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Exploring Changes in Students' Understanding the Basic Concepts of Data Analysis in Introductory Laboratory Course "Search for Physics Laws"

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Abstract

Laboratory courses have always been one of the most important components of university science courses. It is expected that first-year engineering students will acquire basic skills to deal with experimental data after such course. This ability to generate knowledge using experiments they could and should use later in subsequent courses. However, a number of pedagogical researches revealed that most students do not master the necessary skills. As one possible way to solve this problem, the course "Search for Physics Laws" was developed. This course is based on the theory of the gradual formation of mental actions and can be put into educational practice by using different laboratory equipment. Evaluation of the course showed that the organized in the new way laboratory sessions is more effective than traditional laboratory sessions. In this work, we consider in detail how students' understanding of the basic concepts of error analysis changes over the course.

Keywords: *systematic construction of mental actions, laboratory course, analysis of experimental data, physics law*

1. Introduction

The course "Search for Physics Laws" [1-2] started in 2017 as an introductory laboratory physics course for first-year engineering students at the National University "Zaporizhzhia Polytechnic". Using the theory of the gradual formation of mental actions the set of 12 laboratory works was sorted out, adapted, and put into practice in the order that allows to teach students the basics of data analysis gradually, from the relatively simple procedures (as estimation uncertainties in repeatable measurements) to more complicated (as using some ideas of data mining).

This course was developed as an attempt to solve one of well-known teaching problems: first-year students have significant difficulties with analyzing experimental data [3-5]. The main meaningful lines of this course are: 1) experiments were generally arranged from mechanics to thermodynamics and electrodynamics, in the same order these topics are studied in the lecture course; 2) we taught students the graphical method of data analysis that gives an intuitive understanding of an experimental situation; 3) laboratory works were adopted in a way that allows students to learn about different types of experimental uncertainties slowly, step by step; 4) chosen experiments also allowed us to show students how to apply some general methods of research such as dimensional analysis, extrapolation, interpolation, modelling, and testing a hypothesis.

The first part of the course was evaluated and results [6] showed that the organized in the new way laboratory sessions have been significantly more successful in improving students' basic skills of data analysis than traditional laboratory sessions.

In this paper, we present findings obtained over the next five years of teaching this course. Unfortunately, over these years, it was impossible to deliver the course in the same way and gather the information about students' performance. In 2020 due to COVID-2019, we switched to online mode and although we did not change the content of the course, the new organization of the educational process could not but affect students' results. In 2022 due to Russian aggression, part of the findings became inaccessible. Nevertheless, even available data give us necessary information about the effectiveness of the course and the peculiarities of the learning process.

2. Stability of students' results in the course over time

In this section, we answer the questions about the stability of students' results in the course over time. To check whether the results obtained earlier [6] were not coincidental, the research was continued for the next two years.

2.1 Participants and data collection

The study was conducted in 2018 and 2019 academic years with 136 first-year undergraduate students followed 4 year BSc programmes in Engineering at the National University "Zaporizhzhia Polytechnic". For the evaluation of students' results the same written questionnaire (as in 2017) was used [6].

2.2 Analysis and discussion

To evaluate the stability of students' results in the new course we compared them with the results obtained earlier, in 2017 for the control and experimental groups [6]. Results are presented in Figure 1 and Table 1.

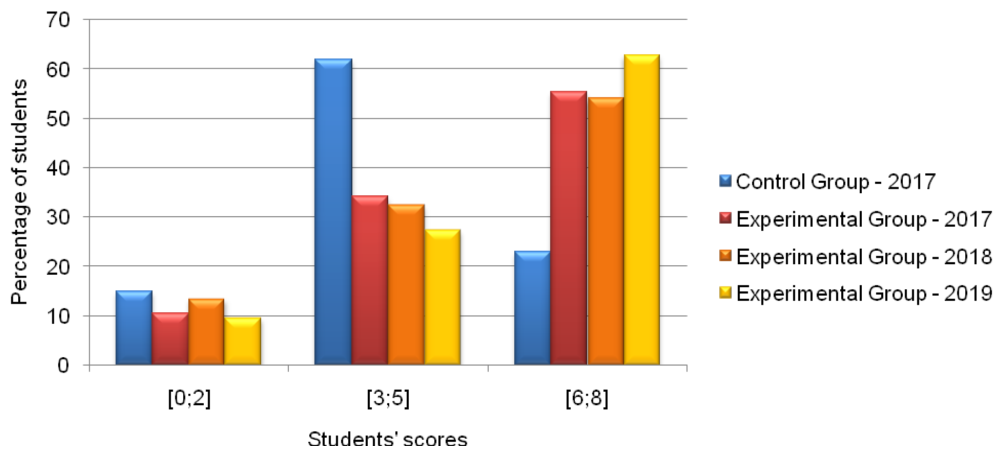

Figure 1. Effectiveness of the new course over three years

For each of the three experimental groups and the control group, chi-squared calculations result in values 50.304 (Cramer's effect size $V = 0.42$), 41.571 ($V = 0.39$), and 56.051 ($V = 0.48$) respectively (df 2, $p < 0.0001$). By conventional criteria, such differences are considered to be extremely statistically significant.

