How can we teach the experiment design skills?

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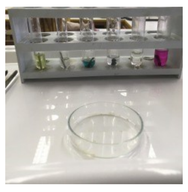
One aspect of the knowledge areas of scientific literacy is **evaluating and designing a scientific inquiry**[1]

Therefore, **the development of experiment design skills is important**.

- We got positive results in our earlier research.[2] The control group did 'step-by-step' experiments. The experimental group designed one or more of the experiments before doing them. All students were 14-15 years old.
- Further investigations were necessary to answer the following **research questions**:
  1. Would the difference between the ability of control and experimental groups to design experiments increase over a 4 year period (longitudinal study)?
  2. Does taking responsibility for designing experiments change students' attitude and motivation to chemistry?
  3. Are students' experiment design skills affected by whether or not they do the designed experiments?

[1] PISA 2015 Assessment and Analytical Framework: Science, Reading, Mathematic and Financial Literacy, PISA, OECD Publishing, Paris.

[2] Szalay, L., Tóth, Z., (2016), An inquiry-based approach of traditional 'step-by-step' experiments, *Chem. Educ. Res. Pract.*, **17**, 923-961.



Research group:

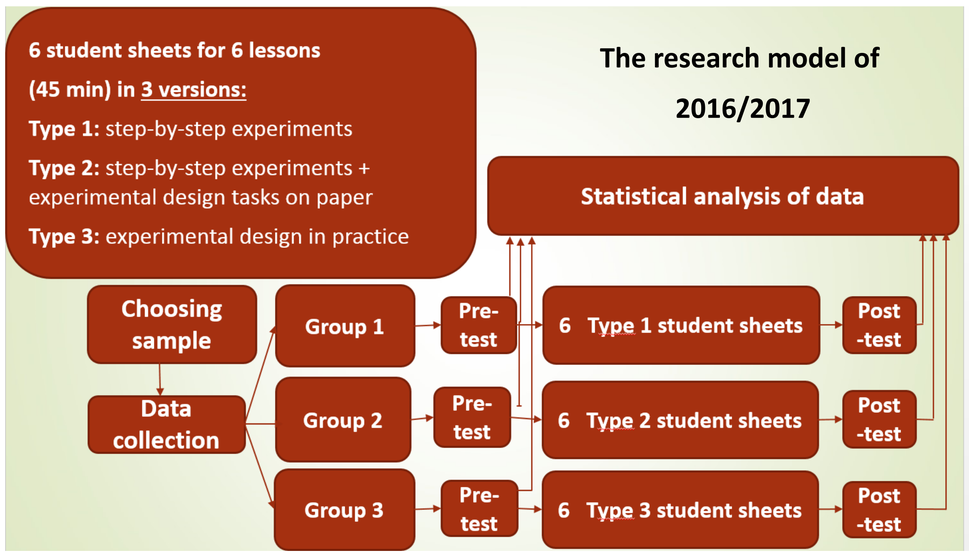
- 25 chemistry teachers, 5 university chemistry lecturers and until now 4 pre-service chemistry teacher students

Research method:

- **4 school years** (2016-2020); **6 students sheets + teacher guides / school year** (altogether: 4x6=**24**)
- **5 tests** (pre-test: September 2016; 4 post-tests in the end of the school years; each consists of 18 items: 3 items for recall, 3 items for understanding, 3 items for application, 9 items for experiment design skills)

Sample:

- 18 secondary schools in Hungary, 31 classes of students (they study chemistry for 4 years)
- **920 students,** 7th grade in 2016/2017 (12-13 years), divided randomly into three groups described below



1st year: school year 2016/2017

Activities of the 3 groups of students:

- Group 1 ('control'): follow **'step-by-step' recipes when doing the experiments**
- Group 2: follow the same **'step-by-step' recipes and design other experiments 'on paper'**
- Group 3: doing the same student experiments as Group 1 and Group 2 , but **design one or more experiments before doing them**.

Statistical methods: calculation of mean, standard deviation, analysis of covariance (ANCOVA). The development of the experimental groups (Group 2 and Group 3) was shown by the Cohen's d that is an effect size to indicate the standardised difference between two means.[3]

(Note: Group 3 had significantly better scores on the pre-test than the other two groups, therefore matched pair design method was necessary.)

