2023-10-10

Development And Evaluation Of A Teaching Concept That Focuses On Increasing Modeling Competence In Technical Mechanics (TM)

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Conference Key Areas: *Innovative teaching and learning methods*
Keywords: *technical mechanics, problem solving skills, strategy training, modeling*

ABSTRACT

Engineering students often learn by retracing pre-calculated given solutions of tasks and try to understand this problem-solving way. This reconstruction is not always successful in solving new types of problem via modified tasks (Rossow 2008).
Every mechanical exercise follows the same solution methodology (Müller-Slany 2018). Applying this basic problem-solving structure correctly is a Pre-condition for solution's reflection and is therefore essential for teaching. To improve these competencies a strategy training is implemented in exercise-settings in Technical Mechanics (TM).
By solving in separated model steps pre-structured exercises with differences in depth of structure and always visualizing these steps, the awareness and applying of

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each step should be increased. This research approach aims to investigate the effects of explicit strategy training on the problem-solving skills of engineering students in TM in an experimental design. Research Questions are: what influence does the strategy training have on the knowledge and recognition of the model? What influence does this training have on correct application of this methodology? What influence does this application have on the correct solution of tasks?

As part of a quantitative analysis a self-constructed test for measuring the modeling recognition in Multiple Choice format as well as a competence test to evaluate the application of the problem-solving model were implemented and tested. First results of the research design and the intervention itself are presented.

1 INTRODUCTION

1.1 Background

For engineers it is important to solve problems in a structured way (cf. Lehmann 2008), so good problem-solving skills are a basic for successful engineering work. In engineering study courses, the lectures of the first two semesters are often oriented on basic knowledge and training of mathematical skills, but there is less teaching time for supporting transfer knowledge in the field of technical mechanics (cf. Müller-Slany 2018).

The processing of problems in form of tasks is of central importance in Technical Mechanics (TM). They are used for learning in the form of exercises, but also serve as examination tasks to evaluate students' competencies. For students in TM it is often difficult to work on exercises: they rarely find the approach and/or fail at the mathematical implementation to solving the tasks (Brandenburger 2014). During the exercise, students often try to learn mechanical knowledge by retracing pre-calculated given solutions of tasks (cf. Rossow 2008). But with this learning approach students often do not recognize the based solution methodology and so cannot transfer this problem-solving model to new, unknown tasks. High failure rates in mechanical exams often are a consequence of a lack of transfer knowledge (Rossow 2008). This limited technical problem-solving ability leads to bad exam results.

In TM all tasks can be solved through the same solution methodology. To improve the ability for applying transfer knowledge and so achieving an improvement of students learning outcomes by solving new tasks of various contexts correctly, the awareness and application of the correct (single) solution method must be practiced in teaching visibly and actively.

1.2 Problem-solving Process

In Germany teaching is often structured by problems that are mainly presented in the form of exercises and with these exercises the learners' performance can be classified (cf. DAAD German Academic Exchange Service 2023).

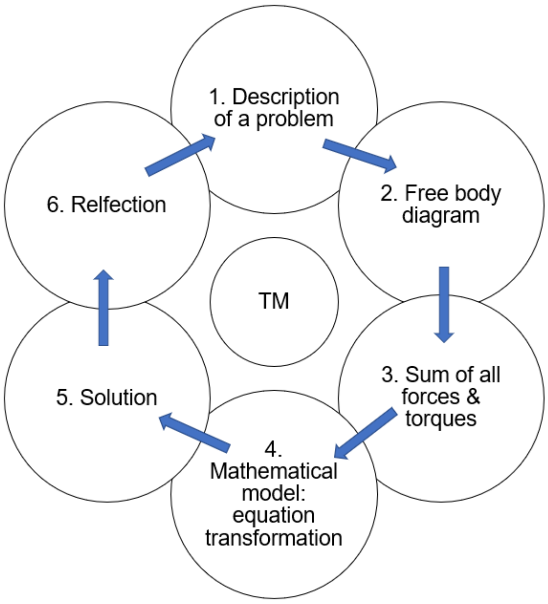

Fig. 1. Solution Methodology of TM tasks (cf. Müller-Slany 2018)

