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Hands-On Experiments in the Interactive Physics Laboratory: Students' Intrinsic Motivation and Understanding

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Experiments in different forms can certainly be suitable tools for increasing student interest in physics. However, educators continuously discuss which forms of experimenting (if any) are the most beneficial for these purposes. At the Faculty of Mathematics and Physics, Charles University, Prague, two different forms of physics experiments are offered to upper secondary students: hands-on experimental work in the Interactive Physics Laboratory, and physics demonstration shows where the students watch experiments conducted by a lecturer. Our research focuses primarily on student feedback about their immediate attitudes towards these two projects. Data collection was undertaken using questionnaire research based on the Intrinsic Motivation Inventory. This research was subsequently supplemented with a qualitative study examining the influence of students' experimental work in the Interactive Physics Laboratory on their understanding of selected physics concepts. The results of the main research show that the two projects do not exhibit significant differences in terms of student interest and perceived usefulness; nevertheless, students felt the need for significantly more effort and experienced pressure during their work in the Interactive Physics Laboratory. One interesting finding, which goes against our original hypothesis, is that grades in physics are quite a strong predictor of students' assessment of the projects: better grades indicate more positive assessment of both projects as well as less pressure felt during hands-on activities in the laboratory.

Keywords: laboratory activities, upper secondary school students, intrinsic motivation, optics concepts, physics demonstrations

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Preprosti poskusi v interaktivnem fizikalnem laboratoriju: dijakova notranja motivacija in razumevanje

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Poskusi v različnih oblikah so gotovo lahko primerno orodje za povečevanje zanimanja dijakov za fiziko, vendar učitelji kontinuirano razpravljajo, katere oblike poskusov (če katere) najbolj prispevajo k temu. Na Fakulteti za matematiko in fiziko Karlove univerze v Pragi ponujajo dijakom dve različni obliki fizikalnih poskusov: preproste poskuse v okviru interaktivnega fizikalnega laboratorija in demonstracijske fizikalne poskuse, v okviru katerih dijaki opazujejo poskuse, ki jih izvaja učitelj. Naša raziskava se primarno osredinja na povratne informacije dijakov o njihovih izkušnjah o teh oblikah. Zbiranje podatkov je potekalo z uporabo vprašalnika, ki je temeljil na vprašalniku The Intrinsic Motivation Inventory. Raziskava je bila posledično dopolnjena s kvalitativno študijo, ki je preučevala vpliv eksperimentalnega dela v interaktivnem fizikalnem laboratoriju na dijakovo razumevanje izbranih fizikalnih konceptov. Rezultati glavnega dela raziskave kažejo, da obe obliki ne kažeta pomembnih razlik v smislu zanimanja in dojemanja uporabnosti, vendar so dijaki občutili potrebo po znatno več truda in izkusili pritisk med njihovim delom v interaktivnem fizikalnem laboratoriju. Ena izmed zanimivih ugotovitev, ki je v nasprotju z našo prvotno hipotezo, je, da so ocene pri fiziki precej močen napovedovalec dijakovega vrednotenja omenjenih oblik: boljše ocene kažejo na pozitivnejše vrednotenje obeh oblik pa tudi manj pritiska, ki so ga občutili med preprostimi poskusi v laboratoriju.

Ključne besede: laboratorijske aktivnosti, dijaki, notranja motivacija, koncepti optike, fizikalni demonstracijski poskusi

Introduction

Physics (together with chemistry and mathematics) is among the school science subjects that are evaluated as the least favourite by upper secondary school students in the Czech Republic (Höfer, Půlpán, & Svoboda, 2005). However, this problem is not only the domain of the Czech Republic, but is widespread throughout the world. It is commonly stated that many upper secondary school students view physics as a difficult and boring subject (Veloo, Nor, & Khalid, 2015; Wong & Bakar, 2009). In order to show students the "beauty" of physics, science centres are being established across Europe and many physics faculties offer various out-of-school activities to students (physics demonstrations, shows, hands-on experimentation, interest groups, etc.).

