Scope of Thesis Research in the Area of Physical Science Education

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Abstract. We have analyzed the topics of the candidate's and doctor's degree theses on theory and methods of teaching physics defended in 2000–2015. In the paper, we justify using a thesis database to identify the key areas of research in this field. We describe how thesis topics are distributed across levels of education (secondary and tertiary), how topics of the theses dealing with tertiary education are distributed across specializations and areas of research defined by the formal specialty description. We also identify the most active research topics in theory and methods of teaching physics as well as top-priority research avenues for the foreseeable future.

Keywords: physics education, school, higher education institution, education program, thesis research, physics syllabus, computer information technology, inclusive education.

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Information society of the 21st century is characterized by a controversial and ambivalent understanding of the role of science in its evolution. On the one hand, public opinion allows that scientific breakthrough is critical for progress, social wellbeing, and the quality of life. On the other hand, "the positive image of science is accompanied by some negative implications entailed and risks associated with environmental deterioration, industrial disasters, and a menace to all mankind as such" [Solomin, Laptev 2015]. Natural sciences, including physics, are the first to be held accountable, as it was research into nature that gave birth to engineering, technology, technocratic rationality, and, ultimately, the "technogenic civilization".

Obviously, this attitude to the role of science stems from the utilitarian approach to assessment, which highlights what science can give the humanity in a year, two, or ten. Meanwhile, it sidelines the fundamental role of science in social development, which is not reduced to immediate research applications, as well as personal development of researchers as an additional effect.

However, there is growing recognition of the fact that the importance of science goes far beyond its applications. As outstanding physicist Erwin Schrödinger said more than half a century ago, "We tend to forget that all natural sciences have to do with universal human culture, and scientific discoveries that seem to be the most progressive and only understandable by the select few at the moment are still meaningless outside their cultural context" (cited by [Prigozhin, Stengers 2014: 31]). The history of science, physics in particular, has seen numerous examples of how a major scientific discovery received no acceptance or demand from its contemporaries, being mismatched with the general cultural context, or when different researchers made the same discovery, of which the idea had been in the air, virtually at the same time, by historical standards.

"Recent research has been calling us more and more away from treating humans and nature as opposites. Our knowledge about humans is growing ever more harmonized with that about nature, reducing the gaps and smoothing the contrasts," emphasized Nobel Prize winner Ilya Prigozhin [Ibid.: 18]. It means that today's science produces outcomes far beyond the pragmatic goals of wealth accumulation—it actually shapes a new kind of thinking. Someone who investigates into nature engages in spiritual development. Society of the future will need first of all creative, competent business people with universal yet paradoxical minds, capable of finding their way in the abundance of varied information, analyzing and screening it quickly to make the right decisions. In the ever-changing world, it becomes more and more difficult to secure oneself a full-fledged life using established stereotypes and behavioral templates. In fact, we have to be researchers and scientific thinkers more and more often [Larchenkova 2013]. This explains to a large extent the recent increase in the interest for research in all fields including education.

The interdependence of science and education is clear: gaining new knowledge is always associated with transferring it to the generations that follow. The goals and meaning of education are undergoing fundamental transformations due to the global changes in the life of modern society: the coexistence of numerous different cultures, the rapidly growing pace of life, the increasing amount of information, the emergence of new technology and means of communication, etc. In a world of head-spinning change, we ought to teach not only what has been accumulated by the previous generations but also what can happen in the future, which means that students should be armed with possible scenarios of the future they will have to live in. Development of scientific enquiry skills thus becomes the key prerequisite for satisfying the social demand for upraising and educating the man of the future. This goal has been given priority in the current modernization program, which seeks to integrate research activities at all levels of education and solidify the methodological component of learning. Education today should represent an integral process combining *science components* that define the content, methods and goals of education, *teaching components* that determine the technology, techniques and methods of transferring knowledge, skills and traditions, and *research/heuristic components*.

Physics has made an unquestionable contribution to general human culture, having produced effective scientific thinking strategies, the scientific worldview, and research methodology. Physics was the cradle of the very first ideas of the principles of causality, complementarity, uncertainty, and correspondence, which are now classified as methodological and interdisciplinary. This status of physics is the reason why it should be taught at all levels of education.

1. Thesis topics as an indicator of developing trends in scientific research

Present-day research studies are projected and carried out in the framework of various research programs, but theses hold a special place among them, determined by the social demand for research outcomes as such (applied and culturological aspects) and the development needs of science itself (fundamental aspect) [Solomin, Laptev 2015].

A thesis is supposed to present novel, theoretically and practically significant research findings that offer a solution to a scientific problem. The paradox of modern thesis assessment criteria is that thesis is understood first of all as a tool to assess the author's scientific skills but not as a mechanism for developing scientific knowledge in a specific field. Academic degrees open the door to the world of science for all holders.

The annual number of theses defended in pedagogical sciences was constantly growing during the last two decades, up until 2014. Apart from that, theses devoted to teaching various subjects including physics have now acquired some specific features.

More and more educational institutions at all levels combine teaching activities with research and experiments. Besides, some successful instructors consider it necessary to consolidate their unique teaching techniques or observations in the form of theses [Novikov 2003]. Pedagogical experiments are now allowed to be conducted at the author's workplace, and no complicated procedure to acquire the status of a testing site is required anymore. In addition, recent graduates from teacher training universities also have access to postgraduate studies in theory and methodology of education and teaching, which contributes to the number of academic degree seekers.

Research and project technologies are prioritized today at all stages of the learning process, but the best part of the teaching force is not ready for this kind of work. Quite naturally, university instructors and school teachers who have never been engaged in any research project simply possess no skills required to organize research activities of students. According to survey data, teachers often find difficulty articulating and justifying the goal of their research (53%), forecasting outcomes, selecting means and methods of research (52%), summarizing and presenting research findings (47%) [Lebedeva 2010]. This should come as no surprise, as objectives of a teacher and those of a researcher are essentially different [Novikov 2003]. Teacher seeks first of all to achieve a high level of academic performance, while researcher aims at obtaining new scientific knowledge, explaining instructional phenomena, and forecasting the outcomes of pedagogical influence.