For understanding the way of problem-solving in detail to solve tasks with unknown contexts in TM its necessary to use an efficient focused strategy.
This strategy consists of a structured solution methodology that focuses on a knowledge-based approach (cf. Friege 2001). The basis is the always the same systematic structure of the solution path of mechanical tasks (cf. Müller-Slany 2018) illustrated in figure 1.
By applying this general model to TM, the following steps of solution methodology result: The problem will be represented by visualizing the free body diagram with all relevant variables (e.g., forces and torques) in the given system. In addition, assumptions are made to simplify the following calculation.
The sum of all forces and torques are established and transformed into an equation. The solution is developed by resorting to factual knowledge (e.g., $\sum F_i = 0$) and relationships between knowledge elements (e.g., forces can be summarized to one resultant force with the same effect on the system).
A mathematical model is defined for calculating the unknown variables. A formula for solving the unknown variables is given by a relation between the known variables. A solution is worked out by a solution path (e.g., equivalent transformation of an equation).
After a solution has been determined, its correctness and meaning in relation to the task context have to be evaluated. A more detailed examination shows that the phases of problem solving vary in difficulty. Solving and understanding a problem is often easier than creating a representation and working out a solution. This is shown in research results on problem solving (Chi et al. 1981). It is mentioned that the representation and development of a solution (steps 1 to 3 according to Müller-Slany) are basically to find the solution of a problem. The solution of the searched variable is then just a correctly typed sequence of values in the calculator and a logical consequence after the correctly applied solution way. (cf. Heller et al. 1984).

2 METHODOLOGY

2.1 Intervention

Due to the unsatisfactory results of the students in the problem-solving process for mechanical tasks, a new teaching concept is developed and implemented in a mechanical engineering course. It should promote problem-solving skills of engineering students to solve TM problems. For this, a strategy training is used that should improve the reflection process of the methodological proceeding on the one hand and the evaluation of the solution itself on the other hand. In the strategy training (pre-)structured learning tasks are provided to varying degrees. The initially specified and visualized structure and the systematically dissolving of this to the end of the semester should increase the internalization of the schema. As a consequence, students should be able to apply the schema correct (cf. Beland 2017). Each exercise is divided into subtasks inspired by the modeling cycle and visualized as an Advance Organizer. After applying the model to a (solution of a) task of high complexity through the teacher, the next tasks' solutions have to be worked out by the students themselves to encourage the learning activity (Atkinson et al. 2003).
Students are guided through each problem-solving step, which is defined in detail in form of subtasks. The whole solution path is following this guidance for solving

prototypical, partially contextualised learning tasks. The following figure shows the schedule of the strategy training implemented in an exercise course.

