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Meta-Subject Approach to Development of Educational Courses for Masters in STEM-Specialties

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Abstract. This paper discusses the issues of meta-subject construction of "Special chapters of physics" course contents for masters in STEM-specialties. The main informative unit of the course – the term of physical world-image (PWI) – displaying coherence and correlation of humanitarian, science and technology knowledge is introduced. The choice of methodological platform for PWI conceptual apparatus systematization – a theory of "scientific revolutions" by T.Kuhn – is justified. It has been indicated that the upper-mentioned basis could allow to present PWI structure as two interrelated blocks: scientific paradigm and scientific knowledge. PWI scientific paradigm block is represented by two conceptual levels: philosophical and scientific perceptions. PWI scientific knowledge block is divided to empirical basis, theoretical basis and PWI core. Technology of construction of every conceptual level reflecting the logics of every PWI scientific knowledge development is described. It is also shown that utilization of T.Kuhn's paradigmatics allows explaining genesis and development of mechanistic, electrodynamic and quantum-and-field world image using the single methodological positions. Contents of educational modules of the course and elements of an educational and methodical complex are provided. Complex of meta-competencies which can be formed during the practical educational implementation of the offered approach to course contents construction is analyzed.

1. Introduction

Modern stage of the world's educational system development is oriented on formation of meta-competencies within the students, contributing to their cultural, personal and cognitive development. A problem of studying the essence and structure of meta-competencies, as well as mechanisms of its formation has already gone beyond the scope of the educational system in both foreign [1,2,3,4] and Russian researches [5,6,7,8]. Current problem is becoming the subject of study for many sciences – sociology and cultural studies, engineering and knowledge management, theories of administration and measurements [9,10,11,12]. Despite a substantial layer of studies the problem is still far from its theoretical and practical solution. Theoretical aspect demonstrates lack of studies on epistemology and semantics of such complicated definitions as meta-knowledge and meta-competencies; lack of unambiguous approach to identification of complex of necessary meta-competencies that form professional and personal status of the future specialist. Practical aspect lacks justified studies revealing technologies of meta-knowledge and meta-competencies formation, as well as mechanisms of meta-subject approach realization in the framework of educational subjects.

Nevertheless, in regard to changes in educational guidelines, meta-subject approach to construction of educational courses and organization of educational process is considered as a basis to the formation of holistic mindset and to mastering universal activity methods. In the framework of each discipline informative, methodic and didactic means should be revealed and reasonably implemented. These means may assist in formation both meta-knowledge (that is knowledge about its premise and structuring) and meta-competencies (systemic mindset, cognitive skills, etc.).

In this respect it is hard to overestimate the contribution of physics course to meta-knowledge and meta-competencies formation. Scientific knowledge of physics inherently becomes meta-subject. Epistemological basis of physics identify its interrelation with philosophy, logics, methodology of science and represent a part of universal human culture. Ontological basis of physics "rule" the construction of scientific knowledge of a large range of science and technology disciplines. However, in real educational practice a powerful methodological and philosophical foundation of physical knowledge stays beyond the students' "cognitive map" at least in the system of Bachelor's degree. This is linked to a great complex of both objective and subjective reasons. They include a drastic decrease of labor input to Physics as a discipline and informative unpreparedness of students for perceiving "meta-subjectness" of physical knowledge (not introduces to courses on philosophy, logics, theoretical mechanics, technology disciplines) and a set of didactic reasons.

It becomes feasible to solve this vital sociologic, cultural and pedagogic task at a higher level of educational structure – the system of Master's Degree. Practically on every specialization of academic and applied technical master's degree the course "Special issues (chapters) of physics" is regulated by modern educational standards. Traditionally present course includes elements of physical knowledge forming the system of technical knowledge of corresponding subjects area which is either not discussed at the level of Bachelor's degree or requires a more detailed consideration and comprehension. Generally, the issues of physical knowledge and scientific cognition methodology remain outside the informative focus, as well as the issues of construction of scientific knowledge principles for both physical and technical knowledge. It is noteworthy that American and West European universities almost always include integrated educational courses on methodology of science and physics into educational practice of all the majors of STEM-specialties master's degrees (Science, Technology, Engineering, and Mathematics) synthesizing humanitarian, science and technology programs of Bachelor's degree [13,14,15].

Considering a high educational status of Master's degree, it seems appropriate to actualize the preparations of meta-subject approach to build establish the contents of this course based not on statements about discrete branch of physics but on highlighting methodological and philosophical issues of physical knowledge, its dominant role in the complex of sciences about Nature and the system of technic knowledge. This paper demonstrates experience in development of such course implemented in a Far East State University's educational practice in the context of an academic system of master's degree in "IT-technologies" 11.04.02.

