British Journal of Arts and Social Sciences
ISSN: 2046-9578, Vol.14 NoII (2013)

http://www.bjournal.co.uk/BJASS.aspx

The effects of experimental learning on the development of procedural knowledge – outcomes of an empirical study in structural engineering

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Abstract

The vocational education sector makes limited use of experimental learning / teaching strategies in the field of technical training. In order to test the impact of experimental pedagogy on the learning outcomes of trainee teachers in structural engineering and timber processing technologies, a small scale study was undertaken by researchers at Otto-von-Guericke-University, Magdeburg. This paper summarises the outcomes and the evaluation of the research.The results of the study confirm that experimental training can have a positive influence on learning achievement. Notably, the research shows that experimentally designed training is particularly supportive for the development of procedural knowledge.

Keywords: Experimental Learning, Active Learning, Empiric Evaluation of Learning

The educational policy context

The restructuring of the framework for qualifications in vocational training in 1999 heralded a new era in Germany with changes emerging in phases, beginning with qualifications in the field of structural engineering. In 2003 the fields of electronics and electro technology were also radically altered, not only with regard to the vocational education curricula, but also to the development and identification of new roles and job titles for those emerging with qualifications in special and applied sciences.

The national restructuring of vocational education included the development of curricula which support '*active learning* '*(co BADER & SCHÄFER 1998)* within the framework and principles of the newly defined 'Lernfeldkonzept' [1]. This recent focus on *'active learning'* has become the centre of intense debate among educators in the sector, particularly in relation to the design of training programmes which realise successfully *active learning*. A possible way of ensuring *active learning* takes place is to focus on 'experimental training'. This method makes use of the experiment as the key vehicle to learning.

Pedagogic approaches to training in structural engineering and timber processing technology offer a limited range of teaching strategies which make use of experimental learning. For this reason the researchers at Berufs- und Betriebspädagogik Otto-von-Guericke Universität Magdeburg were charged with developing a theoretically based methodology for the teaching of structural engineering and timber processing using experimental learning.

The experiments developed as part of this research are not documented in this paper since they have already been published (BÜNNING, F 2006, *Experimentierendes Lernen in der Holz- und Bautechnik – Fachwissenschaftlich und handlungstheoretisch begründete Experimente für die Berufsfelder Bau- und Holztechnik*, Bertelsmann Verlag, Bielefeld).

The experiments were developed for teachers of structural engineering and timber processing technologies and were subject to empirical evaluation. This article summarises the outcomes of the research and the empiric evaluation.

Purpose of the Research

The purpose of the research was to evaluate the effects of experimental learning on learning achievement. Two experiments were selected and carried out in a practical environment at the vocational school BBS2 in Stendal, Germany. The experiments were:

Experiment 1: Woodworking joints in timber construction: experimental identification of the interrelation of maximum compression load and 'Vorholzlänge'[2] at front and double displacement and

Experiment 2: The influence of the length of the Rebar on the flexural strength of a steel reinforced beam.

Four groups of students in their first year of training were available for the study. For the purpose of the research the experiments were integrated into 'Lernfelder'.

Experiment 1 was integrated into a section entitled "Manufacturing of a timber construction" and Experiment 2 was integrated into a section entitled, "Manufacturing of a ferroconcrete component". The experiments were integrated into learning contexts.

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[1] "Lernfelder" integrate competences in a multidisciplinary/vocational context.

[2] The 'Vorholzlänge' is an important gauge for traditional (German) woodworking joints in timber construction.

This paper is structured in two parts:

Part I describes the evaluation of Experiment 1.

Part 2 describes the evaluation of Experiment 2.

In the sample group, three of the four classes acted as focus groups for the research and one class as the control group in order to ensure a fair outcome. This ratio also enabled the researcher to gain more data from those participating in the research study.

Both experiments were conducted in the same way with three participating groups and one control group. In part I class S.05 acted as control group and in part II class AB.05 were the control group.

Four classes were available for the evaluation of the technical experiments and consequently four experimental groups were formed. The application of a quasi-experimental research methodology with a control group was agreed to be appropriate. Randomization was not possible since the learners were divided into classes according to their career choice and could not be recomposed by random sampling. Therefore, the implementation of pre-tests for the determination of dependant variables was necessary in order to be able to make statements about changes in the experimental groups. The purpose of the pre tests was to identify possible differences between the experimental and the control groups at the beginning of the research. The basic conditions are reference data against which intervention-related changes are measured. (co. BORITZ & DÖRING 2002, p 530).

The following order was applied to the tests in the study.