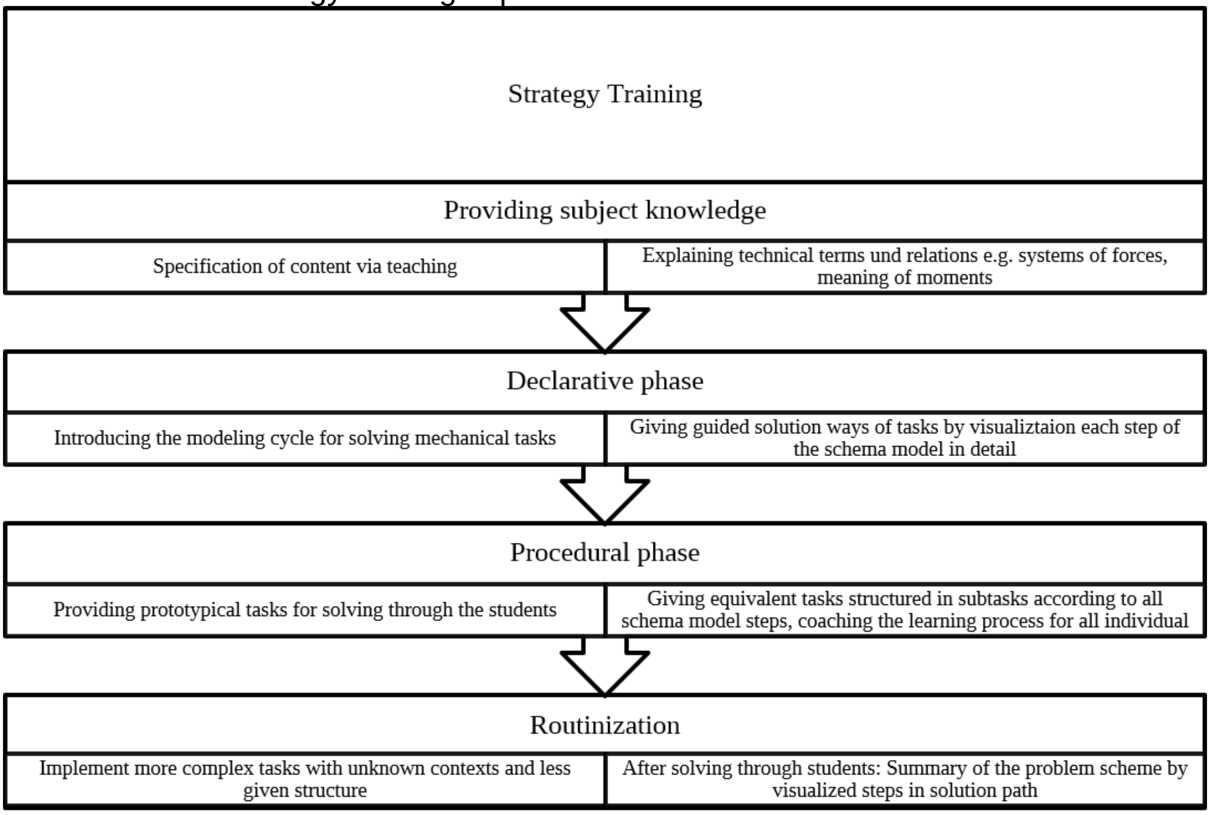

Fig. 2. Schedule of strategy training

At the beginning of the exercise the teacher gives an overview of the topic, shows a worked example of high complexity with (all) visualized modelling steps in the solution path. During the exercise students work on their learning material on their own and could ask subject related questions, but there are no instructions that influence the problem-solving process. They have the opportunity to get coaching individually during their problem solving but the teacher is not giving solutions, just prompts. This framework leads to an active participation of the students.

The problem-solving scheme in all subjects (systems of forces, equilibrium systems, stress resultants and trusses) is the same so that the strategy training is performed equally for each subject. As the number of semester weeks increases, the complexity of the tasks automatically increases, since more relations are used and the modeling cycle for a task is repeated several times when the topics are expanded over the semester. There are more systems for describing all variables and as a consequence the complexity of the solution path increases. Because of this the scaffolding approach is implemented just at the end of the semester.

2.2 Method

With this research study the effect of the used strategy training on problem solving skills of mechanical engineering students in statics will be investigated. For measuring these effects two self-designed tests for evaluation the schema recognition and the schema application are implemented.

As a longitude study the tests are used in a pre-post design: at the beginning and end of the semester to comprehend a base between the two groups and to compare later results to this condition for measuring the learning increase.
The influence of the strategy training could be evaluated with a direct comparison in a 2x1- design. There are two different exercise groups: one with the implemented intervention and one with a regular teaching format for exercise courses. The intervention is implemented in a mechanical exercise related to the ongoing lecture. For data evaluation, both tests are evaluated using the Rasch model that describes the students' performance. Subsequently group comparisons will be made that provide results for the success in problem solving of TM tasks.