The decline of student interest in and popularity of science, or more precisely physics, over the period of secondary education is a major concern to many science educators and researchers (Holstermann, Grube, & Bögeholz, 2010; Jack & Lin, 2017; Potvin & Hasin, 2014). Researchers are therefore focusing on finding ways to make physics more attractive to students (e.g., Owen, 2008).

According to Palmer (2009), many students lack motivation, but motivation is "an essential pre-requisite and co-requisite for learning". In his research, Palmer focused on situational interest – temporary interest that arises spontaneously due to aspects of a specific situation – and its sources, as interest is an effective motivator that can positively influence learning and test results (Laukenmann et al., 2003; Schraw, Flowerday, & Lehman, 2001).

Experiments in different forms naturally permeate all levels of physics education from the beginning of science teaching, and they undoubtedly play an important role when trying to understand the world around us in depth. Therefore, they certainly represent a suitable tool for increasing student interest in (and understanding of) physics. However, educators continuously discuss which forms of experimenting (if any) are the most beneficial for these purposes. Essentially, two main ways of performing experiments arise from previous comparisons: physics demonstrations conducted by lecturers (i.e., activities that are passive for students), and students' own experimental work (active involvement). These approaches are present in varying degrees in all levels of inquiry.

Focusing on experiments and other instructional strategies and their immediate impact on students, it is clear that active involvement (e.g., hands-on activities, doing experiments) together with novelty and social involvement (e.g., group work) play a key role in supporting students' situational interest (e.g., Dohn, Madsen, & Malte, 2009; Palmer, 2009; Zahorik, 1996). Moreover, doing experiments and group work are not only liked by students, they are also considered useful (Owen, 2008). In comparison, passive activities are perceived more critically in terms of whether an activity is liked by students and how they view its usefulness.

As situational interest is an aspect of intrinsic motivation (Hidi & Harackiewicz, 2000), the aim of the present study was to explore students' perception of a learning activity that is used in our Interactive Physics Laboratory (IPL). The activity complies with the key elements for supporting students' situational interest: it is a hands-on activity with social involvement and it has a novel character for many students who attend the laboratory. It was also decided to compare student feedback about their immediate attitudes to the hands-on activity with their attitudes towards watching physics demonstrations (DEMOS) for upper secondary students. Questionnaire research based on the Intrinsic Motivation Inventory (n.d.) was used for data collection.

Although the main aim of the research was to explore the immediate impact of the two aforementioned projects on students, it was decided to execute an accompanying qualitative study examining the influence of students' experimenting in the IPL on their understanding of selected physics concepts.

As both research projects – the students' perception of learning activities and the influence of students' hands-on experimenting – are related to learning activities organised for upper secondary students by our department (the IPL and DEMOS), these activities are briefly described in the following section.

The Interactive Physics Laboratory

The Interactive Physics Laboratory was established by the Faculty of Mathematics and Physics of Charles University to provide upper secondary school students with a space for conducting physics experiments in the form of structured inquiry (Banchi & Bell, 2008). In groups of up to three or four, visiting students spend a total of 120 minutes in the laboratory, working on experimental units that together create an experimental set related to a particular physics topic. The IPL currently offers eight experimental sets (see Table 1), each of which consists of four to six units. The experiments contained in the units are mostly of a dual nature: they are either experiments that would be difficult to carry out in the classroom due to the amount of time required or equipment demands, or those that have the potential to strengthen students' conceptual understanding.

Table 1
Topics offered by the IPL (November 2017)

Electrostatics	Oscillations and rigid body mechanics
Motions under gravity	Rotating frames of reference
Magnetic field of solenoids	Thermodynamics I – quantitative approach
Optics	Thermodynamics II – qualitative approach

The main goal of the laboratory is to allow visitors to grasp physics with their own hands, both in the literal and the metaphorical sense. Students are given maximal autonomy: they perform all of the activities independently, including preparing measurements, and recording and evaluating data. Furthermore, at the end of each IPL visit, each workgroup describes one of the experimental units in a presentation lasting a few minutes, including major findings and results; the description should also be intelligible for workgroups that have not completed the unit being described (due to time constraints, in most cases students do not complete all the units of the experimental set.)

