

## Stimulating the Cognitive Activity of Students while Conducting Experimental Work

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### Abstract

One of the most effective ways to shape knowledge and skills is conducting experimental work. An experimental test is reproducible under specified conditions any amount of times and always brings identical result. Conducting a laboratory practicum, we can set numerous goals, that would allow to significantly enlarge the boundaries of knowledge, to essentially enrich and diversify the learning process. Good results are obtained by the combination of classical forms of education with modern computer technologies. Creating a virtual educational environment, using multimedia means of teaching, we can achieve significant results, while also solving the tasks of developing the students' intellectual abilities. As a rule, the method of learning to acquire certain information, commonly employed nowadays, is a targeted one, but it is usually limited to taking special courses in logic or psychology, or to taking different kinds of individual psychological training for improving one's memory, thinking, and so on. But taking into account the above mentioned possibilities, we can now distinguish certain stages in stimulating the students' experimental and research activity, and their connection to the levels in the development of cognitive inquisitiveness. Resulting from a research in the cognitive activity of students that was conducted throughout several years, a table has been compiled, linking the stages in the stimulation of the learning to the levels in the development of cognitive interest. Promoting the students through the levels, one can nurture the range of knowledge and skills, required from students in order to successfully conduct scientific research, and therefore to become who they were meant to be, and build a successful career.

**Keywords:** The experiment, the levels of cognitive inquisitiveness, development, motivation

### 1. Introduction

It is currently assumed, that general educational subjects are taught consistently and learners' development comes naturally. Many professional physicists and lecturers believe that the content of the subject area of physics itself gives food for thought, which is hard to disagree with. However, the progress during the learning process is spontaneous and depends on the personal characteristics and the intellectual capabilities of the learner. It turns out that, as far as the learning process is concerned, various types of knowledge, skills, values, psychological skills are shaped in a disparate way. As a rule, the method of learning to acquire certain information, commonly employed nowadays, is a targeted one, but it is usually limited to taking special courses in logic or psychology, or to taking different kinds of individual psychological training for improving one's memory, thinking, and so on. Such programs are usually available either in grammar schools, or to gifted children, or in specialized classes, or within some program of pedagogical support [1, 2].

The acceleration in scientific and technological progress, the rapid pace of social transformations cause the necessity of enhancement and intensification in different areas of human professional activity, and first of all, of intensifying the processes of teaching and knowledge acquisition. Boosting the learning and cognition activity today means converting it into a process, directed towards more intense engagement of the teacher and the learner, pushing it to an energetic and purposeful implementation, it means overcoming stagnation, the passivity of the stereotype forms of teaching and learning.

The questions of motivation and effective interaction between the teacher and the students are among the most prioritative in the theory of teaching. In the work [3] it was explored how steering questions from the teacher, and feedback, influence boosting the cognitive activity of the students, what qualities of students are the most significant and powerful in the learning process. The research assumed there was a connection between the individual traits, gender of the learners and their learning and cognitive activity, as well as the shaping of their intrinsic motivation. The sample included processing a large number of questionnaires, collected in randomly chosen schools of Germany, Switzerland and Russia. Students' individual traits and the way they affect cognitive and learning activity, the emergence of a persistent motivation – all this was explored over a long period of time, estimated at the introductory and conclusive stages, and videotaped. This method demonstrates positive results, although the female students reported a smaller impact on the cognition process.

The questions of a negative effect of extrinsic rewards, of how they affect conceptual understanding and striving for achievement in education, the motivation of striving, were examined during an educational game [4, 5]. The question was posed, whether feedback can lessen the anticipated [4] negative effects of extrinsic rewards. The experiments were conducted in two groups, in one of them (n=50), in the course of the educational game, encouraging rewards were allowed, in the other group (the controls) (n=56), the learning process went on without extrinsic rewards. The experimental data was gathered and analyzed at a number of levels. The results showed that extrinsic rewards couldn't disrupt the students' motivation (at the proximal and distal levels, for example). On the other hand, being rewarded, the students demonstrated by far greater success in the conceptual understanding (of the proximal) and insignificantly bigger success in achievement (the distal levels). Therefore, the predicted negative effects of extrinsic rewards can be overcome within this new generation of learning environments.