Order for the research of the experiments (Example Part Study I)

Class	1st pre-test	2nd pre-test	Experiment	1st re-test	2nd re-test
M.05 (Bricklayer)	O	O	X	O	O
AB.05 (General builder)	O	O	X	O	O
Da.05 (Roofer)	O	O	X	O	O
S.05 (Groundworker)	O	O		O	O

Notes:

1st pre-test before the beginning of the 'Lernfeld'

2nd pre-test before the experiment;

Implementation of the experiment (2-6 lessons);

1st re-test after the experiment;

2nd re-test in the next block (Determining the duration of the knowledge gained)

With the help of tests, an assessment of the learning outcome about declarative, procedural and problem-solving knowledge was carried out. The tests were divided into three parts, each respectively contains questions about declarative, procedural and problem-solving knowledge.

The test instruments were developed based on published examinations of the IHK (Chamber of Industry and Commerce) and from examination literature. Established assessment methods were chosen, as they were considered reliable. An appropriate assessment mode was chosen in order to meet the aims of the research study.

The part of the test which concentrated on declarative knowledge made use of the assignment answer-choice-form, as this was considered appropriate. The procedural memory retains knowledge in the form of units, independently of procedural rules, which is why the construction/application test was applied to this part. In the part of the test dealing with problem-solving knowledge the type of assignment construction was applied in which the learners had to develop the solution themselves. For each part of the test nine points were assigned.

The experiments to be empirically evaluated were embedded in the relevant 'Lernfeld'. Furthermore, learning situations were developed in which the experiment was carried out. The respective learning contexts for the study contained 60 lessons. The learning situation and the experiment were integrated after about 30 lessons.

Within the study the following hypotheses were formulated:

H1: Experimental training promotes the acquirement of declarative knowledge similarly to direct training.

H2: Experimental training promotes the acquirement of procedural knowledge and with that the ability to understand and modify processes independently.

H3: Experimental training promotes the acquirement of problem-solving knowledge regarding the ability to solve problems in the specialist field of the learner.

H4: Experimental training promotes the acquirement of all three knowledge areas (declarative, procedural, problem-solving knowledge) by high-performance learners. Weak learners in contrast are disadvantaged.

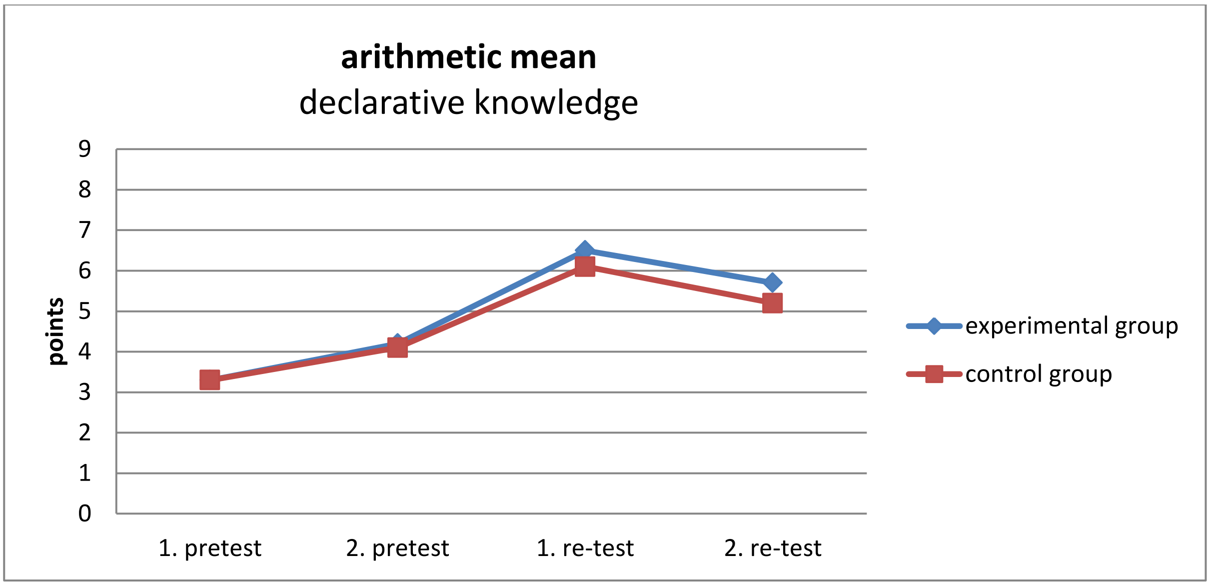
Outcome of the empirical study

Declarative knowledge

Part I

Part of the analysis was the mean comparison gained by the different groups (M.05, AB.05, Da.05 und S.05) at a different time (1st pre-test to 2nd re-test). This comparison shows the development of the classes subject to the intervention of the experiment. The outcomes are broken down into three fields of testing: declarative knowledge, procedural knowledge and problem-solving knowledge.

