Effective ways of teaching experimental design skills

Luca Szalay[1], Réka Borbás[2], Zoltán Tóth[3]

[1]ELTE, Eötvös Loránd University, Budapest, Hungary
[2]Szent István Secondary School, Ajtósi Dürer sor 15, 1146 Budapest, Hungary
[3]University of Debrecen, Debrecen, Hungary

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http://ttomc.elte.hu/publications/90
Luca Szalay: luca.szalay@ttk.elte.hu

Two research projects about changing step-by-step student experiments to student experiments partially designed by the students

	Brief research*: in school year 2014/2015	Longitudinal research**: in 4 school years 2016-2020 (2021!)
Intervention	3 lessons	6 lessons/school year (=24 lessons)
Tests	Pre-test+post-test	Test 0 (**T0**): September 2016 + **T1, T2, T3, T4**: end of school year
Number of students	660	920
Age of students (years)	14/15 Grade 9	12/13:2016; 15/16:2020 Grade 7-10
Number of teachers	15 (in service)	41 (in-service) + 5 (pre-service)
Number of schools	12	18
Group 1 (control)	only step-by-step exp.	only step-by-step experiments
Group 2 (experimental)	designs experiments	**theoretical** experiment design
Group 3 (experimental)	-	experiment design **in practice**

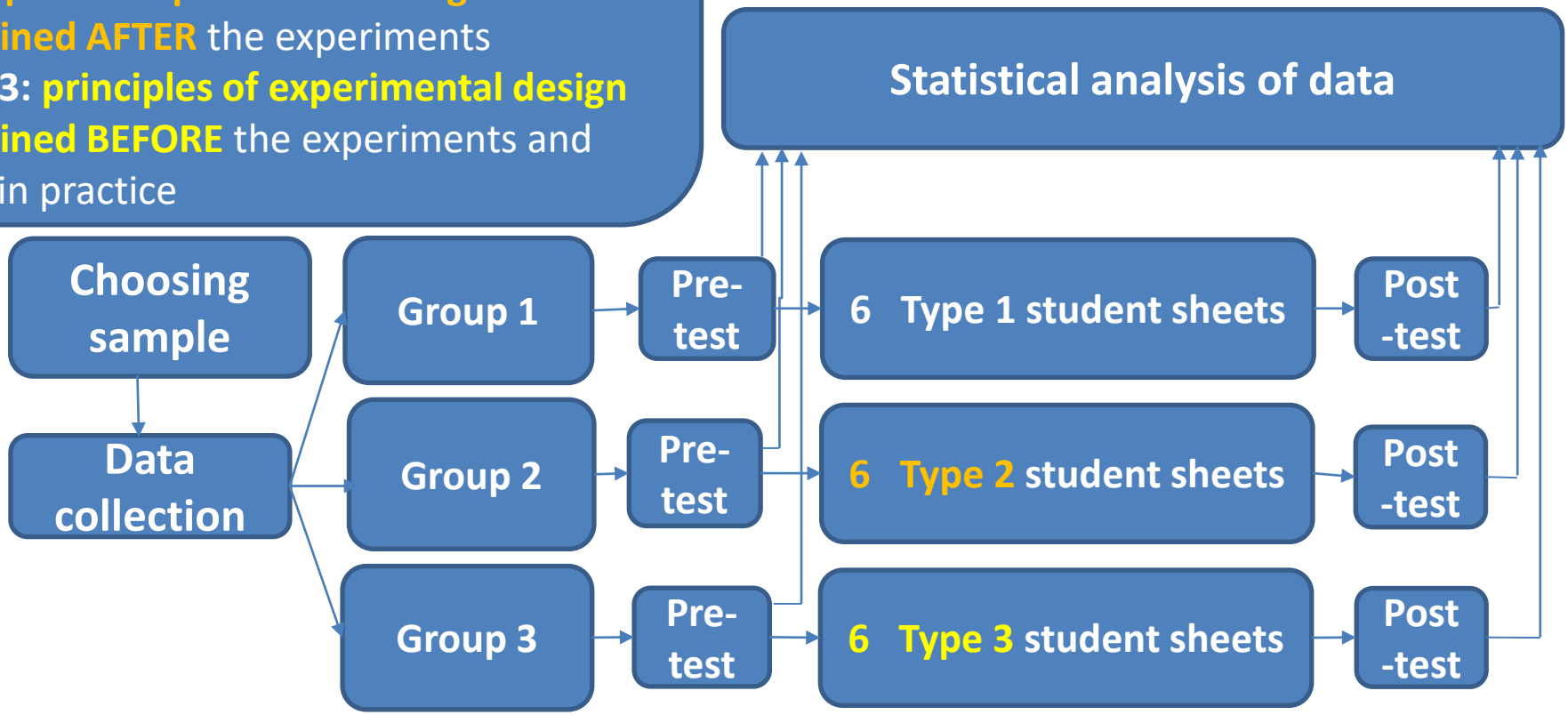
*Szalay, L., Tóth, Z., (2016), An inquiry-based approach of traditional 'step-by-step' experiments, *Chem. Educ. Res. Pract.*, **17**, 923-961.