Other researches in this direction [6] also confirm the conclusion that direct and indirect links between various types of persuasion and encouragement, and cognition in science, shape the motivation and striving for understanding and for taking competent actions to achieve a goal. A hypothetical model was tried out in this experiment, that generated and tested the above mentioned links, over a hundred of students participated. Even though some negative effects were revealed during the research, overall, the nurturing of motivation is the path to success in student science.

Interesting questions are raised in the work [7], where researches have been taken, to find out how the situational interest is connected with the acquisition of knowledge. The situational interest can be explained as a motivational response to the lack of perceived knowledge. Experiments were conducted, which modeled the situations, where this lack reveals itself at solving a problem. In the first research, where 32 university students participated, the researchers manipulated the amount of prior knowledge, required to carry out a task. Only the students who lacked the required knowledge demonstrated a rise in the situational interest after the problem was introduced. In the second research there were 60 students, who demonstrated that they lacked the knowledge to understand the problem. As a result, the students showed an elevated situational interest in grasping the problem. In the third research, 86 students participated, who demonstrated the situational interest in the course of three classes. The data shows that the situational interest decreases along with gaining the knowledge about the introduced problem. These results contradict the widely acknowledged view that the situational interest and knowledge are bound to have a positive influence upon each other.

## 2. Discussion and Results

In order to study the ways of stimulating cognition in learners, researches have been conducted in student groups over a period of several years, to find out how the level of development is impacted by structuring the cognition activity. Experiments took place within the frames of student research work, during the execution of laboratory practicums. The students were divided into «the group of control» and «the experimental group». In the experimental group, the students were graded by the levels of their knowledge, which was defined by means of testing and interviewing. The groups that formed, being at the same level of knowledge, shared interests, enjoyed equal abilities to gain knowledge, could exchange their thoughts and abilities to acquire new information. Each group had the opportunity to be consulted by the teacher, a schedule for individual meeting was established, and, sometimes, more advanced students took the role of consultants. The students of the experimental groups suggested subjects for a research for student scientific conferences and for the competitions of scientific research projects more often, winning rewards in the form of diplomas and certificates for prize positions.

Most effectively, the structured stimulation of the cognition process, which depends on the learner's level of development – is applied in the course of conducting experimental work [8-10]. The experiment is a method of research, that can be numerously reproduced under specified conditions and brings an identical result.

Planning a practicum in physics, one needs to set many goals. These goals can be related to shaping, solidifying,

testing the skills, including the skills in the subject, to the formation of certain navigating values and mindsets in the area of physics.

The carrying out of the experimental tasks of the practicum can also be coordinated with the implementation of various formative objectives. If thoroughly considered, and applying imagination, a plenty of methods can be found and implemented, while conducting an experimental practicum in physics, to form the students' skills in experimental work, and to connect the tasks to the problems, dealing, in one way or another, with the issues of upbringing.

While organizing an experiment, it is, of course, possible to achieve the goals concerning the students' personal development. We can purposefully shape such personal qualities as activity and originality of intellectual and practical performance, such qualities as honesty, objectivity and industriousness. The objectives can deal with cultivating logic processes, such as, for example, the power of observation, good memory, vision, creative imagination.

At the same time, we might not strive for such large-scale goals, not even suspect such a possibility, and limit ourselves to one, narrow and very simple purpose: to organize the carrying out of the tasks for an experimental practicum in physics. Planning a laboratory experiment for a course in physics, one could set the following goals:

- 1) General educational goals, the ones to do with the acquisition of the knowledge in the subjects, and general scientific knowledge.
- 2) Goals to do with shaping the experience of performance in standard situations (experimental skills learned from a particular instance). Independent work of the students is to be organized, on verifying the dependencies between the physical parameters that have been priorly defined in a showcase experiment.
- 3) The objectives to do with shaping the experience of performance in non-standard situations, the encouragement of the creative abilities of the students. If we package the components of laboratory equipment like a technical construction set, we can create a system of individual, non-repeating, both problematic and programmed tasks, which would make the students carry out laboratory experiments independently, plan and conduct an experiment, and process its results. A practicum in physics could be organized in such a way, that instead of providing extensive instructions on carrying out laboratory sessions, only the assignments would be given, without specifying how to carry them out.
- 4) Goals to do with shaping personal qualities in a student. To make everyone behave actively, while conducting experimental assignments of a physical practicum, work should be organized in such a way, that everyone receives an individual assignment, and then independently reports executing it. To form the intellectual and practical independence of everyone, the partly-heuristic method should be employed as basic, for organizing the laboratory practicum, when every laboratory session consists of elementary steps.
- 5) Goals to do with shaping the personal qualities of the student (industriousness, objectivity) – systematic self-assessment and mutual cross-assessment is to be organized in the course of carrying out the laboratory work. The student's judgements are to be trusted, and their opinions are to be taken into account when the teacher gives his/her own grade.
- 6) Goals, that deal with cultivating logical processes. To teach them competently formulate a scientific assignment, one must have them briefly summarize the physical essence of the process, that was examined in the experiment, its methodology and results, when defending the results of every performed laboratory task. To provoke their creative imagination, give them the opportunity, depending on the objectives of the assignment: to independently construct a laboratory device, to develop the strategy and the tactics of the experiment, to invent and apply the ways of verifying the accuracy of the obtained results. In order to provide them with correct ideas about the phenomena, studied in the course of physics, arrange the set of experimental laboratory assignments so as to allow the students to observe and study them independently, and reproduce the showcase experiments.
- 7) Goals to do with upbringing. To acquire working skills, students should be offered to construct the laboratory equipment themselves, construct some elements of this equipment. Knowledge acquisition is more effective, when teaching is based on the physical experiment. Taking such possibilities into account, certain stages can be distinguished in stimulating the research and experimental operation, and connected with the levels in the development of cognitive inquisitiveness [11, 12]. By studying the literature [13, 14], making our own observations, analyzing the obtained results of researches over several years, using a number of student groups as an example, we were able to compile a table, that shows the links between the stages in stimulating the cognition activity of the students and the characteristics of their levels of development.

