Hands-on experiments in the interactive physics laboratory: A study of students’ intrinsic motivation

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Abstract. Experiments in different forms can be suitable tools how to increase students’ interest in physics. However, educators discuss which ways of experimenting are the most beneficial for these purposes. At our department, two different forms of physics experiments are offered to upper secondary students – students’ hands-on experimental work and physics demonstration shows where the students watch experiments conducted by a lecturer. Our research aims primarily at students’ feedback about their immediate attitudes towards the hands-on experimenting and differences in perception of this experimenting and watching the lecture demonstrations. For collecting data we used a questionnaire based on Intrinsic Motivation Inventory.

1. Introduction
Physics belongs to science school subjects that are evaluated as the least favourite, the most difficult and the most boring by upper secondary school students probably all over the world. The decline of students’ interest in and popularity of physics over the period of secondary education concerns many science educators and researchers [1, 2]. For this reason, the researchers are focusing on finding ways how physics might be made more attractive for students, e.g. [3], and physics experiments naturally play an important role in this effort. At our faculty, we offer students and their teachers two long-term activities directly related to experimenting.

The Interactive Physics Laboratory (IPL) established by the Faculty of Mathematics and Physics of Charles University provides upper secondary school students a space for conducting physics experiments in the form of structured inquiry [4]. The main goal of the laboratory is to allow its visitors to grasp physics with their own hands, both in the literal and the metaphorical sense. Students are led to maximal autonomy, therefore they perform all activities independently, including preparing measurements, recording data or evaluating them.

The permanently increasing interest of upper secondary school teachers and their students became a motivation to start a research on how the visit of the laboratory influences the students. As our department offers physics demonstrations (DEMOS) for upper secondary students, we also decided to compare students’ feedback about their immediate attitudes to the hands-on activity with their attitudes towards watching DEMOS.
2. Description of both physics projects

2.1. The Interactive Physics Laboratory

The IPL was put into regular operation in 2012 and since that time, the number of visitors has been continuously growing up to the present, when more than 800 students go through the laboratory every year.

In groups of three or four, the students spent a total of 120 minutes in the laboratory (see figure 1). They work on experiments that together create an experimental set focused on a particular physics topic. These days, the IPL offers nine experimental sets (see table 1), each of which consists of four to six experimental units. At the end of the IPL visit, each workgroup describes one of the experimental units in a presentation lasting several minutes, including major findings and results.

| Experimental sets in the IPL | Experimental sets in the IPL |
|------------------------------|------------------------------|
| Electrostatics               | Quantum effects in the microworld |
| Motions under gravity        | Rotating frames of reference |
| Magnetic field of solenoids  | Thermodynamics I – quantitative approach |
| Optics                       | Thermodynamics II – qualitative approach |
| Oscillations and rigid body mechanics | |

Every unit has its own worksheet, which guides the students throughout the experiments. It is also given to the students to record their results. During the entire time of their visit, students can consult with lecturers regarding the steps of the experiments. The lecturers are undergraduates or postgraduates or younger employees of the Department of Physics Education. In conjunction with the students’ own teachers, the role of the lecturers in the IPL is only to provide support.

2.2. Physics demonstrations

The DEMOS have a tradition of almost three decades at the Faculty of Mathematics and Physics, Charles University. During the whole academic year, one day a week is dedicated to this experimental show for upper secondary students. The students visit the lecture hall with their teachers in groups of up to 90 persons (see figure 2). Each performance takes 75 minutes and it is repeated three times in a row, which means that around 5 000 students visit the DEMOS every year.

At present, seven physics topics are offered to choose from (see table 2). The shows are overseen and executed by employees of the department of Physics Education.
Table 2. Topics offered for DEMOS (January 2019).

| Physics topics for DEMOS |
|--------------------------|
| Acoustics                | Mechanics          |
| Electricity and magnetism| Optics             |
| Electromagnetic radiation| Thermodynamics     |
| Ionizing radiation       |                    |

Figure 2. Physics demonstrations at Faculty of Mathematics and Physics.