2.3 Research Questions

To assess the effect of strategy training on problem solving in engineering mechanics, the following research questions need to be addressed:
(Research Question 1) What influence does the strategy training have on student's declarative knowledge of schema steps? (Hypothesis 1) Due to a permanent visualization and repetition of the schema steps in each task, the knowledge about the existence of the steps and the corresponding content elements is highly expected due to the recognition effect.
(Research Question 2) What effect does the strategy training have on student's procedural knowledge of the schema? (Hypothesis 2) Because of the continuous visual assignment of the schematic steps in the solution path of each task, the knowledge of the processed steps and the corresponding (mathematical) actions is also highly expected.
(Research Question 3) What influence does the exercise concept have on the technically correct application of the schema to new, unknown tasks? (Hypothesis 3) It is assumed that the always same predefined solution structure in the form of subtasks, which are based on the modeling cycle, is internalized in such a way that these steps can also be applied correctly to new tasks independently.
(Research Question 4) What is the relation between the correct application of the schema and the correct end result of the task? H4: If all schema steps are applied completely, a high correlation is expected between a high solution rate of the schema application and the correct final result of the unknown variable of the task.

2.4 Test Instruments

The influence of the strategy training on the schema recognition and application will be evaluated by using a self-designed schema recognition Moodle test in a multiple-choice format as well as a problem-solving test for mechanical tasks (on exam level).

2.4.1 Schema recognition test

This Moodle test is divided into two parts. There are some questions to evaluate the declarative schema knowledge and another part for measuring the schema recognition to procedural knowledge. The first part based on describing the steps in the modelling cycle, so the students have to determine the content elements of each step and put the steps in the correct order. Also, they have to assign steps to given solution parts (8 items in total).
In the procedural part of the test the students have to recognize the (in task named) steps in precalculated solutions of tasks that differ in the number of solution steps that have already been calculated (Fig.3). This procedure is applied to all four

subjects and for each precalculated step so there are 20 Items in total for this assignment.

