight away. The interventions were evaluated by applying them to treatment groups and comparing their learning outcomes with those of control groups, which were not subjected to interventions. The results revealed that for most of the groups to which the interventions were applied, learning outcomes were better. However, there were also exceptions. Further analysis was needed to explain these. This research is relevant for lecturers who apply group work in their lectures because it reveals some mechanisms behind collaborative learning, and provides insight in variables that can be adjusted for further improvement.

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1 INTRODUCTION

1.1 Research background and objective

In the past years, the importance of collaborative learning has increased substantially. Collaborative learning can be defined as instruction that involves students working in teams to accomplish a common goal, under conditions that include team members' interdependence, individual accountability, face-to-face promotive interaction, the use of collaborative skills, and group processing [1, 2]. Collaborative learning can take many forms such as students working together on projects, Problem-Based-Learning and Team-Based-Learning. Collaborative learning has gained importance in higher education because of its effectiveness. Among others, collaborative learning tends to exhibit higher academic achievement, greater persistence through graduation, better high-level reasoning and critical thinking skills, and deeper understanding of learned material [3, 4].

Many lecturers acknowledge the importance of collaborative learning and apply this in some form in their courses, but despite the attention for collaborative learning and the existing body of knowledge on that topic, many lecturers experience problems when implementing collaborative learning. Consequently, the theoretical benefits of collaborative learning are not always achieved in practice. To address this gap between theory and practice, this research studied higher education students collaborating on an engineering design-assignment during lectures, as a form of collaborative learning. The specific research question is: how can lecturers improve learning outcomes of small groups working on an engineering design-assignment during lectures? The corresponding goal of this study is to develop interventions to improve the learning outcomes of small groups working on an engineering design-assignment during lectures. This research is relevant for lecturers who apply group work in their courses because it provides actions to improve learning outcomes and reveals some mechanisms behind collaborative learning.

1.2 Activity Theory as a theoretical framework

In this research, a well-supported theory is used for analysing collaborative learning in groups working on an assignment. This theory is called Activity Theory (AT). The theory is suitable for studying collaborative learning in various learning environments [5]. Moreover, the theory has been used earlier to analyse collaborative learning in design and engineering education and in other learning environments too. In addition, key steps for carrying out research with the use of AT have been formulated [6], and an example of applying this theory in an engineering design setting at higher education is also available [7]. Thus, there is reference material to facilitate a thorough and evidence-based research.

AT assumes that learning should be studied within the context in which it occurs because context and learning are intertwined. AT therefore can be categorised under the heading of the social constructivist learning perspectives. Rather than being a

process of knowledge transmission, knowledge is socially constructed, based on the intentionality, history, culture and tool mediation used in the process. AT helps to understand the subtleties of the collaborative learning process and the dynamics of collaboration between group members.

1.3 Elements of Activity Theory

AT distinguishes six interrelated elements to interpret an activity carried out by a group. The elements are related to one another, forming the AT triangle (Figure 1).

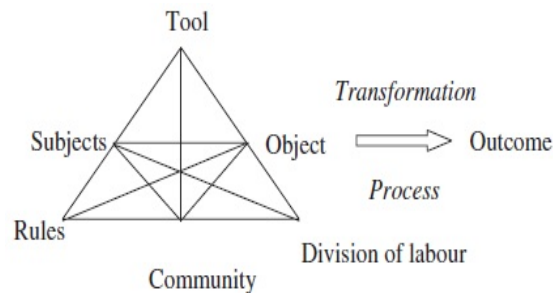


Figure 1 Activity Theory Triangle [6]

The core elements, forming the AT triangle, can be described as follows:

- The subject is the participant in an (learning) activity, motivated towards a purpose or attainment of the object.
- The object describes the problem space at which the subject is directing his or her attention. It is an invitation to interpretation, personal sense-making, and societal transformation. It is the raw material and future-oriented purpose of an activity. The object as such, represents the motives for a subject to engage in an activity. For example, an object can be a certain design task that the student has to complete.
- The outcome is the consequences that the subject faces because of his/her actions driven by the object. This is the 'ultimate goal'. In an educational setting, these outcomes could be passing the course, or getting a high grade.
- Tools are socially shared cognitive and/or material resources that the subject can use to attain the object. For example, the student may use a certain design methodology or strategy (cognitive resources), or a computer (material resource), for achieving the object.
- Informal or formal rules regulate the subject's participation while engaging in an activity. For example, an informal rule is that the student is not allowed to cheat. This is a rule that is not stated explicitly, but students know it is not allowed. A formal rule could be that the activity should be finished within two hours.
- The community is the group or organisation that has a relation with the object and that can influence how the subject behaves. For example, in an assignment in class, the lecturer belongs to the community. In addition, other students or groups that work on the same, or similar, assignment can be part of the community, as they can exert influence.

- The division of labour is the shared participation responsibilities in the activity. For example, the subject/student makes appointments with his/her other team members about the division of tasks and responsibilities

The elements within the AT triangle are related to one another. For example, the subjects (S) could experience that they are not able to work with a specific tool, such as a software program (T). In that situation, there is a tension between S and T. By studying the elements as well as the relationship between the elements of the AT triangle, groups can be analysed, as demonstrated by Zahedi et al. [7]. According to AT, the tensions within and between the elements in the AT triangle can provide the leverage points for improving learning. For example, the lecturer can apply interventions to these tensions. An intervention can be defined as: “*A purposeful action by a human agent to create change*” [8]. AT adopts a perspective of learning that sees the members of the group as actively constructing meaning within a cultural-historical context. Although the group members are conceived of as active, it is the responsibility of the culturally more advanced facilitator (e.g. lecturer) to provide opportunities for acceptable constructions, and to create opportunities for groups to learn.

2 METHODOLOGY

This section describes how the research was carried out. The research is a design-based research, aimed at systematically investigating problems, and designing and testing solutions to improve lecturers’ actions and education.

2.1 Step 1 – Data collection

As a first step, the groups working on an assignment during a lecture were observed. This assignment was part of a design course: Course I. The purpose of this step was to understand what is going on in the groups when they are working on the assignment during lectures. The groups were only observed and there was minimal intervention by the lecturer. Observations were done from the perspective of AT, meaning that the elements of the activity triangle were studied [6]. There was one lecturer involved as the main lecturer and another lecturer to assist with the video recordings. The main lecturer was also the researcher. The data collection method used in this step was video recording. This method was used because this allowed the researcher to gather in-depth data simultaneously on multiple groups. Five of the twelve groups in Course I were studied in this step. The groups were first-year university Bachelor students and were randomly selected from all groups in Course I. Each group consisted of 5 to 6 students. Analysis was done in keeping with the approach proposed by Zahedi et al. [7]. Based on an analysis of speech and behaviour in the group, the recordings were tagged with the elements of the AT triangle, using the software program Atlas.ti.

After the AT framework was described and put in a timeline, the learning outcomes were studied. The outcome of the group assignment is a FAST diagram (Function

Analysis System Technique). It represents the functionality of a system with boxes and arrows that connect the boxes. This FAST diagram, as developed by each group, was assessed with an assessment protocol. The basis for this protocol were the learning goals of the assignment. The protocol was validated with a peer-lecturer with knowledge of FAST diagrams. This validation showed that the protocol is robust.

2.2 Step 2 – Data analysis

In the second step, the AT observations and scores of the groups were compared to one another and differences and similarities were assessed. It was also tried to identify patterns. It is relevant to analyse differences, similarities and patterns, because this provides directions for interventions.

2.3 Step 3 – Developing the interventions

In the third step, the interventions were developed, based on the findings of the previous steps. This was a creative step in the research and could not be completely designed in advance, as it was not known beforehand what was exactly going on in the groups. The interventions were discussed with experts and lecturers to validate them.