For a school or university teacher, academic degree is an exclusive and very meaningful indicator of their professional growth, which attests the breadth of their knowledge, their systems thinking skills, their ability to identify and solve problems as well as to organize a learning process to meet present-day requirements. From this perspective, one cannot but welcome the growing number of theses in pedagogy defended by practicing teachers, particularly given the fact that selecting a major and a topic of research is a challenging task for many of them.

Any thesis begins with justifying the topic of research. The range of topics in pedagogy is so wide, it may seem that choosing a fresh one for research should not present any problem. However, prospective researchers experience the most difficulty finding “their own place in the field”, identifying the area that would be the closest to their academic interests, finding out how well that area has been studied so far, which unsolved problems they can analyze or which solved ones can be resolved in another way. Meanwhile, it is important to ensure that the chosen topic is justified by objective practical and theoretical requirements, on one hand, and fits in the existing cultural situation regardless of momentary factors, on the other hand.

In this paper, we study theses in specialty 13.00.02 “Theory and Methods of Teaching and Education (Physics, Secondary and Tertiary Education Levels)”. However, we do not evaluate researchers’ expertise (assuming that a successfully defended thesis is an evidence of scientific skills and, consequently, its topic is consistent with the formal specialization description). Instead, we analyze their topics as an indicator of developing trends in scientific research.

The article seeks to identify research directions in the abovementioned specialization, the importance of which is determined not only by the current social demands but also by more long-term development trends.

2. The good reason behind identifying research problematics based on thesis topics

We find it acceptable to use a thesis database to identify research problematics in physics theory and teaching methods based on the following factors: (i) research findings are subject to pre-reviews prior to publication; (ii) theses are easily available for study, distribution, and use of their findings; (iii) a defended thesis is an indicator of research success.

So, first of all, the critical components of research are pre-reviewed at the stages of thesis preparation and defense. The quality of research and validity of research results are ensured upon evaluation of research findings and their publication in print and electronic media.

The existing level of scientific communication and the infinite possibilities of presenting, storing and spreading information in the Internet necessitate a thorough evaluation of research products. In a situation where anyone can publish their work, there has been a sharp increase in the overall number of publications and an obvious reduction in their average quality, while an in-depth analysis of works is becoming not that easy. That is why it does not seem productive to include all publicly available publications in the analysis of research topics. Ideally, relevant and valuable information should come from peer-reviewed journals, some of which can be found on the list recommended by the Higher Attestation Commission (VAK) [Belyaeva, Shubina 2014]. Thesis findings are published in the form of articles in journals from the list.

As for publications devoted specifically to methods of teaching physics, there are only two Russian journals specialized in this area: *Fizika v shkole* and *Fizicheskoe obrazovanie v vuzakh*, which have no foreign analogues that we know of. A large part of articles within specialty 13.00.02 “Theory and Methods of Teaching and Education (Physics)” are published in multidisciplinary journals. Such journals are designed to develop an integral perception of the science industry, so their requirements for the content of articles concern not only the subject-related aspect but also the cross-disciplinary one. Moreover, as soon as articles are prepared at various stages of research, they can present not final but provisional results, and length restrictions make authors include only fragmented or rather generalized research data, omitting a good deal of details. The same applies to conference proceedings.

Second of all, theses are easily available for study, distribution, and use of their findings today. Degree seekers used to spend a lot of time in reference rooms of Russia’s central libraries, but computer information technology recently applied to library services has not only allowed creating online thesis catalogues available to anyone but also provided the opportunity to access theses and extended abstracts remotely. A high availability of e-catalogues and texts imposes stricter requirements to justifying the significance, novelty, and usefulness of prospective research by degree seekers. Of course, an author has a chance to present their findings in more details by publishing them in a monograph, but it will hardly attract more readership. Nowadays, monographs are published in limited quantities, have no effective distribution system and thus often do not reach their reader. Under the existing circumstances, theses are easier to access than monographs.

Consequently, a thesis catalogue, e.g. that of the Russian State Library, can serve a reliable base for analysis of research topics in the selected field.

Third of all, thesis is a good indicator of successful research in pedagogy. Institutions and teams engaged in research in this field present their results in a number of ways: as research performance progress reports, published articles and monographs, published textbooks and guidance materials, or new learning equipment and electronic resources. Still, results reported in a thesis, prepared and defended using the research materials, are a key indicator of successful research. As an example, we can refer to Marina Demidova's doctoral thesis *Metodicheskaya sistema otsenki uchebnykh dostizheniy uchashchikhsya po fizike v usloviyakh vvedeniya FGOS* [A System of Methods to Assess Academic Performance in Physics after the Introduction of the Federal State Education Standard (FGOS)] (Moscow State Pedagogical University, 2014), which she wrote in the course of a many-years cooperation with the Federal Institute of Pedagogical Dimensions in the development of USE (Unified State Exam) tests in physics.

Therefore, in the object of our study, which is research in theory and methods of teaching physics, we can identify the subject, which is conformance of research problematics to the existing social demands for physics education as well as to the development prospect justification requirements. The analysis database is limited to theses in specialty 13.00.02 "Theory and Methods of Teaching and Education (Physics, Secondary and Tertiary Education Levels)".

The key research methods include qualitative and quantitative analysis of research directions observed in the database, comparison of these directions to those stipulated in formal specialization descriptions as well to the requirements imposed by the modern level of education and social development, and statistical processing of the data obtained.

3. Analysis of the topics of theses devoted to theory and methods of teaching physics

In order to draw up a list of theses in specialty 13.00.02 "Theory and Methods of Teaching and Education (Physics, Secondary and Tertiary Education Levels)" defended between 2000 and 2013, we used the online thesis catalogue (http://diss.rsl.ru) of the Russian State Library, as it provides quite a complete picture of the given period.

Data for the period 2014–2015 is based on the upcoming defense announcements posted on the VAK website, so it is rough. Using this method, we traced a total of 520 works.