During the entire time of their visit, students can consult with lecturers regarding the steps of the experiment. The lecturers are normally students 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.

Every unit has its own worksheet, which is given to the students to record their results. After the session, the students can take this sheet with them, thus giving their teacher an opportunity to build on the experimenting in the IPL in his/her subsequent regular lessons.

Demonstrations for secondary school students

At our faculty, the project of physics demonstrations (DEMOS) has a tradition of more than a decade. During both semesters, one forenoon a week is dedicated to an experimental show for upper secondary students, who visit the lecture hall with their teachers in groups of up to 90 persons. Each performance takes 75 minutes and is repeated three times in a row, meaning that more than 250 students can watch the show in one day.

At present, seven different physics topics are offered for teachers to choose from (see Table 2). The shows are overseen and executed by employees of the Physics Education Department.

Table 2
Topics offered for DEMOS (November 2017)

Acoustics	Electricity and magnetism
Electromagnetic radiation	Ionizing radiation
Mechanics	Optics
Thermodynamics	

Research focus

The IPL was put into regular operation in 2012, and since that time the number of visitors has grown continuously to the present level of more than 800 students going through the laboratory every year. The increasing interest of upper secondary school teachers and their students was the motivation to initiate a study on how visiting the laboratory influences students. This intention naturally offers two main research branches: one focused on the students' attitudes/motivation towards the executed activity itself, and the other aimed at potential changes in their conceptual understanding.

Although the literature search (see *Introduction*) revealed that researchers are still searching for suitable instructional strategies to support students' situational interest, it was decided to deal primarily with this topic, so that the data obtained could provide relevant feedback concerning the overall functioning of the IPL. The main part of the present paper is therefore focused on student motivation towards practical work in the IPL and, from this point of view, comparison with lecture demonstrations. The following text is based on this research and on our second, minor qualitative study, which focused on students' explanations of optics concepts. This is described at the end of the paper, in the subchapter *Does experimenting in the IPL influence the understanding of concepts in physics?*

Research questions

At the beginning of the study, the following research questions Q1–Q3 were stated, complemented with hypotheses H1–H3:

Q1: *Is there any statistically significant difference in the way practical work in the IPL is perceived by girls and boys?*

H1: According to our personal experience, we hypothesised that girls were more critical than boys.

Q2: *Is there any difference in the way experimenting in the IPL is perceived in comparison with perceptions of DEMOS?*

H2: We expected that experimenting in the IPL would be found to be more demanding by students, but more useful for them.

Q3: Is there any correlation between students' intrinsic motivation towards activities in the IPL and their grade in physics?

H3: We did not expect such a correlation.

In addition to these questions, we were naturally interested in which aspects of experimental work in the IPL were the most positively/negatively perceived in terms of students' attitudes/motivation.

Methodology

General research background

From a methodological point of view, a quantitative approach was used when trying to answer the research questions. The research plan was an ex-post-facto study, with the data being collected using a standardised questionnaire.

Sample selection

The study focused on upper secondary school students taking physics courses as part of their general education programme. The sample was made up of students who had visited the IPL or DEMOS on the discretion of their teachers. From this point of view, a selective effect must be taken into account, so the sample cannot be considered representative, e.g., it could be suggested that teachers bringing their students to the IPL or DEMOS are more engaged and active in looking for attractive teaching approaches, so their students could be accustomed to a "high level" of teaching.

Moreover, another strong effect is determined by the fact that both projects are situated in the Czech capital Prague, and visiting students live mostly in the capital or its immediate surroundings.

Data was collected from a total of 1,122 upper secondary school students aged from 15 to 19. In the IPL, the sample is made up of 303 visitors (145 girls and 158 boys), whereas in DEMOS it includes 819 visitors (412 girls and 407 boys).