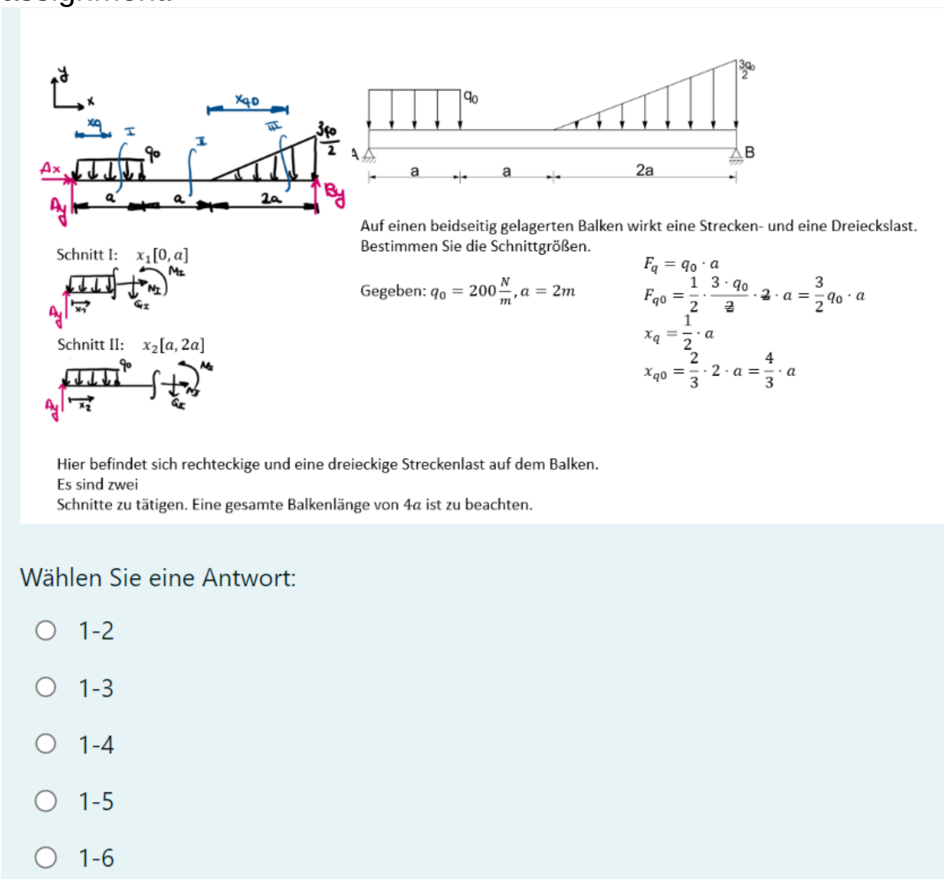

Fig. 3. Part-Screenshot schema recognition test: procedural knowledge (german version)

2.4.2 Schema application test

The competence test was implemented last semester as a paper pencil test with tasks of open format. To give an overview of the test format, there is given one example of task of the actual problem-solving test in the following figure.

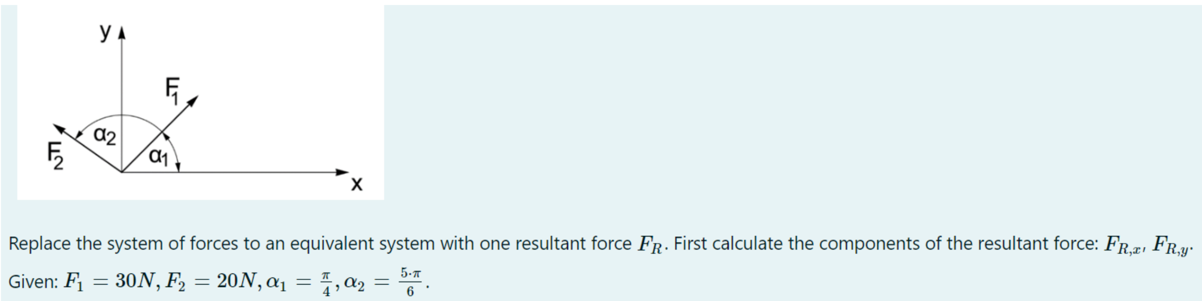

Fig. 4. Example of task of schema application test

Here both forces have to be resolved in their components with a drawing and calculation that is named the free body diagram and then the sum of forces in both coordinate directions must be deployed (= sum of forces). After setting up the sums of each coordinate axis the components can be calculated (=formula) and via Pythagoras added up to the resultant force (= solution). In the last step the result has to be reflected (= evaluation) in the context of the task.

3 PRELIMARY RESULTS

The first implementation of the described intervention was piloted in the winter semester 2022/2023 via an experimental-control-group design in an exercise course of business engineering students in statics with a sample size of 90 students in total at the beginning of the semester. This size decreases during the semester to a size of 70. Only 15 students regularly participated in the strategy training. The exercise was a voluntary offer and thus, the number of students who participated in the study was too small. Due to this, no group comparisons could be made.The number of students that have done the tests completely was about 70. The schema recognition test was implemented via Moodle and the competence test via paper-pencil format. Then both tests were evaluated via Rasch analysis.

Results of the tests instruments are that the schema recognition test divided into declarative and procedural knowledge are too easy because of the lack of relation to mechanical subjects. Due to the smaller number of items that measure declarative knowledge a separated evaluation of declarative and procedural schema knowledge is not possible.

The following table shows the values of the average discrimination (DIS) and person (R_P) as well as item reliability (R_I) according to Cronbach's Alpha of each schema recognition test at the three measurements (pre, midterm and post).