Figure 1 shows that 2004 and 2006 were the peak years of interest for methods of teaching physics among grade seekers, the number of such works plummeting in 2011. However, it would be wrong to talk about a decreasing enthusiasm for research in this area based on this data alone, because the period in question witnessed some or-

Figure 1. **Number of theses defended**

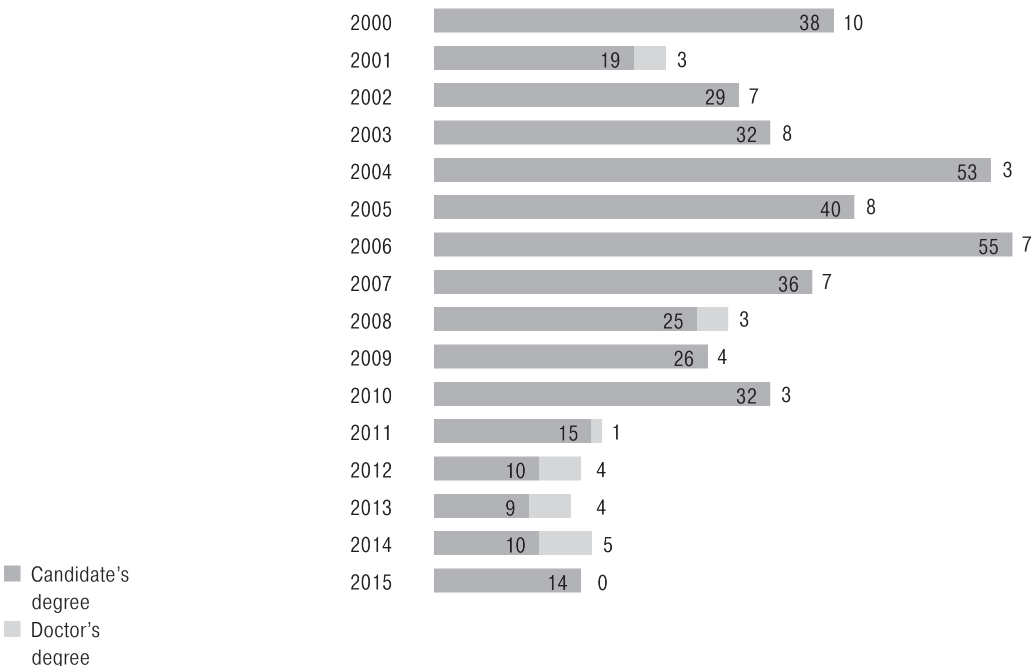
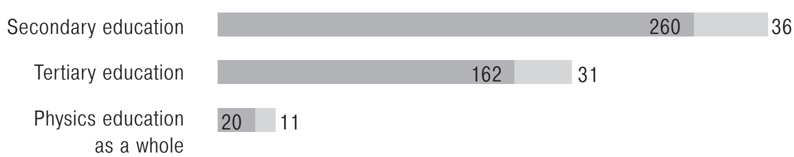


Figure 2. **Thesis topics distributed across education levels involved**



ganizational reforms that changed the defense procedure and the way thesis committees worked. Time will tell whether this downward trend is a persistent effect or only an adaptive response to the new context and whether the change in the requirements will enhance the quality of theses or complicate the defense procedure, scaring away prospective researchers.

As we can see from Figure 2, most theses focus on methods of teaching physics at school (57%), a large proportion is devoted to problems in tertiary education (37%), and only few studies investigate into physics education as a whole, including the lifelong learning aspect (6%).

Among theses devoted to secondary education, 15% study high school problems (15%) and 25% focus on junior high school. 60% of works assume that their problem-solving approaches can be equally applied to any level of secondary education or provide continuity of teaching physics in terms of secondary education.

Theses dealing with tertiary education suggest methodological systems and conceptions for teaching physics in higher education institutions of various specialization: medical, military, technical, pedagogical, and classical universities (Fig. 3). Nearly half of the studies about teaching physics in universities investigate into teacher training.

Only 11 theses in 16 years (2000–2015) explored teaching physics at the level of vocational education, leaving the area almost uncovered.

The formal description of specialty 13.00.02 “Theory and Methods of Teaching and Education (Physics, Secondary and Tertiary Education Levels)” defines four areas of research: 1) methodology of teaching physics; 2) goals and values of physics education; 3) methods of ensuring and evaluating the quality of physics education; 4) theory and methods of teaching extracurricular and out-of-class awareness-raising activities (рис. 4).

These four areas are further divided into narrower research directions. With a view to find out which areas and directions were the most popular in theses devoted to theory and methods of teaching physics, we thought it possible to judge about problematics based on thesis topics, as they were supposed to give the idea of the problem analyzed, according to the requirements.

Although the boundaries between the areas are rather conventional and research can be conducted at the interface of two or even three closely related areas, we were able to see clearly:

- the distribution of thesis topics across the areas;
- the most popular areas;
- the unexplored areas.

As Figure 4 demonstrates, the highest proportion of the works is devoted to the methods of ensuring and evaluating the quality of physics education (65%). The formal specialty description divides this area into 31 directions. Within the thesis database analyzed, the following areas are investigated most often (hereinafter as a percentage from the number of theses in the given area):

- Theorizing the best practices in teaching and education (13%);
- Methods, means, forms and techniques of physics education, awareness-raising and self-training (12%);
- Development of methodological conceptions for the content of physics education and the process of relevant knowledge acquisition (11%);
- Interrelation, continuity and integration of subjects and areas in the structure of secondary and tertiary education (9%);
- Monitoring of teaching and educating quality at different levels of instruction (8%).