Research tool

The Intrinsic Motivation Inventory (n.d.) 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 activities performed in laboratory experiments. In both the original and a modified version, the Intrinsic Motivation Inventory (IMI) has been repeatedly used in many previous studies (Deci, Eghrari, Patrick, & Leone, 1994; Leng, Wan Ali, Baki, & Mahmud, 2010; Monteiro, Mata, & Peixoto, 2015; Plant & Ryan, 1985; Ryan, 1982; Ryan, Mims, & Koestner, 1983). The use of this tool far exceeds the limits of education: for instance, psychologists use the IMI with business employees, children, athletes, people with mental illnesses, etc.

In the original IMI, students express their intrinsic motivation towards the studied activity on seven subscales: *interest/enjoyment*, *perceived competence*, *effort/importance*, *felt pressure/tension*, *perceived choice*, *value/usefulness* and *relatedness*. To be precise, only the first scale measures the intrinsic motivation itself, while the others either serve as positive/negative predictors for intrinsic motivation or express other motivational aspects of the participants' attitude towards the assessed activity.

McAuley, Duncan and Tammen (1987) 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.

The full-length IMI consists of 45 items and was translated into Czech in 2012. For the purposes of our research, we used 23 items (19 for DEMOS); we decided to entirely exclude the scales *perceived choice* and *relatedness*, as they are irrelevant to our conditions. In addition, the scale *perceived competence* was excluded from the DEMOS research. The students should assess every item on a seven-point Likert scale ranging from *this claim is not at all true for me* (scored by 1) to *this claim is very true for me* (scored by 7). 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.

Procedure

The study was designed so as to administer the IMI in the form of a paper-and-pencil questionnaire immediately after the assessed activity: experimental work in the IPL, or watching experiments in DEMOS. Before they left the laboratory or the lecture hall, students were given time to fill in the IMI, supplemented with a few personal questions (gender, age, year, grade in physics). Most of the students completed this task within five minutes, but there was no upper time limit for completing the questionnaire.

While the students were completing the IMI, the lecturers always left the room where the students were sitting, in order to exclude any influence of the lecturers' physical presence on the participants' decisions.

Data collection in the IPL took place from April to October 2017. During this time, a total of 303 students from 25 workgroups and 12 different upper secondary schools were involved in the study. Collecting data during the DEMOS project took place from May to October 2017, during which 12 different thematic shows took place and 819 students from 16 schools were engaged in the research.

Data analysis

For each IMI item, elementary statistics were calculated, including average score, standard deviation and variance; to calculate the final score for reverse items, the average value obtained was subtracted from 8. 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.

Results

General and gender-separated data

As mentioned above, data from more than 1,100 respondents was collected and subsequently processed by statistical methods.

The basic data for particular IMI scales is summarised in Table 3. The correlations of the scales are shown in Table 4 (for IPL data) and Table 5 (for DEMOS data).

As explained above, the respondents assessed every item on a seven-point Likert scale ranging from *this claim is not at all true for me* (scored by 1) to *this claim is very true for me* (scored by 7), i.e., the higher scores in the following tables correspond to stronger student feeling on the measured scale.

Table 3
Basic data obtained by the IMI questionnaire

scale	average score	SD	var	average score		*p*-value
				Girls	Boys	
data from the IPL						
interest / enjoyment	**5.54**	*1.52*	*2.30*	**5.47**	**5.52**	.704
perceived competence	**5.17**	*1.56*	*2.44*	**4.98**	**5.32**	.016
effort / importance	**4.67**	*1.65*	*2.73*	**4.73**	**4.60**	.319
felt pressure / tension	**2.45**	*1.56*	*2.42*	**2.43**	**2.42**	.942
value / usefulness	**5.58**	*1.48*	*2.20*	**5.60**	**5.54**	.672

scale	average score	SD	var	average score		p-value
				Girls	Boys	
data from DEMOS						
interest / enjoyment	**5.67**	*1.17*	*1.37*	**5.61**	**5.72**	.154
effort / importance	**4.10**	*1.28*	*1.64*	**3.98**	**4.21**	.063
felt pressure / tension	**2.34**	*1.04*	*1.07*	**2.24**	**2.43**	.063
value / usefulness	**5.51**	*1.00*	*1.00*	**5.57**	**5.46**	.117