**Table 1.** The stages in stimulation and their relation to the levels of development of cognitive inquisitiveness.

Groups of stimuli and their meaning.	Signs of the development of cognitive inquisitiveness	The activity of the learners
1	2	3
<b>1st Stage: Preparatory and Organizing / 1st Level: Understanding</b>		
<i>The aspect of the subject</i>		
1 The novelty of the material, the effect of unexpectedness and entertainment through the use of an object. 2 Getting acquainted with the methods of scientific knowledge.	An interest in the exploration of scientific facts, in the methods of scientific cognition, revealed in connection with an externally entertaining form.	Studying the methods of scientific cognition and their structure.
<i>The aspect of practice</i>		
1 Using demonstrations with the equipment, made by the scientific advisor him/herself, or by the learner. 2 Encouraging to construct the simplest devices. 3 Encouraging to devise the scheme and a compact physical laboratory.	To verify a phenomenon, to construct a device. The student needs constant stimulation.	Constructing devices, calibrating, measuring length, volume, temperature and other physical parameters.
<i>The organizational aspect</i>		
	Young scientists try to efficiently organize their activity, they choose the day of the week for conducting experiments and observations.	They put down the working plan, prepare the experimental pit, carry out experiments, analyze the obtained data and document the obtained results.
<i>The emotional aspect</i>		
1 The inspiring emotional support of the scientific advisor. 2 Discussions that stimulate suggestions, concerning the ways and means of conducting the experiment.	The emotional signs of involvement: of surprise, attention, understanding; interjections.	A talk, suggesting initiatives.
<i>The motivation and the cognitive properties at the 1st stage</i>		
The motivation	The level of development of the logical thinking	
The level of it is low, plans are vague, not connected with physics, the students are only intrigued by the external entertaining side of the experiments, their specific meaning does not attract them much.	The scientific knowledge does not have intertwining links, only the simplest actions are performed, specifying the goal of the experiment, conducting an experiment, the simplest calculations, analyzing and drawing conclusions about the experiment, carrying out experiments and reporting on the taken research.	
<b>2nd stage: implementing / 2nd level: exploration and research</b>		
<i>The aspect of the subject</i>		
1 Creating problematic situations when shaping tasks. 2 Using the heuristic method while elaborating the content of the tasks.	Research activity of both the experimental and theoretical type, of conducting a scientific experiment.	The student conducts experiments, observations and laboratory sessions, applying the methods of scientific cognition
The continuation of table 1		
1	2	3
<i>The aspect of practice</i>		
1 Demonstrating the practical significance of carrying out a task 2 Demonstrations, reproducing individual experiments.	Activity aimed at the implementation of the knowledge.	Preparation, adjusting and calibrating the equipment, reproducing experiments.
<i>The organizational aspect</i>		
1 A weekly load of tasks and the possibility for it; 2 Diversifying the choice and the possibility for it; 3 Organizing competitions; 4 Games or other alternative forms; 5 Individual or group tutoring.	Young scientists choose the amount of tasks themselves, form groups, choose a leader, independently specify the time and place for conducting an experiment. In case of difficulties, approach the supervisor.	Choosing tasks, carrying out one or several experimental tasks, choosing the time and place for conducting an experiment.
<i>The emotional aspect</i>		
1 Mutual support; 2 The motional charge in communication. 3 The effect of beauty. 4 Games, discussions, panel games, diversity in the types of events.	Revealed in captivated attention, active perception and vision and imagination, effort and creativity kicked into gear.	Emotional satisfaction, participating in discussions, being helpful and supportive.
<i>The motivation and the cognitive properties at the 2nd stage</i>		
The motivation.	The level of development of the logical thinking	
A passion for physics, students are passionately involved into research work.	Processing the calculations, applying logical methods, various means of presentation, developing graphic skills, analyzing the results of an experiment, the ability to shape and conduct an experiment in imagination, the ability to draw conclusions, demonstrating the concepts and phenomena.	

<b>3rd stage: generalizing and creative / 3rd level: academic and scientific creativity.</b>		
<i>The aspect of the subject</i>		
1 An independent research. 2 Tasks aimed at inventing one's own experiment. 3 Achieving high personal results. 4 Achieving results in various activities of different levels. 5 The possibility to work with an individual speed and by an individual schedule.	Expressed in the main elements of the research activity, an interest in scientific notions, in the laws of the progress of physics as a science.	Inventing the student's own experiments, carrying out observations for an independently suggested objective and hypothesis.
<i>The aspect of practice</i>		
1 Holding exhibitions. 2 Revealing and demonstrating the practical significance of the research. 3 Appearances with the reports on the conducted work. 4 Reports at scientific conferences of different levels.	Independently conducting experimental tasks and all steps of the research activity, conducting a research for an independently chosen objective, a search for new variants of conducting experiments, the systematic use of scientific literature.	Demonstrations of constructed devices, defending the research that has been carried out.
The continuation of table 1		
1	2	3
<i>The organizational aspect</i>		
1 Engagement in taking science-management decisions. 2 Cross-control. 3 Involvement in the devising of tasks. 4 The assessment of experimental work. 5 Leading a group while carrying out collective tasks. 6 Collective and individual consultations. 7 Stimulating responsibility.	Independent choosing the tasks, the advisor, spreading the tasks correctly, striving to conduct an independent scientific research individually or with a group.	Forming groups, consulting the advisor, organizing the student's own activity aimed at an appearance at a scientific conferences of different levels.
<i>The emotional aspect</i>		
1 Creating success. 2 Trusting one's own cognitive and creative abilities. 3 The effect produced by games and roleplays. 4 A favourable psychological climate in the team, the atmosphere of the quest and creativity.	Active participation, the desire to help others, a critical attitude, an emotional attitude to one's own personal success, tasting success.	Participation in organizing games, roleplays, cooperation.
<i>The motivation and the cognitive properties at the 3rd stage</i>		
The motivation	The level of development of the logical thinking	
Highly motivated, applying the knowledge of physics to practical work, self-developing one's own capabilities and thinking, the motivation of achieving success.	The ability to independently reveal the problem, analyze, find the ways to solve it, implement and verify the solutions, formulate conclusions, self-development and the skill to conduct a research, the ability to reveal regularities The student possesses imagination and thinking, revealed in constructing the student's own devices, conducting observations of the physical phenomena and carrying out experiments, in the ability to generalize a large amount of materials on physics etc.	