Figure 3. **Topics of theses devoted to teaching physics in tertiary education distributed across types of educational institutions**

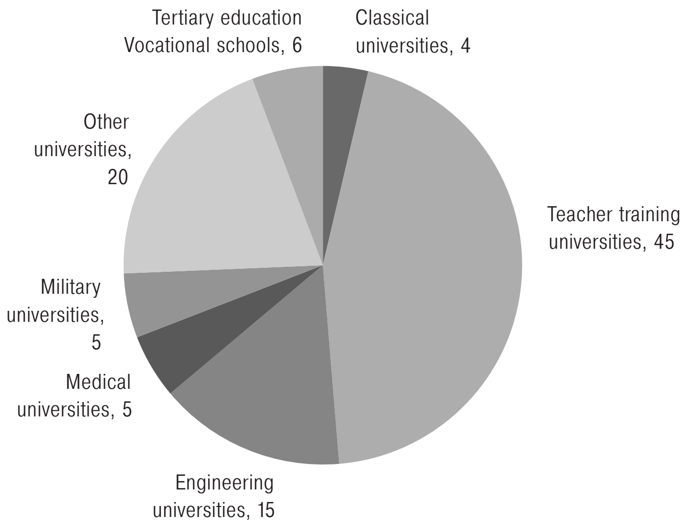
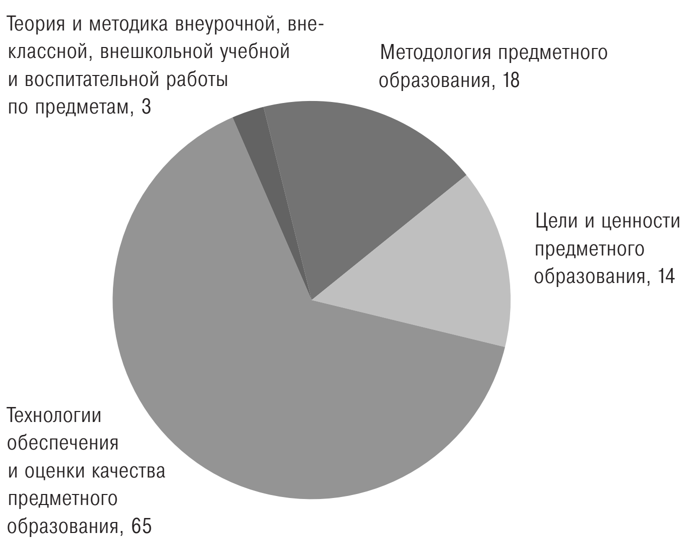


Figure 4. **Thesis topics distributed across areas of research defined in specialty 13.00.02 formal description**



Researchers in the area “Methodology of teaching the subject” work in the following directions:

- Opportunities and limitations of applying generic scientific knowledge acquisition methods to methodological subject teaching conceptions (28%);
- Trends in the development of different methodological approaches to organizing the learning process in physics (21%);
- General regularities of the learning process in the context of using the didactic opportunities of information and communications technology (16%).

Researchers within “Goals and values of physics education” tend to prioritize the development and awareness-raising opportunities of subjects (58%) and the problems of developing a positive motivation for learning, a philosophy of life, and a scientific worldview in students (24%).

Since formal specialty description should allow for an ultimately close examination of thesis for compliance to research specialty, it defines 51 directions of study. Within the bulk of theses on theory and methods of teaching physics, we found the following directions to be virtually undemanded:

- Specifics of obtaining knowledge while digesting the content of areas of study, disciplines, subjects, or courses (2 theses);
- Theory and practice of developing state education standards at different levels and indifferent areas of physics education (1 thesis);
- Theory, methods and practice of designing syllabi of different types and levels;
- Design of syllabi for educational institutions of different types and levels;
- Performance assessment of syllabi of different levels and content;
- Techniques of designing syllabi for basic and supplementary education;
- Development of methodological requirements for new-generation subject-related study materials;
- Analysis of positive and negative effects (in terms of education) of using information and communications technology at different levels of physics education;
- Preparing physics teachers to work in the supplementary education system.

4. Design and testing of physics syllabi as a promising research direction

The lack of theses in the abovementioned directions may be explained by the existing situation in Russian education, which complicates the procedure of pedagogical experiment and limits the focus of the academic teaching community to the problems that appear to be the most important in the given period of time. As Vitaly Ginzburg would say, some problems are classified as "especially important" not because others are not important but because they are the focus of attention today, which does not mean they won't be replaced by something else tomorrow [Ginzburg 2004].

Let us analyze the relevance of the aspects of theory and methods of teaching physics that are somehow neglected by degree seekers right now but can thrust to the fore any time soon.

The overview of directions above shows that the least number of theses has been dealing with design, testing and performance assessment of physics syllabi for educational institutions of different types and levels reflecting the content of modern physics education of different types and at different levels. We believe that the main reasons for neglecting this crucial direction are as follows.

In terms of secondary education, the reason is the length of the research cycle and the time required for syllabus testing. As school physics is studied from grade 7 to grade 11, only performance tests for a designed syllabus will take at least five years, and additional time is needed to make and test adjustments. Candidate's and doctor's degree studies last three years each. It becomes quite obvious that external factors make it impossible for a researcher to cram a full-featured experiment into this period so as to provide an exhaustive assessment of syllabus performance, especially using a limited database. At the same time, engaging a research team into a years-long project to analyze their work later and use this data to prepare a thesis is an extremely difficult task.

As for tertiary education, degree seekers neglect design, testing and performance assessment of physics syllabi due to frequent changes in standards and education programs. It would seem that this area provides even more opportunities for experimenting. However, the attempts to regulate the process of syllabus development that had been snowballing since the mid-1990s necessitated the introduction of education standards, which have been changing alarmingly quickly, too (GOS, FGOS-3, FGOS-3+, and FGOS-4 looming on the horizon). Standards come and go faster than syllabi can be developed, let alone tested [Gorokhovatsky et al. 2015]. The unfolding situation can be described quite precisely by the words of Polish satirist Henrik Yagodzinsky: "Changes for the better follow each other so fast that good things have no time to take hold."[1]

The task of upgrading the content of physics education in the present-day context is complex and ambiguous, which is another reason common for all levels of education. The need for upgrading and bring-

[1] Dushenko K. (ed.) (2000) *Bolshaya kniga aforizmov* [The Big Book of Aphorisms], Moscow: EKSMO-Press. P. 705.

ing physics syllabus in line with scientific development and utilitarian requirements has been discussed for a very long time within the framework of modernization of Russian education as such. However, the mission is not anymore possible to accomplish using the conventional encyclopedic, strictly consequential approach to building the syllabus, and here is why:

1. Scientific and technological knowledge has been growing and accumulating explosively. Transition from linear to exponential growth of knowledge and technology in many fields of science was mentioned by presenters at FUTUREMED Conference held in Silicon Valley in January 2013. Humans produced more information in three years (2010–2012) than for the whole period of their existence up to 2008 [Kurakova et al. 2014].
2. The lag time between scientific discovery and technology implementation has shrunk. The whole cycle that used to take decades now only takes 5 to 7 years.
3. Modern physics is so complicated and abstract that integration of scientific achievements into the learning process requires a rigorous selection and adaptation of material to age-specific and cognitive capabilities of school students as well as to specific major requirements in universities.