Note. From left to right, the columns show: average scale score, standard deviation, variance, and the comparison between boys' and girls' average scores, complemented by the *p*-value arising from the *t*-test for the two independent samples. The higher the score, the stronger the students' feeling of measured quality (interest, effort, pressure, etc.).

Table 4

The Pearson correlation table for the IMI scales resulting from the IPL data

perceived competence	.53			
effort / importance	.67	.42		
felt pressure / tension	-.24	-.42	-.07	
value / usefulness	.72	.49	.58	-.21
	interest/ enjoyment	perceived competence	effort/ importance	felt pressure/ tension

Table 5

The Pearson correlation table for the IMI scales resulting from the DEMOS data

effort / importance	.59		
felt pressure / tension	-.03	.13	
value / usefulness	.70	.47	-.09
	interest/enjoyment	effort/importance	felt pressure/tension

In terms of test reliability, both of the IMI questionnaires administered (IPL and DEMOS) exhibit a Cronbach alpha higher than 0.85 (Cronbach, 1951).

Correlation with grades (IPL only)

In the Czech school system, upper secondary school students are graded in particular subjects with marks from 1 to 5, where 1 is the best assessment and 5 the worst. While only a few students stated in the questionnaire that their last term grade in physics was 5, we excluded these responses from the following comparison and analysed the dependence of IMI scores on grades from 1 to 4.

Table 6 shows the Pearson correlation between the grade and the average scores in each scale for IPL visitors.

Table 6
Correlation between grades and IMI scores

half-year grade in physics	interest/ enjoyment	perceived competence	effort/ importance	felt pressure/ tension	value/ usefulness
1	5.65	5.59	4.79	2.31	5.65
2	5.48	5.05	4.59	2.38	5.63
3	5.44	5.12	4.67	2.51	5.60
4	5.12	4.72	4.33	2.58	5.16
Pearson correl.	-.95	-.91	-.86	.99	-.83

Item analysis

For a deeper analysis, Table 7 contains the average score for every item, both in the IPL and DEMOS samples. The (R) stated at the end of some items identifies that these items were assigned in reverse, in order to verify that students had not chosen contradictory answers, which be could sign of a random strategy when completing the questionnaire.

Table 7 contains a generally used version of the IMI items. However, in the questionnaires we used, the phrases “this activity” or “this task” were replaced by “experimenting in the IPL” (in the case of the IPL) or “watching experiments” (in case of DEMOS), both complemented by minor, language-conditioned changes in word order.

Discussion

Gender differences

Generally, the differences between boys and girls are only minor in most of the scales investigated, and do not confirm hypothesis H3 that girls are 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 $p < 0.1$).

Comparison of the IPL and DEMOS

According to the data obtained in the research, students find both experimenting in the IPL and watching experiments during DEMOS quite interesting and useful: on the scales *interest/enjoyment* and *value/usefulness*, both activities achieved an average score over 5.5 (remembering that the mean value of the Likert scale used is 4.0). This is in contradiction with the researchers' claims that watching experiments is less liked by students than hands-on experimenting (see *Introduction*; Owen, 2008).

The differences between the IPL and DEMOS scores in these two scales are statistically insignificant, as are gender-conditioned differences; this is true not only for the entire scales, but for almost all of their items, as well. Expectedly and logically, the exception is item 14, which is focused on developing manual skills.