Table 1. Results of schema recognition tests

	Pre	Midterm	Post
DIS	0.25	0.35	0.38
R_P	0.654	0.451	0.583
R_I	0.621	0.725	0.774

The results show that the reliability values over 0.5 are acceptable so the tests are valid for measuring person ability with these items. The reliability of items increases over the test period. The values of discrimination are under the strong limit of 0.5. Due to insufficient discriminatory power, an item was removed from the test. In this item a step was to be assigned a name, but it was not clear whether it should be just a word or a description. Even if the task was changed, the one word for the last step of the schema (reflection) would not be difficult to find, so the item was removed. Another item was removed from the test because it was the only one that consists of another structure (with answer sentence to differ between reflection and answer sentence) and the result was a poor resolution rate. Then a mean discriminatory power of 0.45 could subsequently be achieved. All items of declarative knowledge were solved with over 90% so the test was too easy because of the lack of reference on subject. The solution quote in the procedural part was solved with an average solution quote of 70%. The test is also quite easy and differences less in complexity. Here the test will be modified by giving the precalculated solution steps not in an extremely structured arrangement as given actually. The analysis to Rasch (dichotomous model) shows the following distribution of item difficulty and person ability via Wright Map for the schema recognition test at post measurement: Here the low complexity of the test is confirmed. The person ability spreads round zero, the item difficulty spreads round – 1,89 (same logit-scale).

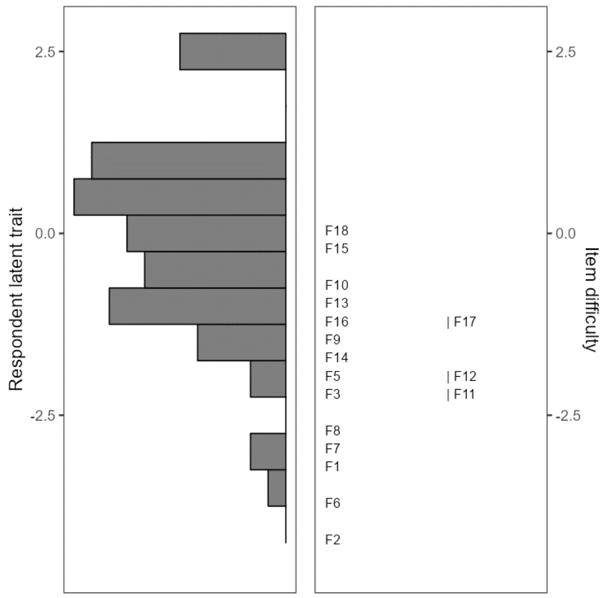

Fig. 5. Wright Map Schema recognition test post

The shift of the distribution shows that the item difficulty is significantly lower than the person ability and that the test is therefore too easy. The competence test was evaluated via code manual and measured a quote of correct schema application (of each step of the modeling cycle). First results show that the tasks differentiate well in complexity and person ability. Because of just five tasks in total an evaluation according to item-response theory is not possible. The setting of this test has to be modified for the main study.

4 SUMMARY

The way of problem solving is essential for understanding and solving technical mechanical tasks, which students try to understand by retracing the solution path. The outlining of the problem-solving strategy is missing. To improve those skills a strategy training is used, that combines worked-examples and the schema application through the students by giving pre-structured tasks according to each step of the modelling cycle and always visualize them. Moodle tests for measuring the influence of the strategy training on schema recognition and application were tested. The declarative knowledge part of the schema recognition test will be adjusted to questions that evaluate knowledge about the modelling steps more related to the subject mechanics. The competence test showed a good selection of tasks that vary in difficulty, but the number of tasks was too small for an evaluation. More tasks in the test means another format for this test because of test economy. The open tasks could not be used for this, instead the individual problem-solving steps must be solved independently via Moodle.

The intervention and test instruments will be implemented to mechanical engineering students of the first semester, the sample size is approx. 100 students. In order to ensure full participation in the study, the processing of the tests is set as an admission to the exam. The strategy training requires attendance. Covariates for this study are: Gender, age, grade of mathematics, grade of physics, repeater of the course, semester, university entrance qualification, prior subject knowledge TM, finale grade, interest in TM.

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