Selection and adaptation of learning material is not too demanded by degree seekers in our database. For example, theses in "Development of physics education content" only account for 3% of all works; they are devoted to adapting some physics topics for school textbooks. "Problems of modeling course structure and content" are analyzed in 2% of theses, and all of them deal with higher education. The near-zero amount of works devoted to selection and adaptation of learning material does not mean at all that the solution has already been found. School syllabi are still designed to teach classical physics mostly, despite the fact that modern development of engineering and technology relies on the physics discoveries of the 20th century in the first place. Indeed, the classical approach to describing physical phenomena provides a clear illustration of macrocosm that fits a school student's living space adequately, and its methods are optimal for teaching teenagers. Yet, it only means that the problem of learning material selection and adaptation is inherently controversial and hard to solve.

A number of theses offer syllabi designed by authors as possible applied results of research, yet all of them most often illustrate the author's arguments instead of being the subject of research. Therefore, identifying the ways to optimize the volume, content and structure of physics syllabi based on thesis findings appears to be a really pressing issue for the moment.

4.1. Possible research avenues

Possible ways of syllabus optimization are determined by the intrinsic logic of physics as a science, which can be summarized in simple terms as follows:

- Finding the universal visualization of interactions and studying nonlinear phenomena;
- Developing computational physics and teaching mathematical modeling as a new research methodology [Kadanoff 1994; Ginzburg 2004; Kondratyev, Priyatkin 2006].

This is not to say that modern trends in scientific development should be immediately and explicitly "transplanted" to physics education at all levels. The problem of reducing the gap between physics as a science and physics as a subject cannot be solved "at the level of child's perception", as Anatoly Gladun mentioned rightfully [Gladun 2010]. However, these trends can and should serve the key guidelines in developing and improving physics education. We are not talking here about radical measures like abandoning specific phenomena and laws in favor of nonlinear systems and high-level abstract generalizations, or replacing experiment with computer modeling, or neglecting the didactic principle of simplicity. What we suggest is looking for methodological opportunities to set priorities in teaching physics that matter the most today.

"Physics has sprawled and branched out so much recently that it becomes hard to see the forest behind the trees, hard to see the whole of modern physics with one's mind's eye. Meanwhile, a whole picture does exist, and physics does have a core amid all of its branches. This core consists of the fundamental concepts and laws." [Ginzburg 2004: 12] Obtaining knowledge conceptually, at the level of progressive ideas, scientific notions and theoretical models, should provide the opportunity to rationalize the composition of scientific knowledge required and sufficient for digestion by various types of learners. This way of obtaining knowledge will enable the development of physics comprehension abilities that are indispensable for both doing research in physics and nurturing thinking skills demanded in any industry today.

Development of mathematical modeling as a new research methodology and its integration in physics education is directly related to the ongoing informatization of science and education. Focus on nonlinear phenomena is increasing largely because using modern computing hardware allows analyzing problems that used to be considered unsolvable.

These trends of modern physics development are closely interdependent. That is why "teaching physics should first of all proceed from the assumption that physics is the ultimate culture of modeling" [Gladun 2010: 48]. Adding elements to simplest models makes them look more realistic; the ever more complex research-related calculations can be done using computers; findings that require knowledge of the fundamental concepts and laws to be deeply comprehended can provide the possibility of going beyond linearity.

Scientific justification is needed to determine to what extent and how exactly these modern development trends could be reflected in syllabi of different types at different levels of education, and this could likely make a good thesis topic. Given that any model has only part of source object's properties, "it should be kept in mind that idealization "takes revenge for itself", giving birth to paradox and confusion" [Ibid.: 50]. For instance, school physics already involves a good deal of models (point mass, weightless inextensible cord, ideal gas, closed loop, mathematical forms of physical laws, and others). Nevertheless, if a teacher pays little attention to their applicability conditions and does not show ways and possibilities of going beyond models, students will treat those models as sophisticated and useless. Indeed, why learn something that has nothing do to with real life? At the same time, shifting the focus to particular phenomena will give them the impression of disorganized isolated cases that are impossible to memorize.

At present, it is often intuition in practice that determines to what extent and in what combinations school-level physics syllabus contains methodological principles and fundamental or purely physical laws, and the latter are often preferred. Natalya Menchinskaya described the balance of general and specific in learning as follows: "Mastering philosophical concepts—matter, consciousness, primacy of matter over consciousness, etc.—requires a wealth of more specific natural knowledge, some of which should be based on specific sense experience. At the same time, mastering highly abstract concepts allows learning the world in all of its specific diversity." [Menchinskaya 2004]

Therefore, problem number one is justifying and designing physics courses based on general methodological principles—symmetry, relativity, etc.—whose biggest benefit, once mastered, will be that students will be able to see clearly the model-like nature of human knowledge and ideas about the outside world, identify the extent of their validity, and apply this information adequately [Kondratyev, Priyatkin 2006; Mayer 2012]. However, to make a course meet such requirements, selection of specific physical knowledge and paths of mastering should presumably become more varied, "nonlinear"—in this case the course will reflect by itself the trends in development of modern physics as a science.

