Two Strategies for Competence Oriented Knowledge Transfer

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Improving University Teaching, July 24-27 2012

Latest Research on Knowledge Transfer

Abstract. We present a strategy to improve the mathematical (or more general the scientific) communication competence of undergraduate students which can be implemented in tutorials. This strategy consists of written elaboration of exercises on which the students get feedback which is itemised with respect to specific competences.

As a second strategy, we present the strategy of preparing a list of expected frequent errors together with the students.

We report on the implementation of these strategies and their evaluation with a multi-perspective study design. We discuss some problems arising during the implementation and possible solutions.

Two sentence summary. We present two strategies for competence oriented knowledge transfer. We report on their implementation and evaluation.

I. Introduction and statement of the problem

For university graduates the ability to communicate on complex topics with other people who have a similar background is of great importance. In this article we call mathematical communication competence the ability

- to formulate mathematical assertions in a formally correct way,
- to formulate proofs in a logically correct and also understandable way and
- to present mathematical topics to different audiences in an appropriate way.

Let us indicate the importance of the first ability with an example: Assume we want to make an assertion on the solutions of an equation of numbers. The statement

"The equation has a positive solution."

means that there is at least one solution to the equation and at least one of them is positive, whereas the assertion

"The equation has exactly one positive solution."

means that the equation has at least one solution and only one of these is positive. Finally the statement

"The equation has exactly one solution and it is positive."

means that there is a unique solution and this solution is positive.

This short example shows that small changes in a mathematical assertion can yield to substantial changes in its meaning. Of course this effect is of greater importance in assertions including more complex mathematical topics.

This mathematical communication competence cannot be obtained a single course, but has

to be trained over more than one term throughout different courses. The starting point for this study was, that many students still had some problems with their mathematical communication competence even after several semesters of studying mathematics.

Another experience, many university teachers seem to be familiar with, is a lack of follow-up of courses by students. Especially many students seem to miss the possibility to learn from mistakes made by themselves or by fellow students. One effect of this situation is that the same mistakes are made several times.

In this article we will present two strategies to cope with these two problem situations and report on their implementation and evaluation. A more detailed version of this article (in German) has been submitted to the University of Innsbruck's "Schaufenster Lehre" (http://www.uibk.ac.at/rektorenteam/lehre/die-lehre-seite/schaufenster-lehre/).

II. Two Strategies and the Methodology for their Evaluation

In this section, we will present two strategies to deal with the situations presented in the preceding section and the methodology the evaluate them. As a preparation we will present some background information on the course where the strategies have been tested and evaluated. The strategies where applied in a second semester Bachelor's course on calculus. This two hour course accompanied a four hour lecture and had the purpose to deepen the topics taught in the lecture but also to train the mathematical communication competence. The course was attended by mathematics students as well as by physics students. The tutorial was taught in nine parallel groups.

In this course the students weekly had to solve exercises at home. These exercises where posed a week in advance. Moreover the students had to mark the exercises they had prepared in a list. In the tutorials they had to present one of the prepared exercises on the blackboard and their solution was discussed with the other students. In addition there were two written

exams during the semester.

As it is a course for second semester students, the improvement of the mathematical communication skills seems to be a very important task.

II.1 Strategies

We implemented the following two strategies to improve both the mathematical communication competence as well as the amount of the students' follow-up.

II.1.1 Written elaborations

Every week six exercises were posed and the students had to present their solutions on the blackboard. We tried to choose the students who had to present in way such that over the whole term the number of presentations did not differ to much from student to student.

Twice per semester every student had to provide a written elaboration of an exercise presented before. After the students handed in their elaborations the teachers corrected them and also made some suggestions for possible but not necessary improvements. The students did not just get the corrected version of their work but also a feedback which was divided into five parts corresponding to the, in our opinion, five main competences which should be obtained during a Bachelor in mathematics.

- **Logic**: the ability to argue in a logically correct way, comprehensibility of the arguments
- **Imagination**: e.g. geometric imagination
- **Abstraction**: Modelling and generalization.
- **Computational skills:** performing computations
- **Communication**: presentation and discussion of mathematical results, both own and others'

We designed and used a feedback form which contained these five competences together with a list of quality criteria concerning these competences. The main reason for this list was

that we wanted the students to know what we expected them to do. For each of these competences the form contained a bar on which we graded the students' elaboration with respect to this category.

Additionally the feedback form contained three fields in which we gave some additional feedback: one field for positive remarks, one field for criticism and a third field for additional suggestions.

II.1.2 A commented list of errors

During the semester and especially in the weeks before the exams, potential errors made in exercises similar to the ones posed were collected. Besides the actual error itself, every entry of the resulting list contained an explanation of the difficulties leading to the error and a way to avoid such kind of errors. This commented error list was part of the e-learning environment of the tutorial and the students had to enter their contribution into an online form. After the exams, errors actually made by the students were added to the list of error, again together with an explanation.