Most important test result: Group 3 students got lower scores for the experiment designing tasks on the first post-test than Group 2 students.

[3] Cohen J., (1988), *Statistical power analysis for the behavioral sciences*, 2nd ed., Lawrence Erlbaum Associates, USA, pp. 20-27.

2nd year: school year 2017/2018

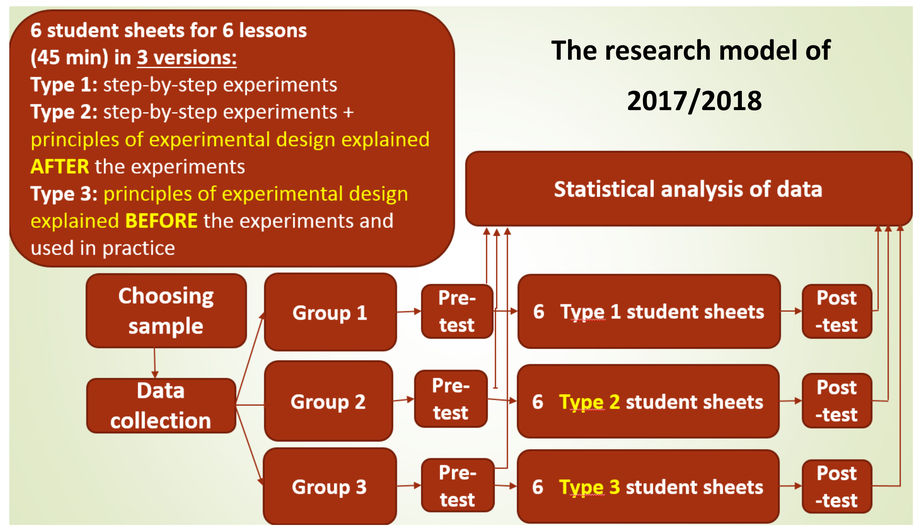
After discussions with experts of psychology and assessment it was concluded that **the important aspects of the experimental design has to be taught**.

Activities of the 3 groups of students:

- Group 1 (,control'): follow **'step-by-step' recipes** when doing the **experiments**
- Group 2: follow the same 'step-by-step' recipes and **are then given explanations of the experimental design of these recipes**
- Group 3: do the same student experiments as Groups 1 and 2 , but **with guidance about experimental design before planning and carrying out some of the experiments .**

Statistical methods are the same as in the previous year to make comparisons.

Aspects of the experimental design taught e.g. dependent and independent variables; significant features of a modelling experiment; main principles of qualitative and quantitative analysis.



Statistical analysis of the 1st and 2nd year tests

All tasks	Pre-test 1st post-test	1st post-test 2nd post-test
	Cohen's *d**	
Group 2	**0,28**	**0,69**
Group 3	**0,20**	**0,67**

Experimental design tasks	Pre-test 1st post-test	1st post-test 2nd post-test
	Cohen's *d**	
Group 2	**0,19**	**0,49**
Group 3	**0,17**	**0,43**

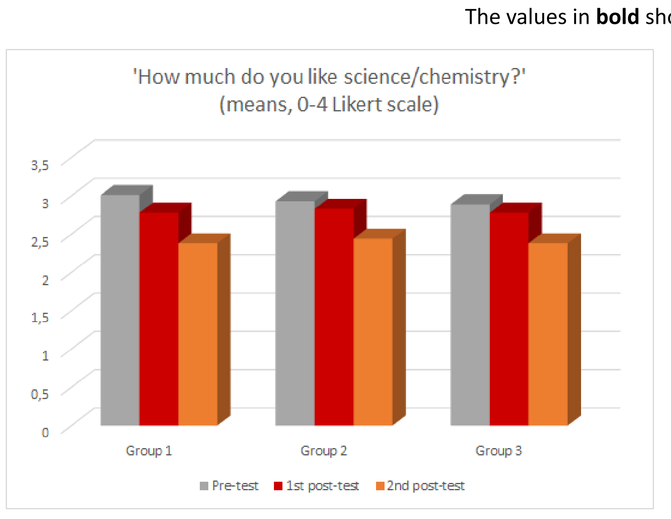
Other tasks	Pre-test 1st post-test	1st post-test 2nd post-test
	Cohen's *d**	
Group 2	**0,20**	**0,52**
Group 3	0,13	**0,55**