In the case of the two remaining scales (of a total of four that can be compared), statistically significant differences were identified. On the scale *effort/importance,* three out of four of its items show at $p < 0.005$ that greater effort is required by experimenting in the IPL than by watching DEMOS. The absolute average scores move around the scale mean of 4.0 for DEMOS, while for the IPL they move around slightly higher values. This could indicate that students devote appropriate effort to both activities, but not extreme effort.

Table 7

IMI items with the achieved scores for the IPL and for DEMOS

no.	scales + items	score IPL	score DEMOS	*p*-value
Interest / enjoyment		**5.49**	**5.67**	**-**
5	This activity did not hold my attention at all. (R)	*5.78*	*6.02*	*.009*
9	I thought this was a boring activity. (R)	*5.74*	*5.88*	*.197*
13	While I was doing this activity, I was thinking about how much I enjoyed it.	*4.85*	*4.98*	*.251*
15	I enjoyed doing this activity very much.	*5.60*	*5.78*	*.052*
Perceived competence		**5.16**	**-**	**-**
4	I was pretty skilled at this activity.	*5.28*	-	-
19	This was an activity that I could not do very well. (R)	*4.79*	-	-
21	I am satisfied with my performance at this task.	*5.36*	-	-
23	After working at this activity for a while, I felt pretty competent.	*5.18*	-	-
Effort / importance		**4.66**	**4.10**	**-**
3	I did not put much energy into this activity. (R)	*4.39*	*4.32*	*.505*
12	I did not try very hard to do well at this activity. (R)	*5.46*	*4.41*	*< 0.005*
17	I tried very hard in this activity.	*4.68*	*3.90*	*< 0.005*
20	I put a lot of effort into this activity.	*4.11*	*3.76*	*< 0.005*
Felt pressure / tension		**2.42**	**2.34**	**-**
2	I did not feel nervous at all while doing this activity. (R)	*2.05*	*1.86*	*0.022*
6	I felt very tense while doing this activity.	*2.73*	*3.16*	*< .005*
11	I felt pressured while doing this activity.	*2.03*	*1.74*	*< .005*
16	I was very relaxed in doing this activity. (R)	*2.89*	*2.61*	*< .005*
Value / usefulness		**5.57**	**5.51**	**-**
1	I think doing this activity could help me to understand physics concepts.	*5.95*	*6.07*	*.175*
7	I think this is an important activity.	*5.55*	*5.58*	*.939*
8	I think it is useful to do this activity because it can increase the attractiveness of physics.	*6.09*	*6.11*	*.878*
10	I think doing this activity could help me to handle physics at school.	*5.15*	*5.22*	*.603*
14	I think doing this activity is useful for gaining manual skills.	*4.91*	*4.38*	*< .005*
18	I would be willing to do this again because it has some value for me.	*5.55*	*5.30*	*.018*
22	I think experimenting in the IPL will be useless for me at school. (R)	*5.78*	*5.90*	*.240*

Note. The *p*-value was obtained by using a *t*-test for two independent samples. The null hypothesis expects that the particular item is assessed equally by both of the studied populations, and it is rejected at the level $p < .005$.

The only scale that shows average scores lower than the mean value of 4.0 is the scale *felt pressure/tension*. For items 2, 11 and 16, the gains for DEMOS are lower than for the IPL, and in the last two items this difference is statistically significant; according to this, DEMOS is less stressful for students than laboratory work, which is not surprising if we consider that watching DEMOS (unlike the IPL) does not require students to demonstrate any physics knowledge. Interesting results are offered by item 6, where students should assess the statement "*I felt very tense while doing this activity*"; unlike the other items of the scale, it shows a significantly higher score for DEMOS. We hypothesise that 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 it a pleasant, exciting feeling of expecting something unusual. In the latter case, such an interpretation could bring DEMOS a higher score, as the show intentionally works with expectations and excitement.

The correlation matrix shown in Tables 4 and 5 suggests that there are generally no strong correlations between any of the scales; the only remarkable Pearson coefficient (higher than 0.70) was identified between *interest/enjoyment* and *value/usefulness*. The effectively zero correlation between *effort/importance* and *felt pressure/tension* scales practically excludes the hypothesis that students who assessed both of the activities as non-stressful did so because they do not devote appropriate effort.