Szalay, L., Tóth, Z., Kiss, E., (2020), Introducing students to experimental design skills, *Chem. Educ. Res. Pract.*, **21, 331 – 356.

The research model from September 2017 (from Grade 8)

6 student sheets for 6 lessons (45 min) in 3 versions:
Type 1: only step-by-step experiments
Type 2: step-by-step experiments + **principles of experimental design explained AFTER** the experiments
Type 3: principles of experimental design explained BEFORE the experiments and used in practice

First year: no significant difference in the development of experimental design skills between the experimental groups and the control group →
lack of scaffolding did not work →



The important aspects of the experimental design (e.g. 'other variables held constant') were taught from September 2017.

Statistical analysis of data

- **Structured paper and pencil tests (T0-T4); tasks intending to measure: same items:**
  disciplinary content knowledge (DCK) + experimental design skills (EDS)
- **2017-2020: avarage scores of Group 2 and 3 students on T0 were significantly better →reduced sample: 3 groups are not sign. diff. in parameters + covariants**
- **COVID-19 →trials of student sheets + T4 test finished in June 2021**
- **461 students took all the 5 tests → *N*=461: no sign. diff. among groups on T0:**
  Group 1: 130; Group 2: 162; Group 3: 169 students
- **Analysis of covariance** (ANCOVA) of the SPSS Statistics software
- **Independent variables (parameters - „sources"):**
  - Groups (3 types of instruction methods: Group 1, Group 2, Group 3)
  - School ranking (3 categories: high, medium and low ranking schools)
  - Mother's education (2 categories: mother has/has not got a degree in HE)
  - Gender of the student (2 categories: boys, girls)
- **Covariant:** Result of Test 0 (continuous variable)
- **Dependent variables: percents of students' scores (%) in the tests (on the total test, on DCK and EDS tasks, respectively)** analysed as continuous variables.
- Bonferroni correction → results are significant at p=0.05/5=0.01 level
- ***Partial eta-squared* (*PES*)** was used as a measure of the **effect size.**

The effect (*PES*) of the assumed parameters on the students' scores and the estimated mean scores (%) on the whole tests (DCK+EDS tasks) (*N* = 461)

Parameter↓ *PES*→	Test 0	Test 1	Test 2	Test 3	Test 4
Group (effect of intervention)	0.017	0.077*	0.047*	0.019	0.004
School ranking**	0.049*	0.026*	0.098*	0.157*	0.050*
Mother's education***	0.077*	0.000	0.000	0.005	0.019*
Gender	0.000	0.001	0.018*	0.007	0.015*
T0	-	0.005	0.113*	0.095*	0.062*

Estimated mean scores (%)↓ *PES*→	Test 0	Test 1	Test 2	Test 3	Test 4
Group 1	36.0	38.1	30.8	32.3	43.3
Group 2	40.2	45.6	41.9	38.2	40.4
Group 3	40.1	32.5	39.8	37.8	40.2
Significant difference among Groups	1–2; 1–3	1-2; 1-3; 2-3	1-2; 1-3	1-2; 1-3	-