4.2. What technology can be used to support physics education under the new conditions

The most active research area is module-based learning, i.e. breaking the content into invariant and variant components (Zaleznaya T. *Individualno orientirovannoe obuchenie budushchego uchitelya fiziki na osnove modulno-reytingovoy tekhnologii* [Individually-Oriented Training of Physics Teachers on the Basis of the Module and Ranking Technology] (Astafyev Krasnoyarsk State Pedagogical University, 2006); Lozinskaya A. *Modulno-reytingovaya tekhnologiya kak sredstvo povysheniya effektivnosti obucheniya fizike v uchrezhdeniyakh srednego professionalnogo obrazovaniya* [Module and Ranking Technology as a Way of Enhancing the Effectiveness of Teaching Physics in Secondary Vocational Education Institutions] (Ural State Pedagogical University, Yekaterinburg, 2009); Shermadina N. *Izuchenie mekhaniki v osnovnoy shkole na osnove modulnoy tekhnologii obucheniya* [Teaching Mechanics in Secondary School Using the Module-Based Technology] (Moscow State Pedagogical University, 2009); Batina Y. *Formirovanie umeniy samostoyatelnoy uchebnoy deyatelnosti uchashchikhsya osnovnoy shkoly pri obuchenii fizike na osnove tekhnologii modulnogo obucheniya* [Developing Self-Learning Skills in School Students While Teaching a Module-Based Physics Course] (Vyatka State University of Humanities, Kirov, 2009); Petrova T. *Invariantny podkhod k proektirovaniyu variativnogo obucheniya fizike* [An Invariant Approach to Design of Variative Teaching] (Far Eastern State University, Vladivostok, 2006); Popovich I. *Variativnost v obuchenii fizike kak didakticheskoe uslovie povysheniya kachestva znaniy uchashchikhsya v sredney shkole* [Variation in Teaching Physics as a Didactic Prerequisite for Increasing the Quality of Knowledge in Secondary School] (Chelyabinsk State Pedagogical University, 2007), and others).

However, introduction of module-based learning, discriminating between invariant and variant parts, and any other new approaches to organizing the learning process cannot solve the problem of building a modern physics course—a fundamental decision regarding the content of such course should be made in the first place. Besides, organizational challenges associated with implementation of new approaches may give rise to contradictions with the principles of continuity, consistency, and conformance to the basic science.

Nonlinearity in selecting the content and building the course inevitably entails changes to the basic unit of learning, e. g. learning situation. Degree seekers apply a lot of effort to elaborate conditions and identify opportunities for project activities in teaching physics (Tretyakova S. *Estestvenno-nauchnye proekty kak sredstvo formirovaniya uchebno-informatsionnykh umeniy u uchashchikhsya pri obuchenii fizike* [Science Projects as a Means of Developing Learning and Information Skills in Physics Students] (Moscow State Pedagogical University, 2004); Barkova Y. *Podgotovka uchashchikhsya k proektnoy deyatelnosti pri obuchenii fizike v sredney shkole* [Preparing Students to Project Activities while Teaching Physics in Secondary School] (Astrakhan State University, 2006); Loboda Y. *Proektnaya deyatelnost v oblasti fizicheskogo eksperimenta kak sredstvo formirovaniya professionalnykh kompetentsiy u studentov pedagogicheskogo vuza* [Physics Experiment Projects as a Way of Developing Professional Competencies in Prospective Teachers] (Tomsk State Pedagogical University, 2006); Vechkanova N. *Proektno-modulnaya sistema* *obucheniya fizike v osnovnoy shkole kak sredstvo razvitiya uchashchikhsya* [Project and Module Technology of Teaching Physics in Secondary School as a Student Development Tool] (Moscow State Pedagogical University, 2009); Grudinina V. *Formirovanie professionalnogo samoopredeleniya obuchayushchikhsya v proektnoy deyatelnosti po fizike v obshcheobrazovatelnoy shkole* [Getting General School Students to Construct Their Professional Identity through Project Activities in Physics] (Moscow Region State University, 2015), and others).

Another promising area is based around considering the unit of learning to be a physics problem and elements of problem solving in all other types of cognitive learning activities. This offers an opportunity to design physics education on the basis of training problems and thus provide the necessary level of information richness and solidity of basic knowledge, on the one hand, and effectiveness and flexibility of the content of physics as a subject, on the other hand (Vorobyev I. *Uchebnaya zadacha kak metodicheskaya osnova postroeniya kursa fiziki* [Training Problem as the Methodological Basis of a Physics Course] (Novosibirsk State Pedagogical University, 2002); Larchenkova L. *Obrazovatelny potentsial uchebnykh fizicheskikh zadach v sovremennoy shkole* [Educational Potential of Training Problems in Modern School Physics] (Herzen State Pedagogical University of Russia, 2014)).

Researchers are starting to explore this topic (8% of theses), though mostly in relation to higher education so far: reforms are easier to implement in universities than in schools because the former are more willing to change the way learning is organized (e. g. to introduce module-based courses) and have intellectually mature students.

The new content of physics education and the new approaches to teaching physics necessitate justification of creating new training aids and analyzing their effectiveness. Integration of information technology is one of the key factors that drive changes in the methods, means and forms of teaching physics. It provides illustrative properties of a new type, allowing to support courses with electronic materials, and generates new instructional models (distance learning, flipped classroom, etc.) and assessment tools. Various aspects of applying information technology in teaching physics are quite popular among degree seekers, with 13% of all theses devoted to the topic, e. g. Nazarov A. *Informatsionnye i kommunikatsionnye tekhnologii v sisteme otkrytogo obucheniya fizike v regionalnom vuze* [Information and Communications Technology in the Physics Open-Learning System of a Regional University] (Herzen State Pedagogical University of Russia, 2005). Another vital aspect of modern physics education is using computer for its original purpose, i. e. to perform a large amount of mathematical calculations within a short time. The possibility of doing such calculations right then and there transforms the requirements for mathematical background of students [Laptev, Shvetsky 1996], on the one hand, and enhances the role of qualitative methods in teaching physics at all levels of education, on the other hand. These methods become especially important as educational priorities change, bringing the development of methodological knowledge and skills to the foreground. Knowing the qualitative methods of analyzing physical situations, students can not only explain specific physical phenomena but also predict the nature of different scenarios and new physics phenomena in some cases.

The opportunity of expanding the range of physics problems by involving computational methods and programming was first demonstrated at the very beginning of introducing computer technology to the learning process [Kondratyev, Laptev 1989; Bursian 1991]. Later, it was developed in two directions of student activities: (i) analyzing pre-configured computer models by modifying widely the parameters of analyzed systems and (ii) actually programming physical phenomena and processes in high-level languages. The existing software allows using mathematical packages (MatCad, MatLab, Maple, etc.) to construct more complex models of physical phenomena even without any deep knowledge of specific computational procedures or programming languages (see, for instance, [Kondratyev, Lyaptsev 2008]).