Grades

As Table 6 shows, better grades generally increase students' assessment in all of the scales, with an exception of the *pressure/tension* scale, which exhibits a strong correlation with grades. In other words, the worse the student's grade, the more pressure s/he felt during activities in the IPL.

Does experimenting in the IPL influence the understanding of concepts in physics?

As mentioned above, one of the experimental sets offered in the Interactive Physics Laboratory is focused on geometrical and wave optics. The experiments are divided into four units with the following topics: (1) *Reflection & refraction of light*; (2) *Total reflection*; (3) *Interference & diffraction* and (4) *Polarisation of light*. Although the students' visit to the laboratory is a one-time event, we decided to prepare a study in order to explore whether the IPL has an influence on secondary school students' understanding of selected concepts in optics.

The research described below is an accompanying qualitative study investigating the influence of students' hands-on experimenting in the IPL on their understanding of selected physics concepts. A qualitative research approach was chosen for the purposes of this study. A questionnaire with open-ended questions, in which students should describe the selected physics concepts, was prepared for data collection. The questionnaires were evaluated using content analysis of students' written answers, as assessed by three independent researchers.

Sample selection

The survey was carried out in spring 2017.

Two secondary school teachers who visited the Interactive Physics Laboratory with their students were asked to be involved in the survey. The participants were 46 students aged 16–17, most of whom (24 boys and 15 girls) attended the optical experimental set in the IPL in three different groups.

Description of the intervention

All of the students who visited the IPL within the framework of the research can be divided into two groups: one group completed units (1) and (2) with experiments from geometrical optics (22 participants: 13 boys and 9 girls), while the other group (17 participants: 11 boys and 6 girls) undertook wave optics experiments, i.e., units (3) and (4). Thanks to this division, during their visit to the IPL, every student encountered two of the physics concepts investigated in the prepared questionnaire. Thus, the answers of students who had encountered a particular physics concept in the IPL were compared with the answers of students who had not encountered that particular concept in the IPL, or with the answers of students who had not visited the laboratory at all.

Three weeks after their visit to the IPL, the students were asked to complete the prepared questionnaires. They were asked to describe, as precisely as possible, the following concepts:

(a) physical phenomena that occur in a water droplet when a rainbow is formed;

(b) the principle of working of an optical fibre and travel of a light ray through the optical fibre;

(c) what is observed on the screen during a double-slit experiment and why this happens;

(d) what happens with linearly polarised light as it passes through optically active solutions with different concentrations.

The students did not have any teaching aids at their disposal while completing the questionnaires.

All of the described concepts are commonly discussed during the optical experimental set in the IPL. Simultaneously with the execution of the survey, the students studied optics during their normal physics lessons at secondary school, as well (according to the curricula and the teachers' statements); they should therefore be familiar with all of the phenomena addressed in the questionnaire.

Results

In the first question, which focused on the formation of a rainbow, there were no differences observed between the students who had visited the corresponding unit in the IPL and the others. Nevertheless, it is very interesting that the students often mentioned dispersion and refraction of light to describe the origin of a rainbow, whereas reflection of light in the water droplet only rarely appeared in the students' answers. Furthermore, none of the students mentioned the double reflection of sunlight inside raindrops, which causes secondary rainbows.

The students who had taken unit (2), which focuses on total reflection, were more successful in answering the question about optical fibres. Their responses were more detailed, they used collocations that can be found in the worksheets for the IPL, they often mentioned "ideal case", and they described total reflection more precisely than the other students. The students also drew the picture of optical fibre that appeared in the worksheets, and their pictures were correctly drawn.