2.4 Step 4 – Applying and evaluating the interventions

In the fourth step, the interventions were applied and evaluated in another design course: Course II. The interventions were applied to eight groups (all groups in the course). Each group consisted of 5 to 6 students. The students in these groups got a similar assignment as those in Course I – to produce a diagram – but for different projects. The reason for using different projects was that the interventions have to be useful in other courses as well. Nevertheless, the method and underlying theory of the assignment remained the same. Only the project to which the method should be applied was different.

3 DATA COLLECTION AND ANALYSIS

In this section, the results of step 1 and 2 of the research approach are described. This concerns data collection and data analysis of the groups in Course I. First, the learning outcomes of the groups are presented, followed by the problems that affected learning outcomes of these groups.

3.1 Learning outcomes

The learning outcomes of the groups in Course I are presented in Table 1. The groups that were analysed were randomly selected. The numbers of the groups were those given in the course. The learning outcome, or score, is the number of points that the groups received for the FAST diagram that they produced. This score was determined with the use of an assessment protocol. Scores range from -7, to +7. In the next section, the problems that affected the learning outcomes are described.

Table 1 Learning outcomes of the groups in Course I

Course I – no intervention	
Group	Score
4	3
5	0
6	-2
7	4
10	1

3.2 Problem 1: Lack of understanding

The lecturer had developed the assignment for Course I to his best knowing. This means that the lecturer estimated that students were able to understand and apply the theory of the FAST assignment during the lecture with the use of instructions on paper. However, based on the observations, it appeared that all groups struggled with understanding the theoretical concepts of the assignment, and had difficulty applying these during the lecture. None of the groups achieved the maximum score. This demonstrates that the lecturer overestimated the students' capabilities to understand and apply the theory and instructions of the assignment. This has been recognized in literature as well and is known as the 'curse of knowledge.' This clearly became apparent during this research. Although the lecturer was aware of this phenomenon, the effect appeared greater than expected.

3.3 Problem 2: Instructions are not read

The results revealed that the two best scoring groups (7, 4) read and followed the provided instructions and examples more carefully than the groups that scored lower. These two groups applied instructions and used the examples provided in all steps of the assignment. In other words, they followed the assignment more strictly than the groups that scored lower (10, 5, 6). The average scoring group (10) applied instructions for step 1 and 2, but not for step 3. The two lowest scoring groups (5, 6) only used the examples provided, but in none of the steps did they apply additional instructions.

3.4 Problem 3: No strategy to handle assignment

The results have revealed that the average group (10) and high scoring groups (7, 4) not only read and followed the provided instructions and examples more carefully than the groups that scored lower, but they also explicitly discussed how to approach the assignment. In AT terms, they devised a strategy for tackling the assignment. The low scoring groups (5, 6) did not do that. They just started working without discussing a strategy in advance.

3.5 Problem 4: Skipping steps

The low scoring groups (5, 6) skipped step 1 of the assignment and jumped straight to step 2. This means that they started immediately with structuring the diagram, without brainstorming its elements first. It appeared that this way of working is less

effective, as these groups scored lower, needed more help from the lecturer, and needed to look at the results of other groups to be able to proceed.

4 DEVELOPING INTERVENTIONS FOR IMPROVING LEARNING OUTCOMES

In the previous section, several problems were described that affected learning outcomes of the groups. In this section, the interventions are described that were developed to solve the problems to improve learning outcomes. This is step 3 in the research.

4.1 Intervention 1: Separating explanation and application

As mentioned in the previous section, the interventions should address the theoretical principles of the assignment more explicitly because groups had trouble applying these. However, it may be ineffective to add this theory to the instructions and/or give students more time, as the results have shown that groups do not always read the instructions, or do not really understand them in the timeframe of a lecture (1.5 hours). A better option might therefore be to explain the theory in another lecture in advance of the application lecture. Thus, separating explanation and application. This provides the students with some digestion-time between the explanation lecture and the application lecture, and students can study the theory more thoroughly.