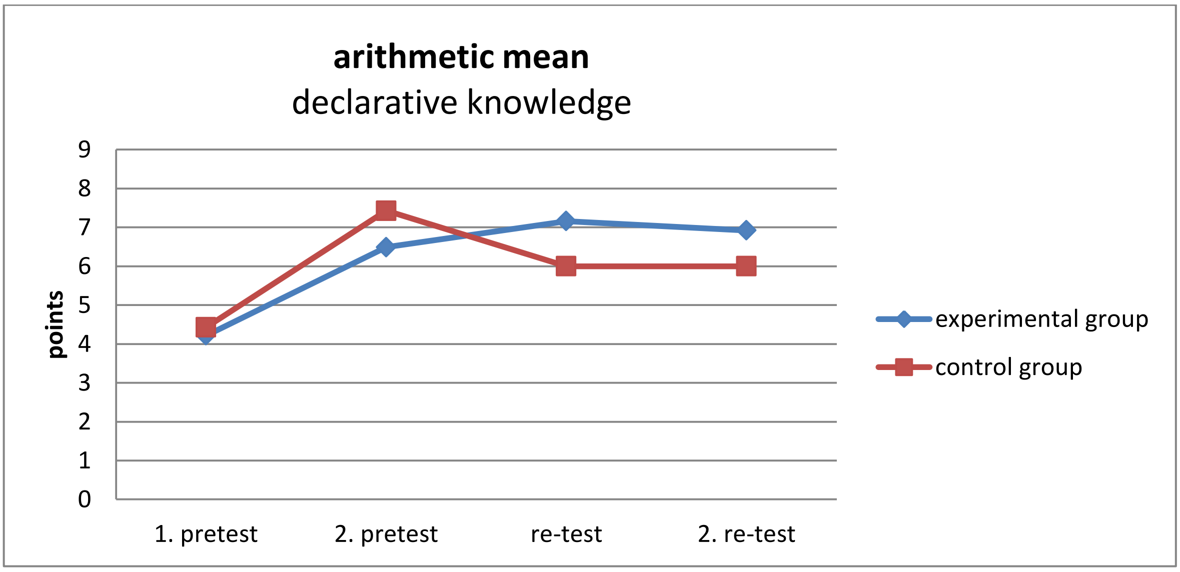
A direct mean comparison of the control group and the experimental groups of study shows that the development of the control group and the experimental group is very similar. However it is notable that the three experimental groups have a slightly higher outcome in the 1st and in the 2nd re-test. The difference between experimental and control group is 42 points in the 1st re-test and 42 points in the 2nd re-test.



Mean comparison – declarative knowledge, experimental and control group – part study I

Part II

In the 1st pre-test, both groups showed a similar outcome (experimental group 4.22 points, control group 4.43 points). In the 2nd pre-test the experimental group shows a lower outcome than the control group (experimental group 6.49 points, control group 7.43 points) with a difference of almost one point. In the 1st re-test, the experimental group shows a higher outcome than the control group (experimental group 7.16 points, control group 6.00 points). In the 2nd re-test a difference between experimental and control group of .92 points can be noted.



Mean comparison – declarative knowledge, experimental and control group – part study II