Examples of two answers of students who had taken the unit focused on total reflection:

- *"In order to be a total reflection, the light must not pass out through the walls of the fibre."*
- *"The light must not be seen when I look at the fibre, i.e., 100% of the light transmission comes out."*

The double split experiment was surprisingly well explained by both groups of students. Terms such as Young's experiment and interference figure, as well as appropriate pictures, appeared in both of the researched groups. Nevertheless, a better understanding of the concept can be found among students who had taken the corresponding experiments in the IPL. Their responses were more detailed, and there were only three students who had entirely incorrect explanations or no explanation of the physical phenomena (in the group that had not attended the unit focused on interference and diffraction, there were thirteen students without a correct explanation).

The last phenomenon, optical activity, was the most difficult for the students to describe. It is evident that both the students who had attended unit (4), which is focused on linear polarisation, and the students who had not taken it had considerable difficulties with the explanation of this physics concept. In our opinion, the main obstacle for the students was the difficulty of the topic. The students have problems even understanding the linear polarisation of light, which is hard for them to imagine.

An unexpected result emerged in the last question about optical activity, as well. In their answers, several students who had visited the IPL but had not attended the particular unit described an experiment involving bending a laser beam in a water tank with sugar (this experiment was part of unit (2) and describes the forming of mirages). Furthermore, the students' responses were often supplemented with an illustrative picture. In all probability, the reason for the confusion of these two experiments is caused by the formulation of the question, where the collocation "differently concentrated optical active solutions" is used. The students could connect this formulation with the fact that they need an environment with a gradient of refractive index to observe mirages, and this environment can be created by a sugar solution whose concentration is constantly changed from the bottom to the surface.

The study also identified the students' obstacles regarding terminology. The students often mistook the word "diffraction" for "dispersion", and vice versa. The phrase "refraction of light" is perceived by students in the sense of "any change of direction of the light ray", and therefore is often used as an alternative for "reflection".

Conclusions

In the main part of our paper, we describe a quantitative study dealing with students' intrinsic motivation and related attitudes towards practical work in the Interactive Physics Laboratory, on the one hand, and towards physics demonstrations, on the other. The research was conducted from spring to autumn 2017.

Using a translated and slightly modified IMI questionnaire, we obtained data from more than 1,000 respondents, with a similar number of girls and boys. Gender differences appeared to be only minor, with the exception of the *perceived competence* scale (administered only in the IPL), where boys state stronger feelings of competency and self-confidence when experimenting independently. In general, hypothesis H1, which assumed that girls would be more critical, can be rejected not only for the IPL, but also for DEMOS.

In comparison with DEMOS, the assessment of the IPL does not exhibit significant differences with regard to *interest/enjoyment* and *value/usefulness*. On the other hand, while experimenting in the IPL, students feel the need to invest significantly more *effort* and experienced a higher level of *tension*. Therefore, hypothesis H2 can be rejected only partially: the students in the study do not see a difference between the usefulness of practical work and watching demonstrations, but they do find the former to be more demanding. The question remains as to whether (and how) the *real*, not only perceived, usefulness of experimenting during DEMOS and in the IPL differs. In connection with this question, we sought to determine what students remember from the experiments they watched during DEMOS and from the experiments they undertook in the IPL.

Contrary to hypothesis H3, grades in physics appeared to be quite good predictors of IMI scores, while averages in particular scales correlate relatively with students grades: better grades are an indicator for more positive IMI assessment.

The research presented opens opportunities for follow-up investigation in the field of student motivation towards different forms of experimenting. We now intend to conduct more extensive research investigating how students' attitudes towards different forms of experimenting correlate with their attitudes towards physics, and to determine the motivation of teachers to bring their students to the IPL and DEMOS.

From the results of the present qualitative, understanding-oriented study, we can formulate the hypothesis that students' experimenting in the IPL has an impact on achieving better understanding of demonstrated physics concepts. However, it is necessary to take into account the difficulty of the given phenomena and the emphasis placed on the students' understanding of the phenomena in their regular physics lessons.

It would be appropriate to build on this study with quantitative research that would clearly confirm or disprove our hypothesis in the future. At the same time, we would like to prepare a similar study for some of the other physics topics that the IPL offers.

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