3. Research purpose and research questions
While the literature search shows that the researchers are still searching for suitable instructional strategies supporting students’ situational interest, we decided to deal primarily with students’ intrinsic motivation and related attitudes towards practical work in the IPL. We were naturally interested in the most positively/negatively perceived aspects of experimental work in the IPL concerning students’ attitudes/motivation. We also decided to compare students’ feedback about their immediate attitudes to the hands-on activities in the IPL with their attitudes to watching physics DEMOS where the experiments are conducted by a lecturer. The two main simple questions we tried to answer in our study were:
1) Is there any statistically significant difference in the way, how the practical work in the IPL is perceived by girls and boys?
2) Is there any difference in the way, how the experimenting in the IPL is perceived in comparison with perceiving DEMOS?

4. Methodology

4.1. Research design and tool
To investigate students’ intrinsic motivation, a qualitative approach was used. The research plan was an ex-post-facto study with the data being collected using a standardized questionnaire.

In the research, the Intrinsic Motivation Inventory (IMI) [5] was used as a research tool. This multidimensional measurement device is based on the Self-Determination Theory and its primary goal is “to assess participants’ subjective experience related to intrinsic motivation and self-regulation”.

The original IMI contains seven scales: interest/enjoyment, perceived competence, effort/importance, felt pressure/tension, perceived choice, value/usefulness and relatedness. McAuley, Duncan and Tammen [6] demonstrated the high validity of the IMI scales (with the exception of the last one, which
was added later) and later studies suggest that the exclusion of any scale does not influence the results in the others, nor does the order of items in a particular scale.

For the purpose of the research, five scales (four for DEMOS) were used (see table 2). The IMI was used in the form of paper-and-pencil questionnaire. The students were asked to fill in the IMI and several complementary questions immediately after the end of the experimenting. They should assess every item on a seven-point Likert scale ranging from “This claim is very true for me” to “This claim is not at all true for me”. In our study, we emphasise the problem of the usefulness of practical work in the laboratory, which is why the scale value/usefulness is represented by more items than any other.

4.2. Sample selection
Data collection took place from April to October 2017. Together, data from more than 1000 upper secondary school students at the age from 15 to 19 was collected. In the IPL, the sample is made up of 303 visitors (145 girls and 158 boys); in DEMOS it includes 819 visitors (412 girls and 407 boys).

The sample is represented by those students who have visited the IPL or the DEMOS by the decision of their teachers. From this point of view, the selective effect must be taken into account, so this sample couldn’t be considered representative. Moreover, another strong effect is determined by the fact that both projects are situated in the capital, and visiting students live mostly in the capital or its immediate surroundings.

5. Results
For each IMI item, elementary statistics were calculated, including average score, standard deviation and variance. Subsequently, the score for each IMI scale was calculated by averaging scores across all of the items on that scale. Gender-separated data were analysed in the same way and compared using a two-sample t-test. Similar t-test-based comparison was made for data obtained in the IPL and in DEMOS.

5.1. General and gender-separated data
The basic data for particular IMI scales is summarised in table 3. As explained above, the students assessed every item on a seven-point Likert scale ranging from “This claim is very true for me” (scored by 1) to “This claim is not at all true for me” (scored by 7). For this reason, the higher scores in the following tables correspond to stronger student feeling of the measured quality (interest, effort, pressure, etc.). In terms of test reliability, both of the IMI questionnaires administered (IPL and DEMOS) exhibit a Cronbach alpha higher than 0.85 [7].

| Scale              | Average Score | Average Score |           |           |
|--------------------|---------------|---------------|-----------|-----------|
|                    | Girls         | Boys          |           |           |
| **IPL**            |               |               |           |           |
| Interest/Enjoyment | 2.46          | 2.43          | 2.48      |           |
| Perceived Competence| 2.83          | 3.02          | 2.68      |           |
| Effort/Importance | 3.33          | 3.27          | 3.40      |           |
| Pressure/Tension  | 5.55          | 5.57          | 5.54      |           |
| Value/Usefulness  | 2.42          | 2.40          | 2.45      |           |
| **DEMOS**          |               |               |           |           |
| Interest/Enjoyment | 2.33          | 2.39          | 2.28      |           |
| Effort/Importance | 3.90          | 4.02          | 3.79      |           |
| Pressure/Tension  | 5.66          | 5.76          | 5.57      |           |
| Value/Usefulness  | 2.49          | 2.43          | 2.54      |           |

Table 3. Basic data obtained by the IMI questionnaire.
5.2. Item analysis
To get deeper insight, we analysed all IMI items we used and compared data from IPL with data obtained in DEMOS. The Table 4 shows those items, where the difference between IPL and DEMOS score was statistically significant at $p < 0.005$.