II.2 Project aims and research questions

The aim of this research project was to implement and evaluate these two strategies. Therefore the two project aims were

1. Improving the students' mathematical communication competence.
2. Improving the follow-up of both the exercises and the examinations.

The strategies were evaluated from three different points of view: the students' point of view, the author's, as a teacher, point of view and additionally the persons teaching the other groups of this course provided their point of view, forming an external perspective. In detail the research questions are:

1. Does the strategy to make written elaborations of the exercises improve the mathematical communicate competence of the students?

2. Does the commented list foster the avoidance of errors?

II.3 Methodology

For the evaluation of these strategies, we used a multi-perspective study design. The occurring perspectives are the students, the teacher (the author) and two colleagues from the department forming an external perspective. The students' perspective was evaluated with two questionnaires. The students completed one of them directly after each discussion of the written elaborations and the other one at the end of the semester to evaluate both strategies. The questionnaires after the feedback-discussions contained the following two questions (translated to English).

1. Feedback form and discussion were useless – very helpful to me. (four-point scale)
2. How do you judge your own mathematical communication competence?

After both discussions of the written elaborations and the corresponding feedback, the students answered this questionnaire.

To cover the teacher's perspective, the feedback form and the teacher's observations during the discussion were collected.

An office colleague of the author also provided his observations in some of the discussions in order to provide an external view.

At the end of the semester the students' view on both strategies was evaluated with a questionnaire containing the following six questions (translated to English).

1. How helpful were the written elaborations and the feedback? (four-point scale)
2. What did I thereby learn the most? (open question)
3. How helpful was the commented list of errors in avoiding errors? (four-point scale)
4. How did the commented list of errors influence my process of learning? (open question)
5. I achieved the aim to be able to apply the methods of calculus in several variables to ...

per cent. (per cent scale)

6. Which competences could I improve/advance in this course? (open question)

In this paper, we will restrict ourselves to the first four questions of this questionnaire.

The teacher's perspective on the commented list of errors was documented by contemplation at the end of the semester containing the observations on this strategy. As the writing of this list took place in an e-learning environment, the external perspective was achieved by two colleagues of the author, who read the list in regular time intervals.

II.4 Method Criticism

The biggest problem of this study is the missing of a methodically correct external perspective. Both of the colleagues forming the external perspective were also teaching a parallel group of the same course, hence both of them were not completely independent. It would have been better to ask completely independent persons for both the observation of the discussions of the written elaboration and also for the observation of the process of creating the commented list of errors.

Also the questionnaire on the written elaborations and the corresponding feedback had some flaws. As I realized too late it was hardly possible to establish a connection between the open question on the mathematical communication competence and specific sub-competences of the mathematical communication competence. Such a reference would have increased the validity of this question and it would have been possible to check the students' judgment on their communication competence against the teacher' judgment. Moreover, it would have been interesting to ask the students how they see the development of their communication competence between the first and the second written elaboration. Also there was only a limited possibility to compare the results of the open question after the first written elaboration with the ones after the second elaboration.

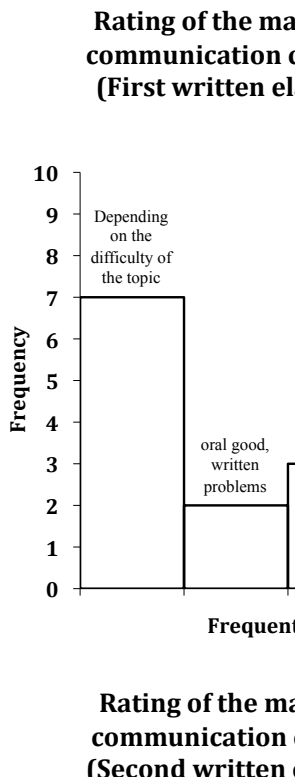
III. Findings

III.1 Written elaborations

In the following, we will present the findings of the study separated into the different perspectives of the multi-perspective study design. We start with the students' perspective.

III.1.1 The students' perspective

As a starting point, we want to consider the question how the students judge their own mathematical communication competence. For this purpose, we present the results of the surveys after the discussion of the elaborations starting with the first one. Whereas only three of the students rated their mathematical communication competence as very good, seven of the in total sixteen students state that they have problems with rigorous formulations. Seven students state that their communication competence depends on the difficulty of the mathematical topics they present. Altogether it seems that at the time of the first written elaboration, most of the students saw a need for improvement of their mathematical communication competence, as ten out of sixteen students made remarks in that direction.