You can help the transition to higher levels of education, using this table. Achieving these levels means that the student demonstrates the ability to create something subjectively new. A goal and the initial conditions are set before the student. Depending on the level of training, a plan of action is chosen and the stimuli, that allow to successfully follow through the assignment. After all the necessary action is taken, the result should be obtained, the one intended in the plan. Intermediary tasks are to be set and carried out by the student independently.

As an example applying the stimulation of the cognitive inquisitiveness in students, when carrying out experimental assignments, we can suggest a practicum for the subject «Defining the spectral lines of the hydrogen atom».

The goal of the practicum: To learn to define the wavelengths of the spectral lines of the hydrogen atom.

For conducting this practicum, the «MS Excel» software is employed, since it is a convenient tool for solving various computational tasks. In this article, we give examples of applying «MS Excel» spreadsheets for solving tasks in the course section of atomic physics. This allows to train and consolidate the skills in the inter-disciplinary subjects of «Electronic tables» and «A mathematical model» from the course of Computer Science, and also to apply the skills and knowledge for the theme «Atomic physics and the atomic nucleus». One and the same theme is offered to all the students, but depending of their level of training, they form groups with shared interests and choose their path to solving the chosen tasks. More capable students, having examined the recommended publications, can choose the methodology of performing the task, compile the plan of work, draw tables, where they put the measurable data. Weaker students can use ready-made detailed recommendations on the methodology of how to carry the work out, with already prepared tables and recommendations on how to solve the problems.

The calculation formula for conducting calculations is:

$$\frac{1}{\lambda} = R \left( \frac{1}{k^2} - \frac{1}{n^2} \right);$$

where R – is the Rydberg constant, it equals to  $1.097373177 \cdot 10^7 \text{ m}^{-1}$

If  $k=1$ ,  $n=2, 3, 4, \dots$  - we obtain the Lyman series in the ultra-violet zone;

If  $k=2$ ,  $n=3, 4, 5, \dots$  - the Balmer series in the visible spectrum is obtained;

If  $k=3$ ,  $n=4, 5, 6, \dots$  - the Paschen series in the infra-red zone is obtained;

If  $k=4$ ,  $n=5, 6, 7, \dots$  - the Brackett series in the infra-red zone is obtained;

If  $k=5$ ,  $n=6, 7, 8, \dots$  - the Pfund series in the infra-red zone is obtained.

The objective: To obtain the shortest  $\lambda_{\min}$  and the longest  $\lambda_{\max}$  wavelengths of the spectral lines of hydrogen in all zones.

The progress of the assignment:

- 1) Download the source table (the menu).
- 2) Enter the original numeric values.
- 3) Enter the value of the Rydberg constant in its exponential form into cell D14, in order to do that, select cell D14 and follow the commands Format → Cell → Tab → Number.
- 4) Select the exponential format of the cell from the list Numeric formats → Exponential Format.
- 5) Into cells C8:C12, enter the values of the k-number for the alternative series
- 6) Into cells D8:F12 – enter the values of the number n.
- 7) Into cell I8, enter the formula that allows to calculate the wavelengths of the hydrogen spectrum lines.