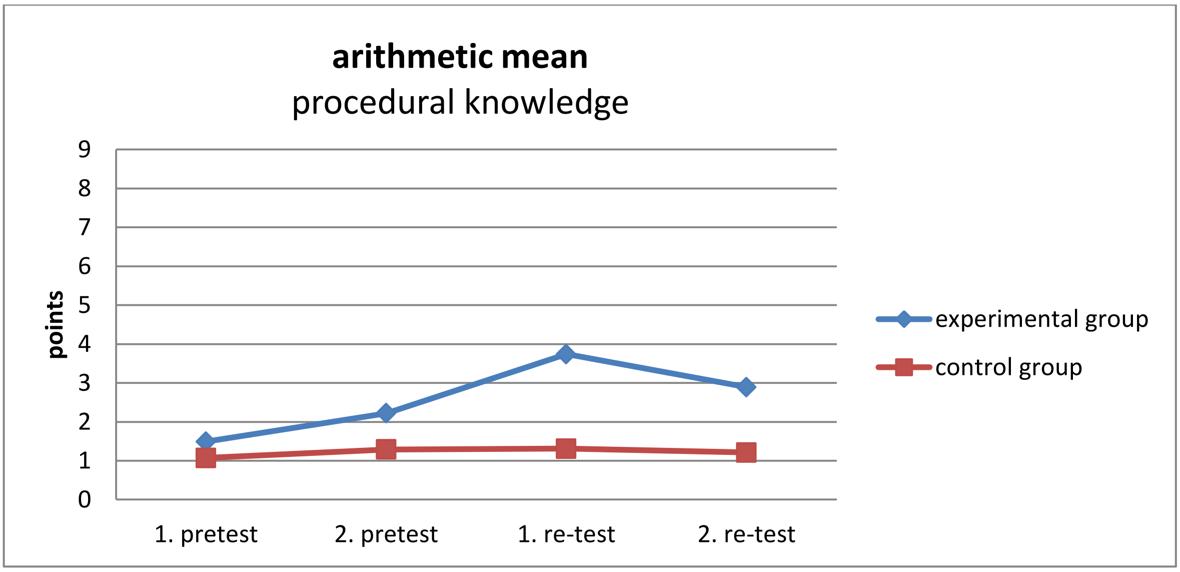
Interim conclusion:

The analysis of the development of the experimental groups and the control groups (Part I and Part II) showed that the intervention (the experiment) led to slightly higher outcomes in the achievement of declarative knowledge. This tendency was observed in both parts of the study whereas the tendency of better outcomes was higher in Part II.

Procedural knowledge

Part I

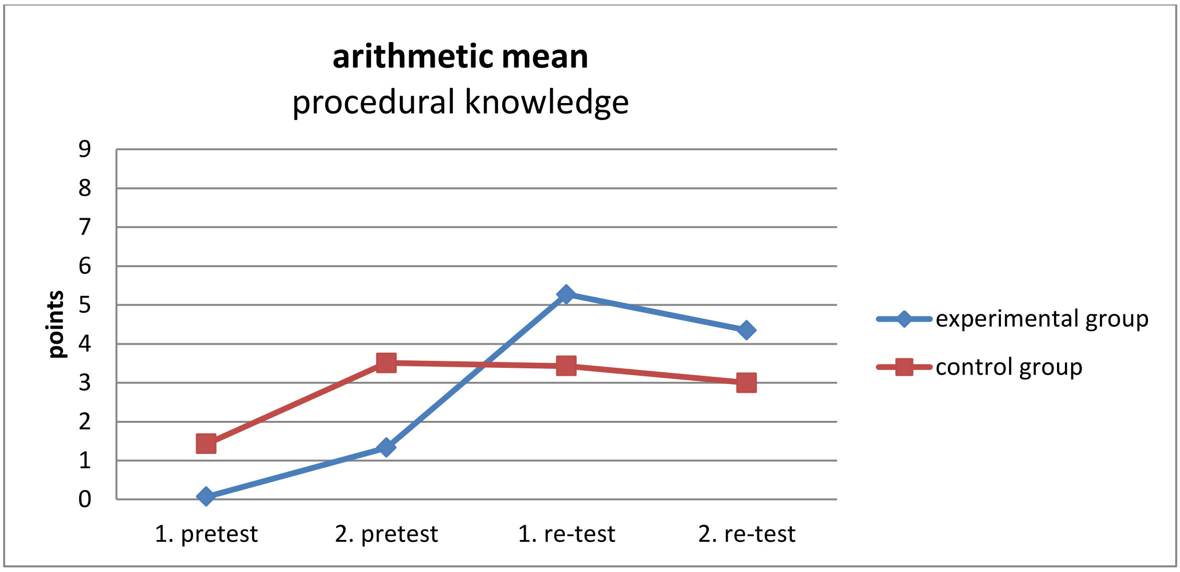
The direct comparison of the control groups and the groups which participated in the experiment showed that the experimental group achieved considerably higher scores in procedural knowledge. In the 1st pre-test, the classes which participated in the experiment achieved 1.49 points on average and in the 2nd re-test 2.89 points. The control group showed outcomes of 1.07 points on average in the 1st pre-test in the field of procedural knowledge. However, in the 2nd re-test the control group achieved 1.21 points. In the further course of the study (from the 2nd pre-test on) the groups already differed significantly from each other. On average, the 'experimental learning group achieved 2.22 points and the control group 1.29 points. This difference cannot be explained by the intervention, i.e. by the experiment, as the experimental unit was not carried out before the 2nd pre-test. It can be assumed that the differences were subject to other influences not controllable during the examination. In addition to the impact of the experiment on the learning achievement of the subjects, the degree of action orientation of the training by the teacher was analysed. It was observed that the teachers in the control group undertook less action-oriented training. The noticeable differences between the groups could therefore be attributed to this factor.