4.2 Intervention 2: Separating steps of the assignment more explicitly

The results have shown that some groups skipped step 1 of the assignment. This means that they started immediately with building a FAST diagram, without brainstorming its elements first. The results have shown that the quality of the FAST diagrams that these groups produce is lower than those of the groups that brainstorm functions first. To prevent jumping to step 2, it could be a good idea to separate the different steps of the assignment more explicitly. This can be done by separating and sequencing the instructions, in combination with timekeeping by the lecturer. By separating steps, the problem of skipping steps is solved, and the attention of the groups is more directed to each separate step.

4.3 Intervention 3: Stressing importance of instructions and strategy

The results have revealed that the high scoring groups read and followed the provided instructions and examples more carefully than the groups that scored lower. They also devised a strategy on how to approach each step. Therefore, at the start of the lecture, lecturers should explicitly stress that it is important to follow the instructions, and to think of a good strategy, before conducting each step of the assignment. Not only at the beginning of the lecture is this needed, but also later during the assignment this should be repeated. The lecturer will also write these instructions explicitly on a whiteboard and direct attention of the groups to the whiteboard during the assignment.

5 APPLYING THE INTERVENTIONS

The interventions were applied to groups in another course: Course II. Each group in Course II consisted of 5 to 6 students. Because there are multiple interventions, it

was also evaluated which interventions had the most effect. This was done by dividing the eight groups in two separate clusters of each four groups. The four groups in cluster A were subjected to a specific intervention (treatment group), while the other four groups in cluster B, were not be subjected to this intervention (control group). The results were compared.

The first intervention was to separate theory explanation from theory application in two different lectures with some days in between them. To test this intervention, it would be logical to subject the groups in one of the clusters to this intervention (treatment group) and the groups in the other cluster not (control group). However, to refuse half of the groups to follow the explanation lecture would be unethical and would probably lead to so much negative spin that the entire experiment would be disturbed. Therefore, all groups were subjected to the first intervention and hence they all followed the theory explanation lecture and the theory application lecture. Thus, with regard to this intervention, there was no difference between cluster A and B in Course II.

The other intervention was to stress at several moments during the application lecture that it is very important to read the instructions and examples carefully, and to devise a strategy. To test the effect of this intervention, it would be logical to subject the groups of one cluster to this intervention (treatment) and the groups in the other cluster not (control). However, that would require two different plenary starts for the two clusters, which would lead to practical problems. Therefore, also this intervention was applied to all groups in both clusters.

The final intervention is to separate the steps of the assignment more explicitly. This intervention was indeed tested in an experiment with a treatment and control group. It means that groups in cluster A received the instructions for each of the steps in the assignment in chunks and in sequence, while the groups in cluster B received all instructions at once and from the start. To carry out this experiment appropriately, the groups of cluster A were separated from those of Cluster B by a moveable wall, and students were not allowed to move beyond the wall. This experiment is ethically acceptable because all groups received the same information, only the sequence is different. Besides, students did not receive a grade for the assignment. Finally, this experiment can be conducted without students noticing it at first glance, because the assignments on the table look the same.

6 EVALUATING INTERVENTIONS

Regarding evaluating the effectiveness of the interventions, the first expectation was that the groups of Course II would score better than those of Course I because they were subjected to the interventions. However, the findings show that this was only partly the case. Four of the eight groups of Course II (groups 2, 3, 6 and 7) indeed scored equal to, or higher than the highest score in Course I (see Table 2). To clarify this, the highest score in Course I is 4 (group 7), but in Course II, four groups score 4

or even higher. This is in keeping with expectations. However, three of the eight groups of Course II (groups 1, 4 and 8) scored equally low, or even lower than the lowest score in Course I. The lowest score in Course I was -2, but the groups of Course II scored -2, -4 and -6. Thus, it cannot be concluded that the interventions have led to an increase in scores of all groups.