Apparently, the shortest wavelength of a spectral line will be for  $n = \infty$ , then the calculation formula will look as follows:

$$R \cdot \frac{1}{k^2};$$

$$\lambda = \frac{1}{R \cdot \frac{1}{k^2}}.$$

hence,

	A	B	C	D	E	F	G	H	I
1	Determination of the wavelengths of spectral lines								
2									
3									
4	The calculation formula		$\frac{1}{\lambda} = R \left( \frac{1}{k^2} - \frac{1}{n^2} \right)$						
5									
6			Define boundaries line series, m						
7			k	n					
8	Lyman series		1	2	3	4		$\lambda_{\max}$	$\lambda_{\min}$
9	Balmer series		2	3	4	5			
10	Paschen series		3	4	5	6			
11	Brackett series		4	5	6	7			
12	Pfund series		5	6	7	8			
13									
14	R Rydberg constant		1,1·10 <sup>7</sup>						
15	The smallest wavelength of the spectral lines will be at $n = \infty$								
16									
17									
18									
19									

Figure 1. The look of the table for entering the data.

Hence, in cell I8 the formula is written:

$$=1/(\$D\$14*(1/power(C8;2)));$$

The longest wavelength corresponds to the first value of the number n in each of the series, the formula for this case will look so:

$$\lambda = \frac{1}{R \cdot \left( \frac{1}{k^2} - \frac{1}{n^2} \right)}$$

8) In cell H8 in «Excel», the following formula is to be entered:

$$=1/(\$D\$14*(1/power(C8;2)-1/power(D8;2)));$$

Spread the formulas in cells I8 and H8 by AutoFill, to define the boundaries of the lines in all series. Compare the obtained results with the tabular data.

**Table 2.** Wavelengths of the spectral lines of the hydrogen atom.

	Define boundaries series of lines, m					
	k	n			$[\lambda_{\min}]$	$[\lambda_{\max}]$
Lyman series	1	2	3	4	$1.21544 \cdot 10^{-7}$	$9.11577 \cdot 10^{-8}$
Balmer series	2	3	4	5	$6.56335 \cdot 10^{-7}$	$2.27894 \cdot 10^{-8}$
Paschen series	3	4	5	6	$1.87524 \cdot 10^{-6}$	$1.01286 \cdot 10^{-8}$
Brackett series	4	5	6	7	$4.05145 \cdot 10^{-6}$	$5.69736 \cdot 10^{-9}$
Pfund series	5	6	7	8	$7.45836 \cdot 10^{-6}$	$3.64631 \cdot 10^{-9}$

### 3. Conclusion

Having revised the assignment, the student must analyze the demonstrations, put down the conclusions and discuss them with the teacher. Students do not always immediately understand the laws of atomic physics and optics, and the principles underlying them. And having a go at understanding them independently, and carrying out, in addition, virtual laboratory assignments, looking through them over and over again, he/she will surely understand the laws' essence. And if the student possesses some computer skills of his own, he might improve the program/code, which will employ his/her knowledge, received from the teacher, as well as imagination, and ordinary scientific inquisitiveness. Therefore, we can, by choosing and properly organizing experimental work, gradually lead the students through the levels of awareness, provoking the cognition inquisitiveness. We believe that the high level of stimulation of the cognition process at every its stage determines the shaping of particular competencies in different subjects, within an academic discipline.

Good results are obtained by the combination of classical forms of teaching with modern computer technologies. Creating a virtual educational environment, using multimedia means of teaching, we can achieve significant results, while also solving the tasks of developing the students' intellectual abilities. In our research, we used virtual laboratory complexes, which significantly alleviated the work of the teacher and allowed to promptly respond in critical situations [15-16].

The research was carried out during three years, six groups of students were involved in the experiment, divided into control and experimental groups. A conclusion can be drawn that the students from the experimental groups more actively participated in various student scientific conferences, in the competitions of scientific research projects, earning all kinds of diplomas and certificates for their appearances. It should be noted that, even having finished to study physics in their Junior years, they continued to take part in carrying out scientific research, by their own initiative, in the Senior years.

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