Mean comparison – procedural knowledge, experimental and control group – part study I

Part II

The results of Part II are compared again with regard to the control and experimental group. The experimental group scored a significantly lower result in the 1st pre-test than the control group (experimental group 0.07 points, control group 1.43 points). In the 2nd pre-test the experimental group performed considerably lower than the control group too. In the 1st re-test the results change and the experimental group achieved a considerably higher result with 5.27 points than the control group with 3.43 points. Also in the 2nd re-test the experimental group was able to achieve a higher result than the control group (experimental group 4.35 points, control group 3.00 points.



Mean comparison – procedural knowledge, experimental and control group – part study II

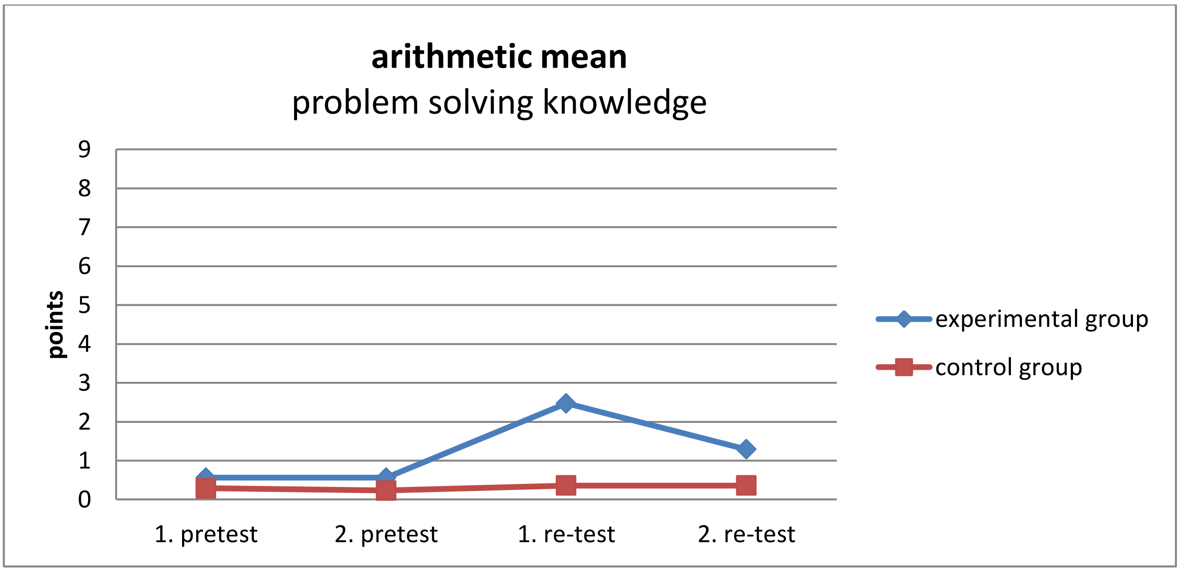
Interim conclusion:

In the development of procedural knowledge, experimental learning shows positive effects. Both in part I and part II the experimental groups achieved higher scores in procedural knowledge. While the development of procedural knowledge of the control group 'plateaued' in part 1, the experimental group showed higher scores in procedural knowledge. In part 2 the control group initially showed better results than the experimental group. After the intervention (Experiment) the experimental group clearly outstripped the control group.