Table 4. Statistically significant differences in particular items.

| Scales and Items                        | Score IPL | Score DEMOS |
|-----------------------------------------|-----------|-------------|
| **Effort/Importance**                   |           |             |
| I didn't try very hard to do well at this activity. | 2.54      | 3.59        |
| I tried very hard on this activity.     | 3.32      | 4.10        |
| I put a lot of effort into this.        | 3.89      | 4.24        |
| **Pressure/Tension**                    |           |             |
| I felt pressured while doing these.     | 5.97      | 6.26        |
| I was very relaxed in doing these.      | 5.11      | 5.39        |
| I felt very tense while doing this activity. | 5.27      | 4.84        |
| **Value/Usefulness**                    |           |             |
| I think doing this activity is useful for gaining manual skills. | 3.09      | 3.62        |

6. Discussion

6.1. Gender differences
Generally, the differences between boys and girls are only minor, which does not confirm our original hypothesis that girls will be probably more critical of practical work in the IPL; the same conclusion can be reached regarding watching DEMOS. At level $p < 0.02$, we registered only one dimension, perceived competence, with a statistically significant difference in gender comparison. This means that, while experimenting in the IPL, boys feel more competent and satisfied, and are probably more self-confident when assessing their own ability to perform well. What is remarkable, however, is the perception of effort/importance when comparing the IPL and DEMOS. While girls assess experimenting in the laboratory as requiring more effort in comparison with boys, for DEMOS the situation is exactly opposite: girls feel less effort is required (with low significance $p < 0.1$).

6.2. Comparison of the IPL and DEMOS
According to our data, students find both experimenting in the IPL and watching experiments during DEMOS quite interesting and useful – on scales interest/enjoyment and value/usefulness both these activities reached average score below 2.5. The differences between IPL and DEMOS scores are in these two scales statistically insignificant, which is true not only for the whole scales, but even for almost all of their items. Expectably, the exception is the item referring to manual skills (see table 4).

Concerning the scale effort/importance, three out of four its items show at $p < 0.005$ higher effort required in IPL in comparison with DEMOS watching. The absolute average scores move around 4.0 for DEMOS, for IPL around 3.3. – this could denote that students give both activities quite appropriate, but not extremely high effort.

The only scale which shows the average scores higher than the mean value of 4.0 is the scale felt pressure/tension. According to the results, DEMOS are for students less stressful in comparison with the laboratory work, which is not surprising if we consider that watching DEMOS (contrary to IPL) does not require students to show up any physics knowledge. Only the statement “I felt very tense while doing this activity” shows an anomaly – its score is lower in DEMOS than in IPL. We hypothesize this could arise from two possible meanings of this item – while some students could interpret tension as a negative manifestation of stress, for others it could be a pleasant, exciting feeling of expecting something unusual.
7. Conclusions
The paper describes a quantitative study dealing with students’ intrinsic motivation and related attitudes towards practical work in the Interactive Physics Laboratory on one side and towards physics demonstrations on the other side. The research was conducted from spring to autumn 2017 using a translated and modified IMI questionnaire. Data from more than 1000 respondents was collected.

According to basic data analysis we have done, gender differences appear to be insignificant with an exception of perceived competence scale (which was administered only in the IPL) where boys declare stronger feeling of competency and self-confidence when they independently experimented.

In comparison with DEMOS, the assessment of the IPL does not exhibit significant differences on interest/enjoyment and value/usefulness scales. However, during their own experimenting in the IPL, respondents felt the need of higher effort and experienced more tension. In other words, according our data students do not see the difference in usefulness of practical work and watching demonstrations, but they find the first to be more demanding and stressful.

The more detailed analysis of data obtained in this research was published in 2018 in [8]. However, feeling the potential of this research topic, we have decided to continue with data collection for one more year. We slightly modified two IMI items and especially we extended the metadata we require from students to study if there are some specific groups of students for whom IPL experiments or DEMOS are more beneficial than for other students. With this updated IMI version, we collected data from 5000 students (DEMOS), resp. 1000 students (IPL) to prepare more sophisticated statistics and comparison. This data is presently under statistical processing.

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9. References
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