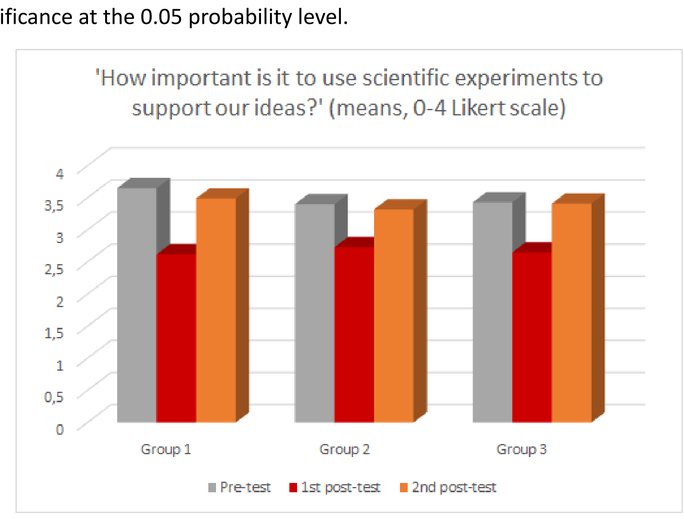
$$d = \frac{\bar{x}_1 - \bar{x}_2}{s_{pooled}} \qquad s_{pooled} = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$$

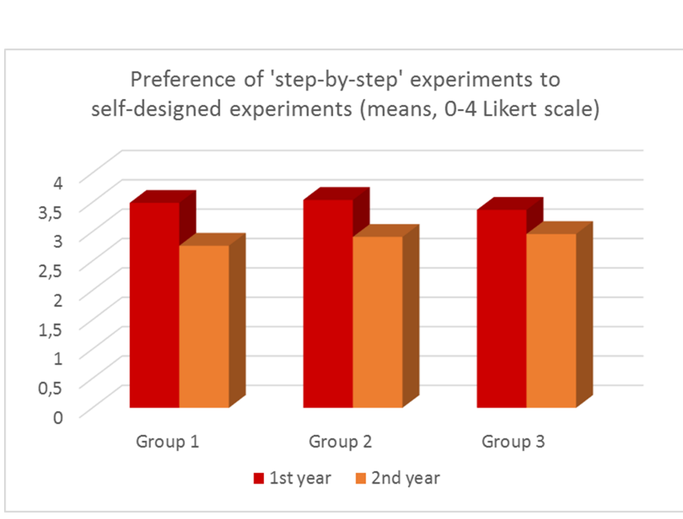
The development of the experimental groups (Group 2 and Group 3) was shown by the ***Cohen's d*** that is an effect size to indicate the standardised difference between two means. (Effect size is defined as a quantitative measure of the magnitude for the difference between two means.)

A Cohen's d value of 1 indicates that the means of the two groups differ by 1 standard deviation. Values around *d*=0,2 are generally considered to be small effect sizes, whereas *d*=0,5 medium and *d*=0,8 large. The Cohen's d values were calculated taking into consideration the means and standard deviations approximated by the ANCOVA analysis.

The values in **bold** show significance at the 0.05 probability level.







The intervention could not stop the negative trends in the attitude of students toward chemistry.

Students in each group thought the role of science experiments significantly less important when they had studied chemistry for a year than they did when they had studied science (the previous two school years). This negative trend turned back in the second year of the project.

Student very strongly favour the 'step-by-step' experiments to the ones they have to design.

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Many thanks for all the colleagues' work.

Summary of the results

- 1st year: Groups 2 had better results than the other two groups. However, the effect size shown by the Cohen's d were only small.
- 2nd year: Moderate positive development in case of the experimental groups (Group 2 and Group 3 students) compared to the control group (Group 1).

Conclusion

- It seems advantageous to teach experimental design skills.

New questions

- Were Group 3 students affected by cognitive overload?
- Can we confirm our belief that it is beneficial to teach the principles of experimental design skills prior to students designing an experiment?

THE 2nd YEAR RESEARCH MODEL IS USED FOR THE FINAL 2 YEARS OF THE PROJECT.