Problem-solving knowledge

Part I

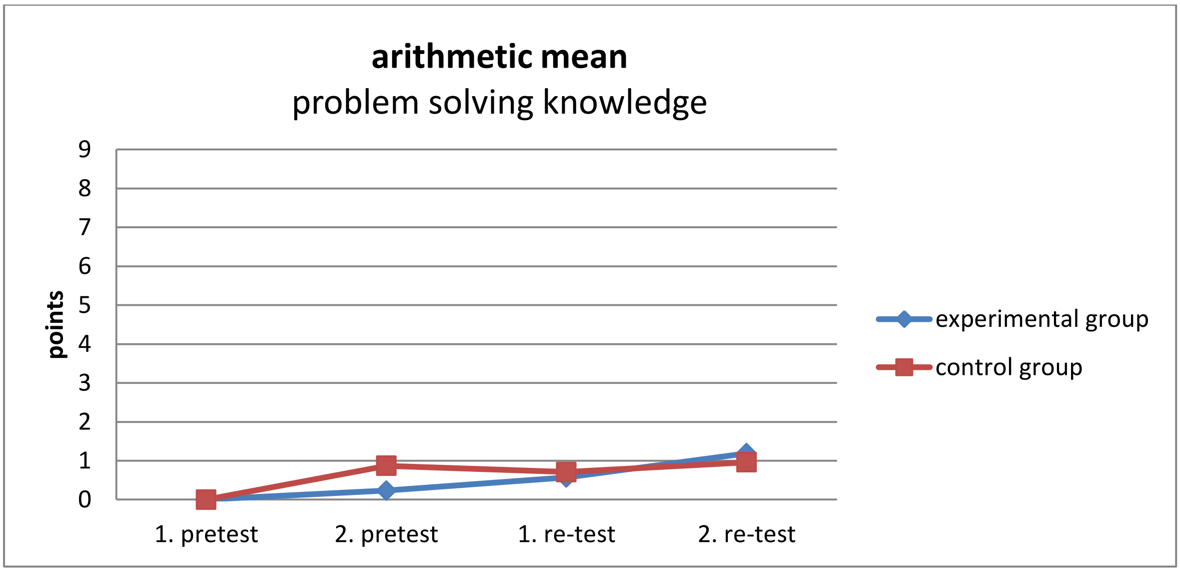
A comparison of the results of the focus group and the control group in Part I draws a clear picture in the area of problem-solving knowledge. While the experimental group achieved .56 points in the 1st pre-test and 2.47 points in the 1st re-test, the control group was only able to improve the results from .29 points in the 1st pre-test to .36 points in the 1st re-test. The experimental group therefore shows an increase of 1.91 points from the 1st pre-test to the 1st re-test. The control group improved the results by .07 points from the 1st pre-test to the 1st re-test.



Mean comparison – problem-solving knowledge, experimental and control group – part study I

Part II

The evaluation of Part II shows a less clear picture than the evaluation of part I. The experimental group showed improved results from .00 in the 1st pre-test to .57 in the 1st re-test. The control group also showed improvements from .00 points in the 1st pre-test to .71 points in the 1st re-test- Both groups show a similar low increase in points.



Mean comparison – problem-solving knowledge, experimental and control group – part study II

Interim conclusion:

Part I shows that the experimental group improved their problem-solving knowledge as a result of intervention. The control group, however, only showed a very low improvement in this area. This very clear development of part I was not confirmed in part s II, however. The experimental group showed a low increase in performance through the intervention. The control group's results decreased slightly over this period of time (2nd pre-test – 1st re-test). In the 2nd re-test both groups showed an only slightly different result (in favour of the experimental group).

Statistical Analysis of Findings

In the context of this study, it was of special interest to analyse the learning achievements from the 2nd pre-test to the 1st re-test. Between these two tests an experimental intervention with the focus groups was undertaken (except the control group) and results were taken from this test. The effect of the experiment on learning success becomes clear in the analysis. Consequently, this area (T-test, variance analysis [ANOVA] and degree of effect size η^2) is regarded separately, and in detail. Apart from the effects of the experiment on learning success, the study also considered the influences of the subjects' educational qualifications on the three areas declarative, procedural and problem-solving knowledge. The development from the 2nd pre-test to the 1st re-test were analysed and notably the effects of the experiment on learning success were most marked within this time frame.

The results of the development from the 2nd pre-test to the 1st re-test were analysed with regard to their correlation to the test subjects' educational qualifications. The development of the learners is made clear by the increase in points between the 2nd pre-test and the 1st re-test, i.e. the score achieved in the 2nd pre-test was subtracted from the score achieved in the 1st re-test. The calculated score was then correlated with the educational qualification.

The most important results of the analysis are presented in tabular form initially.