Creating computer models with the help of mathematical software is available not only to university students but also to school students under the guidance of teachers. This approach is revolutionary for general school practice and certainly requires research and methodological support. However, only 10% of theses devoted to using information and computer technology in teaching physics address using the technology to teach students computer modeling of physical processes so far, and they mostly deal with university education.

Of course, only highly qualified teachers with a strong background in the field can guide students in this type of work at any level of education. Unfortunately, the ongoing reduction of the physics component in curricula of teacher training universities is clearly going against these practical needs [Gorokhovatsky et al. 2015]. Nevertheless, researchers address the need for physics teachers to master new activities more and more often, which also proves the importance of the topic (Oskina O. *Metodika obucheniya osnovam kompyuternogo modelirovaniya budushchikh uchiteley fiziki v pedvuze* [Methods of Teaching the Basics of Computer Modeling to Prospective Physics Teachers] (Samara State Pedagogical University, 2000); Popov S. *Vychislitelnaya fizika v sisteme fundamentalnoy podgotovki uchitelya fiziki* [Computational Physics in the Fundamental Physics Teacher Training System] (Herzen State Pedagogical University of Russia, 2006); Savateev D. *Kompyuternoe modelirovanie v izuchenii fizicheskikh osnov elektromagnitnykh yavleniy v kursakh obshchey fiziki i spetsialnykh distsiplin tekhnicheskogo vuza* [Computer Modeling in Teaching Physical Principles of Electromagnetic Phenomena in General Physics and Specialized Discipline Courses of a Technical University] (Murmansk State Technical University, 2007)).

4.3. Which conditions should be prioritized to develop physics education in the new context

Effectiveness of modern physics education is determined not only by its planned content and technology used in the learning process. It depends to a large extent on the quality of students and development opportunities they are offered. It is vital to identify students with not only research skills but also a disposition for research. Such students are the hope for a breakthrough development of Russian science, bridging the technology gap, and ensuring a sustainable economic growth.

"Anyone who believes intelligence is concentrated in the head of a specific individual is grossly mistaken. In fact, intelligence exists not only in books, dictionaries and notebooks that we use but also in the heads of other people with whom we interact." [Bruner 2006] "Your chance of winning a Nobel Prize, interestingly, increases immeasurably if you have worked in a laboratory with somebody who has already won one, not just because of "stimulation" or "visibility", but because you have shared access to a richer distribution network" [Ibid.], argued Jerome Bruner, referring to other researchers. Science and technology parks, development programs from the leading research universities, and early engagement of students in lab research are designed to create such nutrient medium for talented students.

An integral learning and development system is necessary to bring gifted and interested students to the community of young promising physicists. Such system traditionally includes physico-mathematical schools, the Olympiad movement, and various creative science and technology competitions. Several doctoral theses are devoted to scientific justification of developing this system under the present-day conditions, which proves that the topic is truly relevant and demanded (Shompolov I. *Sistema vyyavleniya, podderzhki i razvitiya molodezhi, odarennoy v oblasti fiziki* [A Method of Identifying, Supporting and Developing Young Students Gifted in Physics] (Moscow Institute of Physics and Technology, 2003); Gurina R. *Podgotovka uchashchikhsya fiziko-matematicheskikh klassov k professionalnoy deyatelnosti v oblasti fiziki* [Preparing Students of Physico-Mathematical Classes to Careers in Physics] (Ulyanovsk State University, 2007); Ryzhikov S. *Razvitie issledovatelskikh sposobnostey odarennykh shkolnikov pri obuchenii fizike* [Developing Research Skills of Gifted School Students in Physics Class] (Moscow State Pedagogical University, 2015)).

Identifying talented school students and motivating them for an in-depth study of physics requires some research to determine the means of mass-scale student motivation and the prerequisites for enhancing the level of mass physics education. The relevance of such research is multiplied as physics courses are being largely cut at all levels of education. University physics is designed more and more to reinforce what was learned at school, while deeper learning is impeded by insufficient basic knowledge and skills possessed by yesterday's high school graduates [Gorokhovatsky et al. 2015; Kozhevnikov 2015].

The concerns about physics background of high school graduates and first-year students of different universities have already been reflected in thesis research (Danilyuk I. *Tekhnologiya razvivayushchego obucheniya v sisteme profilnoy podgotovki abiturientov tekhnicheskogo vuza po fizike* [Developmental Teaching Techniques in Specialty-Specific Physics Courses for Technical University Candidates] (Samara State Technical University, 2006); Vaganova T. *Modulno-kompetentnostnoe obuchenie fizike studentov mladshikh kursov tekhnicheskikh universitetov* [Module and Competency Based Physics Education for Underclassmen in Technical Universities] (Moscow State Pedagogical University, 2007); Starikova Y. *Adaptivnaya napravlennost metodiki obucheniya osnovam fiziki studentov meditsinskogo vuza* [Adaptive Technology in the Methods of Teaching Basic Physics in Medical Universities] (Chelyabinsk State Pedagogical University, 2009); Polonyankin D. *Metodika formirovaniya motivatsii uchebnoy deyatelnosti pri obuchenii fizike studentov mladshikh kursov* [Methods of Developing Motivation for Learning When Teaching Physics to Underclassmen] (Dostoyevsky Omsk State University, 2011), and others).

4.4. What risks for physics education can be anticipated

The envisaged changes to the physics learning approaches may result in some cognitive challenges for different categories of learners, school students particularly.

Physics as a school subject is considered to be difficult and thus barely attractive. This widespread belief has contributed a lot to shrinking the number of hours in the school physics course, despite its developmental potential. One of the reasons behind the decrease in motivation for learning physics is typical cognitive barriers and mistakes that are regularly faced by students, making them believe that the subject is too sophisticated. It becomes important to find ways of detecting such cognitive barriers at an early stage, identifying where they come from and how they can be surmounted or, better, prevented [Larchenkova 2013]. Even effective traditional methods have to be revised due to the fundamental transformations going on in the human mind today.