Table 1. Students' results of questionnaire

Groups	Number of students who obtained scores		
	from 0 to 2	from 3 to 5	from 6 to 8
Control group - 2017 (after a traditional course, *N* = 61)	9 (15%)	38 (62%)	14 (23%)
Experimental group - 2017 (after the new course, *N* = 85)	9 (11%)	29 (34%)	47 (55%)
Experimental group - 2018 (after the new course, *N* = 74)	10 (14%)	24 (32%)	40 (54%)
Experimental group - 2019 (after the new course, *N* = 62)	6 (10%)	17 (27%)	39 (63%)

Chi-squared calculations for each of the three experimental groups between each other result in the following values: 0.491 (df 2, $p = 0.7825$, $V = 0.04$) for the groups in 2017 and 2018; 1.592 (df 2, $p = 0.4510$, $V = 0.07$) for the groups in 2017 and 2019; 2.144 (df 2, $p = 0.3423$, $V = 0.09$) for the groups in 2018 and 2019. Such differences are considered to be not statistically significant.

These findings show that obtained in 2017 results were not coincidental and the introductory laboratory course "Search for Physics Laws" does provide students with basic skills of data analysis more successfully than traditional laboratory sessions.

3. Students' understanding changes over the course

In this section, we present and discuss some results obtained in 2021-2023 during online teaching. The content of the course was not changed but instead of working with real equipment students had to use photos, videos, and simulations. At the beginning of each laboratory session, an instructor (via Zoom) discussed briefly with students the relevant background information and introduced the next idea of data analysis. Over the next two weeks after the session, students had to download their reports and pass the short quiz (3-5 items) about the corresponding method of data analysis. These quizzes and the final quiz at the end of the course allowed us to gather information about the process of changing students understanding of the basic concepts of data analysis.

3.1. Study design

During four semesters 2021-2023, we gathered data on the next generation of first-year undergraduate students followed 4 year BSc programmes in Engineering. In the present work, we focus on the six most difficult for students quiz questions (see Table 2).

Table 2. Students' performance on the most difficult quiz questions

Question	Question description	Post-lab quiz	Final quiz (N = 76)
1.2	Rounding the experimental result: height = 5.032±0.04329 (m).	36 of 72 (50%)	64 (84%)
2.3	Determining the fractional uncertainty of the certain data point using the graph which shows an error bar through each data point.	35 of 63 (56%)	62 (82%)
2.5	Determining the confidence interval in repeatable measurements. Equation for the absolute uncertainty was given.	30 of 63 (48%)	45 (59%)
5.1	Determining parameters b and x_0 in the equations $y = kx + b$ and $y = k(x + x_0)$ using a graph	16 of 46 (35%)	53 (70%)
5.2	Determining the confidence interval for x-intercept using the experimental graph	32 of 68 (47%)	44 (58%)
5.3	Determining confidence interval for y-intercept using the experimental graph	27 of 68 (40%)	43 (57%)

3.2 Results and discussion

As can be seen from Table 2, on three questions we found a great difference between the post-lab and final quizzes.
Even after explanations and short training in the first session, only half of the students were able to apply the rules and complete the task correctly (question 1.2). In the final quiz students' performance was much better, since students had to round obtained results in every laboratory work.
In the second laboratory work, we discussed different types of uncertainties in physics experiments, especially the instrumental uncertainties. Question 2.3 had a surprisingly low number of correct responses. It would be logical to assume that students had difficulties with even more basic knowledge. For example, they could have not known how to find the mean value and the absolute uncertainty using the graph and error bars or how the fractional uncertainty is connected to the mean value and the absolute uncertainty. However, students' responses to other questions showed that it was not the case. After discussing with students we concluded that the main difficulty was to combine these more basic pieces of knowledge. At the end of the course, the situation became significantly better.
Question 5.1 asks for reading the parameters of a straight line from the graph. The most frequent incorrect answer students gave was conditioned by confusion between the x-intercept and parameter x_0 in the equation $y = k(x + x_0)$.
For the other three questions from Table 2, we do not see a significant increase in the correct responses in the final test.

It could be expected that after being given explanations and some experience in calculating confidence intervals while preparing two reports majority of students would answer the question 2.5 correctly, especially considering that the equation for calculating the absolute uncertainty was given in the text of the question as a hint. However, analysis of wrong answers showed that a lot of students forgot about the square root.
The last two questions (questions 5.2 and 5.3) were aimed to check if students understood the graphical method of finding confidence intervals for intercepts. The most frequent mistake students made was not taking into account that the width of the confidence interval depends on the total number of measurements although it was explained during the session.

4. Conclusions

In this study, we presented new results about the introductory laboratory course “Search for Physics Laws”. While the laboratory works themselves are mostly typical for undergraduate courses, the new organisational structure provides an opportunity to improve students’ understanding of the basic concepts of data analysis. We examined the effectiveness of the course with 221 students over three years and found a significant positive effect on students’ knowledge.
Subsequent development of the course allowed us to identify the most challenging for first-year students basic concepts and procedures. We believe that these findings reveal something important about the nature of students’ understanding of these concepts and could be used by other researchers during developing laboratory, data analysis, and statistics courses.
There are three major limitations in the presented work. First, only one control group, from 2017 was used. Second, students’ understanding changes were registered for the whole group, not individually for each student. And third, only the first part of the course was evaluated.
In future studies, we would like to addressed this limitations and extend this work to the second, more complicated part of the course.

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