Table 2 Learning outcomes of the groups in Course I and II

Course I – no intervention		Course II – intervention			
No clustering		Cluster A		Cluster B	
Group	Score	Group	Score	Group	Score
4	3	2	5	1	-6
5	0	3	5	4	-2
6	-2	5	3	7	7
7	4	6	4	8	-4
10	1				

The second expectation was that cluster A groups would score better than cluster B groups, because cluster A groups received the assignments in parts (intervention 2). With regard to this expectation, the findings show that this is largely confirmed. As can be seen in Table 2, the four groups in cluster A scored much better than groups in cluster B. There is, however, one exception: group 7 in cluster B scores the maximum score possible, and higher than the highest score in cluster A. Nevertheless, based on these results, it seems likely that separating and sequencing instructions indeed improves learning outcomes.

7 EXPLAINING THE FINDINGS

The findings show that the groups in Course II score both higher and lower than those in Course I. Four of the eight groups of Course II score similar, or higher, than the best groups of Course I. This is in keeping with expectations and implies that the interventions have an effect. However, it was not expected that three of the eight groups of Course II scored considerably lower than those of Course I. An explanation why the scores of the three groups in Course II are so low, could be that these groups had a less effective group composition. For example, these groups could consist of weak students, or of students that could not work together well. This seems a plausible explanation, because literature has shown that the composition of groups can be of great importance for performance, not only in professional life, but also in higher education [9].

Another finding related to the effectiveness of the interventions is that in Course II, cluster A groups scored considerably higher than Cluster B groups. This means that, as expected, chunking the assignment seemed to have had an effect, as this was the only difference between cluster A and B. This is also in keeping with literature, in particular with the Cognitive Load Theory [10, 11]. Although not undisputed, this theory states, among others, that presenting material in a simple-to-complex, or part-whole sequence, reduces cognitive load and increases performance of groups [12]. This could explain the differences in scores between the groups in cluster A and B.

However, there is also contrasting evidence that does not support the idea that chunking and sequencing the assignment has an effect. Group 7 in cluster B has the highest score observed during this entire research, but this group has not received the instructions in parts and in sequence, but all at once. Based on expectations and Cognitive Load Theory, this group should not score so high. Most likely, group 7 is just a great group. A group that might have scored high under any circumstances. This also supports the idea that group composition is very important.

8 DISCUSSION AND CONCLUSION

There are some final remarks that need to be pointed out to put the research in the appropriate perspective. First, it appeared very difficult to draw valid conclusions with regard to the causal effects of the interventions. Not only because there is a limited data set, but also because there have been some unexpected results that require further study. Apart from the interventions applied, the results showed that there have been other factors that affected learning outcomes, but these are still unclear. Consequently, the interventions that were proposed in this research only increase the likelihood of improving learning outcomes, but do not guarantee it. Further research could study the effects of the interventions more in-depth. In keeping with our findings, it is particularly relevant to study the effect of group composition on learning outcomes. In addition, the effect of chunking and sequencing is worth further exploration. For this, the Cognitive Load Theory could provide helpful directions.

In this research, Activity Theory has been used as a framework to analyse the groups. This theory appeared to be useful as a structuring device to organize the data. However, the theory posits that tensions within or between the elements of group activity (represented by the Activity Theory triangle), can provide the leverage points for the group to learn, but in this research, it appeared that these tensions were difficult to detect. Let alone to observe how these tensions resulted in learning. Therefore, the idea to focus on these tensions had to be abandoned. Nevertheless, as an observation framework the Activity Theory triangle was very effective.

Finally, the goal of this research was to develop interventions to improve the learning outcomes of groups working on an engineering design-assignment during lectures. The idea was initially to limit the interventions to lecture interventions. However, the research showed that in order to improve learning outcomes, lecture interventions needed to be considered in a broader sense too, i.e. at the course level. As a result, the meaning of the word 'intervention' has changed during this research. It has extended to guidelines for embedding lecture assignments in the course as well. Nevertheless, this can be considered a good thing, because interventions in group work during lectures should not be isolated from the broader educational context in which they take place.

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