$p<0.01$

* *: students from lower ranking schools scored significantly less than others

* * *: mother's education (social background) mattered only in T0 and T4

The effect (*PES*) of the assumed parameters on the students' scores and the estimated mean scores (%) on the experimental design skills (EDS) tasks (*N* = 461)

Parameter ↓ *PES* →	Test 0	Test 1	Test 2	Test 3	Test 4
Group (effect of intervention)	0.043*	0.061*	0.045*	0.011	0.008
School ranking* *	0.036*	0.023	0.072*	**0.215***	**0.103***
Mother's education	0.055*	0.001	0.003	0.000	0.001
Gender	0,000	0,000	0,010	0,032*	0,008
T0 (EDS)	-	0,000	0,083*	0,052*	0,068*

Estimated mean scores (%)↓ *PES*→	Test 0	Test 1	Test 2	Test 3	Test 4
Group 1	19.5	34.6	21.3	27.9	41.5
Group 2	27.2	41.3	**34.1**	33.8	36.1
Group 3	20.1	27.2	**33.4**	32.6	36.5
Significant difference among Groups	1-2, 2-3	2-3	**1-2, 1-3**	-	-

*p<0.01

* *: students from lower ranking schools scored significantly less than others

* * *: mother's education (social background) mattered only in T0

The effect (*PES*) of the intervention and the school ranking on the students' scores on the whole tests (*N* = 461)

Intervention↓ *PES* →	Test 0	Test 1	Test 2	Test 3	Test 4
Group 2 – Group 1 (control)	0.014	0.022*	**0.043***	0.016*	0.003
Group 3 – Group 1 (control)	0.014	0.013	**0.031***	0.015*	0.004
School ranking↓ *PES* →	**Test 0**	**Test 1**	**Test 2**	**Test 3**	**Test 4**
High – low	0.039*	0.013	0.093*	0.129*	0.047*
High – medium	0.001	0.022	0.012	0.002	0.005

The effect (*PES*) of the intervention and the school ranking on the students' scores on the EDS tasks (*N* = 461)

Intervention↓ *PES* →	Test 0	Test 1	Test 2	Test 3	Test 4
Group 2 – Group 1 (control)	**0.031***	0.012	**0.038***	0.010	0.007
Group 3 – Group 1 (control)	0,000	0,014	**0.034***	0.007	0.006
School ranking↓ *PES* →	**Test 0**	**Test 1**	**Test 2**	**Test 3**	**Test 4**
High – low	0.015	0.010	0.040*	0.162*	0.103*
High – medium	0.001	0.001	0.000	0.004	0.037*

*p<0.01

Discussion and conclusions

- **Social variables** *(*represented by mother's education) had a significant effect on the students' achievement on the EDS scores of Test 0, than disappeared – students carefully selected by the schools!
- **School variables** (represented by school ranking) **had a stronger effect on the EDS scores than the intervention from T2 (Grade 8).**
- **Direct teaching of experimental design seems to work better –**
  - **T1 (Grade 7):** no significant development in the EDS (younger students and longer period than in the previous brief project!)
  - **T2 (Grade 8): significant development in the EDS in both experimental groups – direct teaching of the experimental design is more effective!**
  - **T3 and T4 (Grade 9 and Grade 10): : no significant development in the EDS – EXPLANATIONS? – What can we say to the teachers?**
    1. **Students in Piaget's formal operational stage can work out how to design experiments?**
    2. **Ability scores are confounded by motivational levels? –(Effect of T0!)**
    3. **Do the tests provide a good enough picture about EDS? (+COVID-19!)**
    4. **Is it better to teach how to use a template to design experiments?**

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Website: http://ttomc.elte.hu/publications/90
E-mail: luca.szalay@ttk.elte.hu

THANK YOU FOR YOUR ATTENTION!