Summary of the statistic analysis results – declarative knowledge

	Part study I	Part study II
Declarative knowledge (2nd pre-test – 1st re-test)		
T-Test EG CG	 T(df)=-7.923(44) p=.000*** T(df)=-4.497(13) P=.001***	 T(df)=-2.350(36) p=.024* T(df)=3.333(6) p=.016*
ANOVA	P=.617 ns η^2 =.004 (no effect)	p=.004** η^2 =.181 (strong effect)
Correlation between the educational ation and the development from 2nd pre-st re-test EG CG	 r=-.105 (p=.492 ns) r=-.489 (p=.076 ns)	 r=-.195 (p=.247 ns) r=.661 (p=.106 ns)

Summary of the statistic analysis results – procedural knowledge

	Part study I	Part study II
Procedural knowledge (2nd pre-test – 1st re-test)		
T-Test EG CG	 T(df)=-5.869(44) p=.000*** T(df)=-.155(13) P=.879 ns	 T(df)=-11.602(36) p=.000*** T(df)=.000(6) p=1.000 ns
ANOVA	p=.011* η^2 =.108 (moderate to strong effect)	p=.000*** η^2 =.320 (very strong effect)
Correlation between the educational ation and the development from 2nd pre-st re-test EG CG	 r=-.219 (p=.148 ns) r=.208 (p=.475 ns)	 r=-.040 (p=.815 ns) r=.573 (p=.179 ns)

Summary of the statistic analysis results –problem-solving knowledge

	Part study I	Part study II
Problem-solving knowledge (2nd pre-test – 1st re-test)		
T-Test EG CG	 T(df)=-6.711(44) p=.000*** T(df)=-1.000(13) P=.336 ns	 T(df)=-2.017(36) p=.051 ns T(df)=1.000(6) p=.356 ns
ANOVA	p=.001*** η^2 =.168 (strong effect)	p=.233 ns η^2 =.034 (small to moderate effect)
Correlation between the educational ation and the development from 2nd pre- st re-test EG CG	 r=.366 (p=.013*) r=-.354 (p=.215 ns)	 r=.179 (p=.289 ns) r=-.496 (p=.258 ns)

EG – Experimental group

CG – Control group

ANOVA – Analysis of Variance

The elaborated hypotheses H1 to H4 are checked by the statistically analysed examinations.

H1: Experimental training promotes the acquirement of declarative knowledge comparable to directive training.

The hypothesis H1 can be verified.

In part study I the hypothesis was verified both in the comparison of the 2nd pre-test and the 1st re-rest and in the comparison of the 1st re-test and the 2nd re-test. The T-test for the experimental group in the 2nd pre-test and the 1st re-test showed that the measured change was highly significant [T(df)=-7.923(44); p=.000]. Highly significant changes were also noted for the control group [T(df)=-4.497(13); p=.001]. The analysis of variance confirmed the results of the T-test. It does not show a significant influence of the experiment in the 2nd pre-test – 1st re-test. Furthermore, no effect is shown by the variance explanation (η^2 =.004).

The analysis of the results in part study II by means of the T-test indicates a [T(df)=-2.350(36); p=.024] in the comparison with the 2nd pre-test and the 1st re-test for the experimental group, i.e. a significant increase through the intervention. For the control group a significant reduction in performance with [T(df)=3.333(6); p=.016] was recorded. Therefore it can be interpreted that experimental training can lead to better results than directive training. This is especially true when a strong effect is shown (η^2 =.18

The analysis clearly shows 2nd pre-test – 1st re-test, the developments of the experimental group and the control group resemble each other also in the following tests of the examination. Also in the 1st re-test – 2nd re-test a comparable development is documented for the experimental group and the control group. In Part I, the experimental group records a [T(df)=3.604(44); p=.000] in the T-test and the control group a [T(df)=2.509(13); p=.026]. Therefore, the experimental group shows a highly significant change and the control group shows a significant change.

In Part II, both the experimental group with [T(df)=-2.350(36); p=.024] and the control group with [T(df)=3.333(6); p=.016] show a significant change, i.e. the experimental groups were similar to the control groups in both part studies in the analysis of the results 1st re-test – 2nd re-test.

Conclusions can be drawn from the analysis of the results of the Parts I and II, namely that experimental training could have a more positive effect on the development of declarative knowledge than directive training. This was made particularly clear in Part II of the study.

H2: Experimental training promotes the acquirement of procedural knowledge and with that the ability to understand and modify processes independently.

The hypothesis H2 can also be verified.

This was confirmed in Part I in the comparison of the 2nd pre-test and the 1st re-test.

The increase in performance of the experimental group between 2nd pre-test and 1st re-test was highly significant [T(df)=-5.869(44); p=.000], whereas the change of the control group was not significant [T(df)=-.155(13); p=.879]. It can be concluded that experimental training has a decisive influence on the development of procedural knowledge. The analysis of variance verifies the results of the T-test as it shows a significant influence of the experiment. Furthermore, the variance explanation indicates that the experiment has a moderate to strong effect on the learning success in the area of procedural knowledge (η^2 .108).