After the discussion of the second written elaboration and the corresponding feedback, the students answered the same questionnaire again. The results of this second survey differ from the results of the first one. In this second survey, only three students declare to have problems with rigorous formulations and only two students think that their mathematical communication competence depends on the difficulty of the content they present. Three students made remarks on the improvement of their communication competence since the first

written elaboration. Two students rate their communication competence as “medium” which is difficult to compare with the results of the first survey. In total fewer students answered the open question the second time, than the first time they completed the questionnaire which

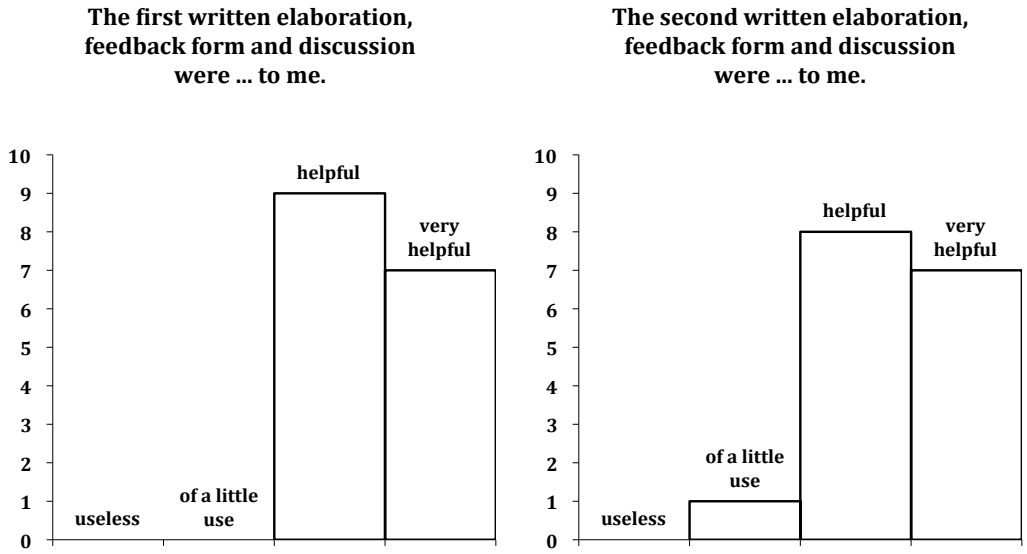


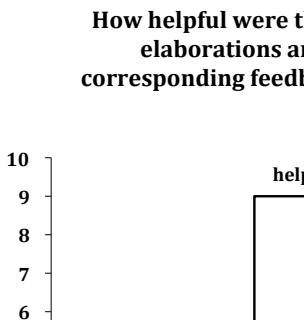
Figure 2: Histograms of the students’ evaluation of the written elaborations and the feedback.

could be a sign of a flaw in the study design (see section II.4). Overall the reduction of the number of students state to have problems with rigorous formulation and the three students examining their improvements indicate that the many students have the impression that their mathematical communication competence has improved. The following two statements (translated to English) seem to be particularly interesting:

- “By written elaborations [the communication competence] was definitely improved.”
- “By following the suggestions made in the discussion of the elaboration, I could improve some formulations.”

A graphical representation of the students' rating of their mathematical communication competence can be found in Figure 1.

After both discussions of the written elaboration the students were asked to answer the question how helpful the written elaboration and the feedback were to them. The students rate the use of the written elaborations in a very positive way. In the first survey, nine out of sixteen rate this strategy as very helpful and seven as helpful. The results of the second survey, after the discussion of the second written examination, are quite similar, here seven students rate the strategy as very helpful, eight students as helpful and one student as a little helpful. None of the students seems to be of the opinion that the written elaborations were useless. A graphical representation of these results can be found in Figure 2.



The results of the survey at the end of the semester, where the students should again rate the helpfulness of the strategy of written elaboration, are again quite similar. The vast majority of the students, i.e., sixteen out of nineteen students rate this strategy as very helpful (seven students) or as helpful (nine students). Two of them rate the strategy as little helpful.

The second question, the students were asked during the final evaluation at the end of the semester, was what they learned the most throughout the written elaborations. Again the results enhance the overall impression that the students had fewer problems with rigorous formulations after the written elaborations than before as seven out of eighteen students state that they trained the ability to formulate mathematical assertions in a rigorous way the most. Another three students state more general that they improved their mathematical presentation competence the most. Moreover (at least) six students improved their mathematical expertise while they were preparing their written elaborations or during the discussions. Three of the students improved their skills to work in a structured way, which is also an important competence. Altogether it seems to be justified to assume that the strategy of written

elaborations was a success from the students' point of view.

III.1.2 The teacher's perspective

Let us start the presentation of the teacher's view with some general observations. During some of the discussions of the written elaboration, especially during the discussion of very good elaborations, I had the impression that the discussions were quite useless. On the other hand I think that the positive personal feedback increased the motivation of the students.

