Progress in developing experiment design skills in primary schools

Luca Szalay[1], Edina Kiss[1], Zoltán Tóth[2]

Research Programme for Public Education Development of the Hungarian Academy of Sciences
MTA-ELTE Research Group on Inquiry-Based Chemistry Education

[1]**ELTE, Eötvös Loránd University, Budapest, Faculty of Science, Institute of Chemistry, Pázmány Péter sétány 1/A, H-1117 Budapest, Hungary**,, luca.szalay@ttk.elte.hu

[2]**University of Debrecen, Faculty of Science and Technology, Institute of Chemistry, Egyetem tér 1., H-4010 Debrecen, Hungary**

- **Inquiry** is the intentional process of diagnosing situations, formulating problems, critiquing experiments and distinguishing alternatives, **planning investigations**, researching conjectures, searching for information, constructing models, debating with peers using evidence and representations and forming coherent arguments[1].
  - **Guided inquiry:** the question to be investigated is given by the teacher and **students have to design a procedure** to find the answer[2].
  - **Experimental design skills (EDS):** controlling for variables while planning a **fair test** ("how to vary one thing at a time" or "other things/variables held constant").
- **Conclusions of previous studies:** students need **more support** to learn how to design experiments and **more motivation** to maintain interest in long term[3].
- **Research questions**:
  1. Would it help the development of the **EDS** if students completed a **scheme** (set of questions) on their worksheets concerning
     - **independent/dependent variable** and **constants;**
     - the choice of **materials** and **equipment;**
     - the **correct steps** in the experiment?
  2. Does it matter whether this **scheme is completed** by the experimental groups
     - **after performing the experiment** following a step-by-step recipe?
     - **before performing the experiment** designed by the students?
  2. Would this intervention change the **disciplinary content knowledge (DCK)** acquired?
- **Context based** and **systems thinking tasks** should be included on the student worksheets to **increase motivation.**

[1] Linn, M. C., Davis, E. A., & Bell, P. (2004). Inquiry and technology. In Internet environments for science education (pp. 3–28). Mahwah, NJ: Lawrence Erlbaum Associates.

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The research model of the school year 2022/2023