The T-test of the experimental group shows a significant increase from the 2nd pre-test **to the 1st re-test for part study II [T(df)=-11.602(36); p=.000]. The control group in contrast** recorded a non-significant change [T(df)=.000(6); p=1.000] from the 2nd pre-test to the 1st re-test. The results are confirmed by the analysis of variance as it reveals a significant influence of the intervention. The variance explanation indicates a strong effect (η^2=.320).

Both part studies show consistency in the results, thus verifying the hypothesis.

H3: Experimental training promotes the acquirement of problem-solving knowledge regarding the ability to solve problems in the specialist field of the learner.

The hypothesis H3 can only be verified in Part I.

It can be seen in the analysis of Part I of the 2nd pre-test and the 1st re-test, the experimental group and the control group develop in very different ways. In the 2nd pre-test and the 1st re-test it can be seen that the experimental group shows a highly significant increase in performance [T(df)=-6.711(44); p=.000], whereas the control group shows a non-significant increase in performance [T(df)=-1.000(13); p=.336]. The results are also confirmed by the analysis of variance, as ANOVA indicates a highly significant influence of the experiment. The Eta-square amounts to .168, which is why a strong effect can be concluded.

In Part II the T-test for the experimental group showed an insignificant change. For the experimental group a [T(df)=-2.017(36); p=.051] is calculated, i.e. there is no significant change. In this connection it is to be noted that the significance limit ($p \leq 0.05$) is only slightly exceeded. The control group recorded [T(df)=1.000(6); p=.356], which is also an insignificant change. The analysis of variance indicates a non-significant influence of the experiment in part II. The Eta-square amounts to .034, therefore a small to moderate effect can be noticed.

The two parts of the study show very different results. The results of Part I show an influence of the experiment on the development of problem-solving knowledge, while in part II no significant influence can be proven.

No conclusion can be drawn from the results, as they are too contradictory. The hypothesis cannot therefore be verified.

H4: Experimental training promotes the acquirement of all three knowledge areas (declarative, procedural and problem-solving knowledge) by high-performance learners, weak learners in contrast are disadvantaged.

The results of the experiment neither falsify nor verify the hypothesis H4, consequently the hypothesis has to be abandoned.

The correlation between the educational qualification and the development from the 2nd pre-test to the 1st re-test was analysed, as between 2nd pre-test and 1st re-test the experimental was carried out and possible connections between educational qualification and learning outcomes were revealed.

No uniform statement can be made with regard to the correlation between educational qualification and development from the 2nd pre-test to the 1st re-test on the basis of the statistical analysis of this study. No significance was identified for the calculated correlations (except part I, area of problem-solving knowledge, EG r=.366 (p=.013*). Furthermore, the correlations between educational attainment and development in the experimental group were low or very low. In the control group there were partially high or almost high correlations, which should be considered with caution given the setting and the relatively small numbers of the control group.

On the basis of the results the hypothesis can, as already stated, neither be falsified not verified and consequently has to be abandoned**.** For this question further research is required. More sophisticated examination tools than those used here are necessary, e.g. a higher number of experimental groups, a higher number of test persons, the inclusion of further personal data beyond the educational qualifications and a test design which concentrates on this problem.

Conclusion

The technical experiment can make a contribution to the realisation of active learning, which is especially focussed by the ‘Lernfelder’ in the reorganised professions concerning structural engineering and electronics and electro technology. Relevant literature deals with sequences with regard to algorithms of the technical experiments (see BADER, BERNARD, EICKER, PAHL etc.).

The initial results of the first study confirm that experimental training has a positive influence on learning achievement. A more detailed breakdown of the first re-test (after the experimental part of the learning field) shows that the groups in the segments of the tests dealing with declarative knowledge do not differ significantly, i.e. the classes with an extensive experimental part and the control classes showed similar results in the test. In the tests dealing with procedural and problem-solving knowledge there are differences between the classes which were trained experimentally and those trained with the „mixed methods“usually used at school. Here the experimentally trained learners performed better than those trained with the „mixed methods“. Consequently it can inferred that experimentally designed training is particularly supportive for the development of the procedural knowledge and problem-solving attributes.

An aspect for specialist pedagogues to debate, research and develop is therefore a theoretically based methodology for experimental learning in structural engineering and timber processing technologies. The challenge for educators is to concentrate on reviewing experiments in their discipline rather than dwelling on theory. In order to meet this need, experiments for the professional subject areas of structural engineering and timber processing technologies should be developed, tested and documented for teachers, in order to encourage them to use the experiment as a vehicle for active learning in the vocational training.

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