Most of the time, I had the impression that the students are highly interested in feedback. In most cases the second written elaboration was better than the first one, an impression which also reflected by the grades of the elaborations.

A difficulty in the discussion of written elaborations with some potential for improvement is to avoid forcing the students into a defensive position which would complicate the discussions.

Altogether I think that the strategy of written elaboration was very successful both in increasing the students' mathematical communication competence and their mathematical expertise.

III.1.3 The external perspective

The office colleague observing some of the discussions of the written elaboration made the following observations. The discussions always took place in a positive climate and the students did not hesitate to ask in case of comprehension problems. Moreover in many discussions, very interesting mathematical discussions arose from the discussion of the written elaboration. Altogether he is of the opinion that the students learned a lot throughout the written elaborations and by the corresponding feedback.

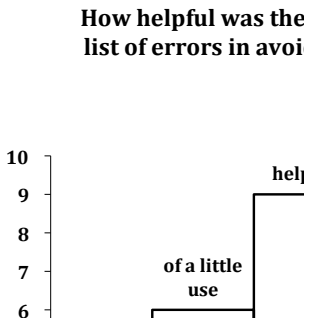
III.2 Commented list of errors

As in the evaluation of the written elaborations, we will present the findings concerning the commented list of errors divided into the different perspectives. Again we start with the

students' perspective.

III.2.1 The students' perspectives

The commented list of errors was evaluated only in the final evaluation at the end of the semester. The results of this evaluation are not as positive as the results of the evaluation of



the written elaborations. None of the students rated the commented list of errors as very helpful and only nine out of eighteen students rated it as helpful. Nearly half of the students rated the list as of a little use (six students) or as useless (one student). Two students did not answer this question at all. Let us now consider the question how the commented list of errors influence the students' process of learning. Only twelve students answered the corresponding question. Four of them did not use the commented list at all at it seems reasonable to assume that at least some of the three students who did not answer this question did not use the list as well. The majority of the students, who used the list, used it for an efficient preparation of the exam (three students) or for a knowledge check or comparison (two students). Three students use it for an analysis of the errors. A graphical representation of the results of this evaluation can be found in Figure 4.

III.2.2 The teacher's perspective

In my opinion the strategy of the commented list of errors did not work too well. One reason is that I did not realize at the beginning of the semester, that the students were not capable of creating an entry in the used wiki-software contain mathematical formulas, as they

would have needed some basic knowledge of the typesetting language LaTeX.

The other problem was that it was difficult to motivate students to take part of the creation of the commented list of errors. One reason may be that this participation was voluntary as I wanted to keep the students' workload in a reasonable range. Another reason may be the students' concern to submit a "stupid error". I tried to counteract on these concerns both by trying to provide a positive learning atmosphere in the course and by limiting the access to the commented list of errors to students registered in my group of the course.

Altogether, I think the commented list of errors only works if there is enough room for it in the course in which is implemented. Also it seems to be necessary that the students are familiar with a tool to write mathematical formulas in an e-learning environment. Additionally the commented list of errors was a lot of work for both the students and the teachers.

III.2.3 The external perspective

As the creation of the commented list of errors completely took place in an e-learning environment, it was difficult to implement an external perspective in a methodically correct way. The colleagues who also taught a group of the tutorial in which the strategies were tested, observed the creation of the list in regular time intervals. The observations of one of them are as follows. The colleague thinks that the students did not use the full potential of the commented list of errors. He stated that this strategy is potentially useful, as the variety of different errors made in same course is not too wide and a commented list of errors could prevent the same error made several times or at least reduce the number of times the same error is made by different students. Altogether, he states that the commented list of errors is a strategy with potential, which did not tap its full potential in this course.

IV. Conclusion and open questions

The strategy of written elaborations was evaluated in a positive way from all occurring

perspectives. Altogether the number of written elaborations should be discussed and evaluated in a future study as well as the number of the corresponding discussions. The workload generated by this strategy was quite high for both the students and the teachers.

Overall, we can conclude that the strategy of written elaboration was implemented in a successful way. We could not only achieve an improvement of the students' mathematical communication competence, but also a growth of mathematical expertise. In some details, there is still room for improvements.

Not all students judge the commented list of errors as a helpful tool and also in the other two perspectives there are some concerns. There were organisational difficulties, which could have been avoided if the students had learned some mathematical typesetting before this course. Afterwards this problem has been solved, as in the new curriculum these skills are taught in the first semester. The question how to encourage the students to participate more actively in the creation of a commented list of errors remains open.

Acknowledgement. I am indebted to F. Kroath and I. Augenstein for their support and guidance. Many thanks to the cooperating teachers in the course where these strategies were implemented, especially to F. Stampfer who provided many of the ideas and materials for the strategies.