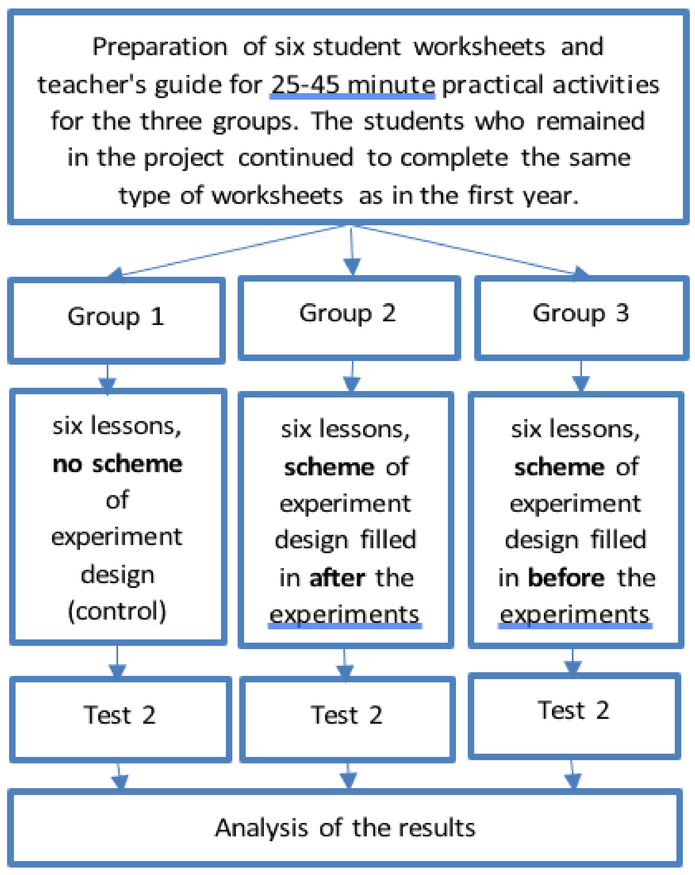

Figure 1 Research model applied in the second school year of the present project

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- **Research group:** 5 university chemistry lecturers and 34 chemistry teachers in the first school year, 31 chemistry teachers in the second school year
- **Research method**:
  - **4 school years**; **6 students sheets + teacher guides / school year** (altogether: 4x6=**24**)
  - **5 tests** (Test 0: September 2021; Test 1-4: four tests in the end of each school year); each consists of 18 items:
    - DCK: 3 items for recall, 3 items for understanding, 3 items for application
    - EDS: 9 items for experiment design skills.
- **Sample:**
  - **25 secondary schools** in Hungary, **38 classes** of students who study chemistry there for 4 years were involved in September 2021
  - **931 students,** 7th grade in 2021/2022 (12-13 years), divided into three groups, of whom **756 students filled in the 3 tests of the first 2 years** (T0, T1, T2)
    - **Group 1** ("control"): follow **"step-by-step" recipes** when carrying out the **experiments**
    - **Group 2: complete the scheme after** following the same **"step-by-step" recipes** as the control
    - **Group 3: complete the scheme before carrying out the experiment** they have to design.
- **Statistical methods:**
  - **Means and standard deviations** (SD) calculated of the raw test scores and comparison of the groups by ANOVA analysis (SPSS Statistics software).
  - **Cohen's *d* effect size** values were calculated taking into consideration the means and standard deviations of the three types of difference between the three test scores (T1 – T0, T2 – T1 and T2 – T0), see Table 1 for DCK and Table 2 for EDS.
  - **ANCOVA analysis** was conducted with test scores as the dependent variable, since students' performance can depend on several factors, not only on the inter-vention. **Group** (the type of instruction methods), **school ranking** (according to the legjobbiskola.hu), **mother's education** and **gender** were the parameters. The covariate was the **student's prior knowledge** (T0 test scores). ***Partial Eta Squared*** (PES) values were used to characterise the **effect sizes** (Table 3-4).
  - **38 classes were divided into the 3 groups after Test 0,** making sure that there were **no significant differences between the groups** in terms of performance on DCK and EDS tasks, or any of the parameters and the covariate. This was checked by **chi-square test.** Considering the two years period, there was no significant difference in the composition of the groups with respect to mother's education [X^2 (2, N = 756) = 2.844, p = .241)] and gender [X^2 (2, N = 756) = 2.523, p = .283)]. However, there was a significant difference in the composition of the groups with respect to school ranking [X^2 (4, N = 756) =13.86, p = .008)], as the difference was significant between Group 1 and Group 3 [X^2 (2, N = 517) =11.81, p = .003)]. It was checked that the changes in the composition of the groups were handled well by this analysis by comparing the T1 test scores estimated by the ANCOVA model at the end of the first and the second year.
  - **Cronbach's alpha values** for the two tests were acceptable: 0.742 for T0 test, 0.692 for T1 test and 0.694 for T2 test.

Results of the 1st and the 2nd school years

Table 1 Cohen's d Effect Size Values Calculated by the ANCOVA Model from the Estimated Changes in Students' Performance on the Tests for the DCK Tasks ("DCK") (*N*=756)

Cohen's *d*	$T1_{DCK} - T0_{DCK}$	$T2_{DCK} - T1_{DCK}$	$T2_{DCK} - T0_{DCK}$
Group 2/Group 1	-0.24	0.28	0.10
Group 3/Group 1	0.01	0.10	0.12
Group 3/ Group 2	0.24	-0.18	0.02

Table 2 Cohen's d Effect Size Values Calculated by the ANCOVA Model from the Estimated Changes in Students' Performance on the Tests for the EDS Tasks ("EDS") (*N*=756)

Cohen's *d*	$T1_{EDS} - T0_{EDS}$	$T2_{EDS} - T1_{EDS}$	$T2_{EDS} - T0_{EDS}$
Group 2/Group 1	-0.07	0.13	0.09
Group 3/Group 1	0.34	-0.12	0.23
Group 3/ Group 2	0.41	-0.26	0.14

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Website: https://ttomc.elte.hu/publications/95

Table 3 The Effects of the Assumed Parameters (Sources) and the Covariate (Prior Knowledge, $T0_{DCK}$) on the Changes for the DCK tasks ("DCK") in the Beginning of the Project (T0), in the End of Grade 7 (T1) and in the End of Grade 8 (T2) (*N*=756)

Parameter (Source)			
	$T0_{DCK}$	$T1_{DCK}$	$T2_{DCK}$
Group	0.001	0.018*	0.004
School ranking	0.033*	0.079*	0.001
Mother's education	0.021*	0.002	0.002
Gender	0.009*	0.000	0.001
Prior knowledge ($T0_{DCK}$)	-	0.053*	0,049*

Note: * Significant at $p < 0.025$ level (Bonferroni correction)

Table 4 The Effects of the Assumed Parameters (Sources) and the Covariate (Prior Knowledge, $T0_{EDS}$) on the Changes for the EDS tasks ("EDS") in the Beginning of the Project (T0), in the End of Grade 7 (T1) and in the End of Grade 8 (T2) (*N*=756)

Parameter (Source)	PES (Partial Eta Squared)		
	$T0_{EDS}$	$T1_{EDS}$	$T2_{EDS}$
Group	0.006	0.040*	0.011*
School ranking	0.113*	0.023*	0.059*
Mother's education	0.001	0.005	0.010*
Gender	0.001	0.001	0.002
Prior knowledge ($T0_{EDS}$)	-	0.070*	0.045*

Note: * Significant at $p < 0.025$ level (Bonferroni correction)

Summary of the results by the end of the second year:

- The achievement of the **Group 3 students exceeded that of the other two groups in the EDS,** although Group 2 developed better in the second school year than Group 3.
- No significant difference in the change in DCK among the three groups could be detected.
- The effect of **"school ranking" and "prior knowledge" on EDS had bigger effect size (PES) than the intervention ("Group").**

Conclusion: Completing the **scheme still seemed to help significantly the development of EDS in case of Group 3**.