Too little attention is paid to the origins of students' cognitive barriers: we found only three works in the database analyzed (Rykov V. *Metodika korrektirovki bazovykh znaniy po fizike* [Methods of Correcting the Basic Knowledge of Physics] (Kuban State University, 2003); Yakovets Y. *Preodolenie matematicheskikh zatrudneniy uchashchikhsya pri obuchenii fizike v osnovnoy shkole* [Overcoming Mathematical Barriers of Students When Teaching Physics in Secondary School] (Moscow State Pedagogical University, 2007); Rogova I. *Metodika organizatsii raboty so slabouspevayushchimi uchenikami v protsesse obucheniya fizike* [Methodology of Dealing with Lagging Students When Teaching Physics] (Kurgan State University, 2008)). In practice, cognitive barriers are surmounted by trial and error, while theses only acknowledge the fact of their existence and describe specific problems of physics learners without trying to find their underlying causes.

At the level of secondary education, attempts to overcome such barriers are made using the differentiated approach to teaching physics, which includes creating specialized classes and grouping students based on their skills and abilities. However, while organization of physics courses for classes and schools of different types—specialized, mass, special—has been studied quite actively, much less attention is paid to cognitive barriers in learning physics. Meanwhile, they are regularly faced by all categories of students.

Talented school students may also experience some difficulties [Sheblanova 2003], so they should be helped to unlock and realize their full potential. Teaching such students should build upon their strong points and upon engaging them in activities that help them unleash their talent, provide them with immediate chances for successful realization of their capabilities and needs, and boost their ambition to overcome barriers.

Teaching children with disabilities, including those that cause developmental delay, is also of critical importance today. Such students go to special schools, many of which offer physics courses among others. Further socialization of special school graduates makes it vital to teach them all general education subjects: a standard secondary school background will enable them to enter a special vocational institution, learn a profession, and get a job. However, there is no information on teaching physics to special students in any of the textbooks, guidance materials, or recommendations available. Teachers are left to deal with cognitive problems of such students face to face and solve them using intuition and improvisation, with varying degrees of success. Neither did we find any thesis on teaching physics in special schools. This research avenue needs desperately to be developed in the context of the growing demand for inclusive education.

Thesis research has never addressed the risks associated with integrating information and communications technology into education. Degree seekers pay a lot of attention to the technology as such, but they mostly adjust it to the learning process, considering it an unconditional benefit. Meanwhile, there is the other side of the coin, too. For instance, the exponential growth of information, as well as its diversity and dialogue at different levels of the social system result in so-called "clip thinking", where people begin to perceive information as mosaic and fragmentary and lose their ability to analyze and build long logical chains. Obviously, it does not contribute to understanding physics. People with "clip thinking" develop good multitasking skills and the ability to switch very quickly between different sources and bulks of information. Is it good or bad? On the one hand, these qualities act as antagonists, since responsiveness develops through concentration, and vice versa. On the other hand, the need to perceive information in fragments as a defense reaction to information overload is not a new phenomenon. Textbooks, reference books and encyclopedia are designed to be read in portions and allow readers to use specific parts of their content as needed. Even a physics problem as a teaching tool is in line with this thinking development trend, its setting representing a clip-like resume of a real-life situation.

Identifying the positive and negative effects of using information and communications technology in physics education will require a cross-disciplinary research and a concerted effort of researchers from different fields, including psychologists, physicists, methodologists, and IT experts.

Scientific justification is also required to underlie the development of physics teaching materials, i. e. textbooks, problem books, and supplementary guidebooks, to meet the requirements imposed by the modern level of basic science, the new instructional approaches, and the different ways in which information is perceived and processed by different categories of students. Although a good deal of physics textbooks has been created in the recent years, there has long been no research to be used as a basis for them. The problem is also pressing for higher education, where teaching aids tend to turn into look-up dictionaries, the methodological value of which falls dramatically due to information availability provided by the Internet [Kozhevnikov 2015]. In our database of theses, we managed to find only one devoted to comparative analysis of the existing physics textbooks for secondary school—Lezhepekova O. *Sravnitelny analiz ispolzovaniya sovremennykh uchebnikov fiziki v osnovnoy shkole* [A Comparative Analysis of Using Modern Physics Textbooks in Secondary School] (Vyatka State University of Humanities, 2009)—and none on digital textbooks. Meanwhile, the demand for e-textbooks is increasing, whereas no relevant requirements have been defined so far, and the whole process has been showing little progress.

5. Conclusion

An investigation into the topics of theses in specialty 13.00.02 "Theory and Methods of Teaching and Education (Physics, Secondary and Tertiary Education Levels)" defended for the last 16 years, the directions of physics development, and the needs of modern physics education allows us to draw the following conclusions.

- Physics education, which lays the foundation for a long-term development of science and technology, is designed to develop personal qualities important not only for doing research but also for living a successful everyday life of a 21st-century person.
- Due to the recent changes in the sociocultural context, various types of learners get more access to thesis research, which creates additional requirements to the relevance and novelty of topics.
- The range of thesis topics is unbalanced, with the least interest shown in such directions as design, testing and performance as-

sessment of physics syllabi of different types and levels, cognitive processes of physics learners, and development of physics teaching aids including textbooks.

- The desirable avenues of physics education development, which need to be supported by research (theses in particular), are closely interrelated. Such avenues include, first of all:
  – Upgrading the content of physics education to make it reflect not only the fundamental principles but also recent physics discoveries, selected and adapted for perception by various categories of learners;
  – Designing new nonlinear syllabi, textbooks, and learning kits to provide diversity and variation when teaching physics to different categories of students in educational institutions of different types;
  – Using new information technology in education not only as a means of illustration and learning process organization but also as a way of transforming the essential basics of teaching physics;
  – Ensuring cohesiveness and continuity of teaching physics across all levels of education and all categories of students.
  – While making no pretence to absolute completeness or finality of our recommendations, which would be inappropriate for a scientific inquiry, we nevertheless believe that the abovementioned research avenues could be defined as top priorities in the research on theory and methods of teaching physics for the foreseeable future.

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