2. Main section

Focusing on the "meta-subjectness" of the course "Special chapters of physics" demanded identifying the conceptual basis for an organic inclusion of methodological and logical knowledge (meta-knowledge) into the course contents allowing to internally integrate physical knowledge with methods of its cognition during the process of studying. The ultimate form of scientific knowledge is the term of the world image [16]. Physical world image is the ultimate level of knowledge systematization which most closely reveals the interrelation between physics and philosophy, logics and methodology [17]. That is why the term "physical world image" stood out as meta-subject category, on which scientific and educational physical knowledge may be structured. A theory of "scientific revolutions" by T. Kuhn was chosen as a methodological basis of structuring. It's worth mentioning that in the 20-th century in a framework of West European and American neo-positivism a substantial amount of interesting, albeit controversial, concepts of development logics and principles of scientific knowledge formation were suggested [19,20,21]. A concept of scientific revolutions appears the most interesting for us

in terms of its adequacy in the logics of physical knowledge development. The history science was presented by T.Kuhn as a changing of general perceptions about the ambient reality, strategies of scientific investigation and methods of scientific activity. He introduces to science a fundamental term that allows describing and differentiating these stages of science history – the term of paradigm defined as a system of knowledge commonly accepted at a current moment of time, and methods of investigation of the ambient reality. This way, the process of science development was considered by T.Kuhn as a two-phase process. Formation of paradigm (phase of seeking "scientific justification") is replaced by the phase of "normal science", which after exhaustion of its possibilities is again replaced by the phase of seeking scientific justification. Replacement of paradigm means a scientific revolution. In our point of view, this approach to the process of science development allows to reveal genesis and development of all three PWI, highlighted in physics methodology – mechanistic (MWI), electrodynamic (EDWI), and quantum and field (QFWI) world images – and therefore, demonstrate their replacement (that is a scientific revolution).

Based on this conceptual structure of a physical theory was presented as two interrelated conceptual structures: "scientific paradigm of PWI" and "scientific knowledge of PWI" blocks. In turn, the structure of every block was identified by the following considerations. Universal philosophical categories revealing the essence of outside world phenomena serve as ground for systematizing and structuring any scientific knowledge. As part of physical world image such categories are matter, movement, space, time, and interrelation. Hence, dialectic row of these terms has formed an ultimate level of "science paradigm of PWI" block – level of general perceptions. Underlying physical term, ideas, principles forming the second level – level of general perceptions – function as a transitional element from philosophical level of methodological theory analysis to the level of its scientific knowledge.

Scientific paradigm forms the second structural element of PWI – scientific knowledge. With a view toward realization of inductive-deductive method of physical cognition students need to clearly picture that the integrity of physical knowledge is provided by interrelation of empirical and theoretical knowledge elements. Involvement of mathematics' methods and logical operations of generalization, analysis, synthesis, abstraction, etc. to the process of cognition leads to building fundamental physical laws comprising a conceptual foundation of a corresponding world image. For these reasons, the structure of "scientific knowledge of PWI" block was represented by three conceptual levels: empirical basis, theoretical basis, and the core of physical world image.

Consequently, the use of T.Kuhn's concept allows to introduce the whole set of physical knowledge as a logically interrelated conceptual structure and, thereby, trace the methodology of physical cognition. In the course of teaching it can be amply demonstrated how appearance of "abnormal elements" of scientific knowledge leads to gradual change in perceptions about fundamental philosophical categories, in other words, to replacement of an existing paradigm. For instance, the sector of electric and magnetic phenomena was not explained by perceptions about the matter as physical substance and mechanistic concept of interrelation (concept of action at a distance). The study on regularities of movement of particles with speeds close to the light speed was not explained by perceptions about absolute space and time. These scientific facts basically expanded the mechanistic paradigm leading it to the point of bifurcation – scientific revolution happened – mechanistic world image was replaced by electrodynamic WI. In turn, in the context of EWI knowledge elements appeared (thermal radiation, photoelectric effect) explanation of which led to introduction of radically different perceptions from classical ones on discreteness and corpuscular-wave dualism of the matte – electrodynamic paradigm was replaced by quantum and field WI.

The choice of primary methodological setup for selecting and structuring educational knowledge of "Special issues of physics" discipline defined the informational field and logical structure of the course. An educational content of the course is structured in two modules. The first module includes the main stages of science of physics development from antiquity to the present days. Issues of methodology of scientific cognition and logics of scientific knowledge development are considered. Special attention is payed towards the most interesting approach to solution of this problem, according to authors' opinions, - theory of "scientific revolutions" by T.Kuhn.

In the content of the second module physical knowledge is presented at a higher level of systematization – level of PWI. From the point of T.Kuhn's paradigmatics genesis and physical knowledge development can be seen – it is shown how the appearance of new physical ideas contributed to distraction of an existing scientific paradigm and led to formation of a new paradigm. Underlying ideas of mechanistic, electrodynamic, and quantum and field WI were marked.

3. Conclusion

Thus, the main educational aim of course contents construction was focused on formation not merely a set of physical knowledge during the process of teaching, but a system of knowledge about the structure, principles of organization and logics of development of this knowledge, ways of its acquisition universal for thhe entire science and technology world, in other words, - meta-knowledge. The extent of interiorization of this knowledge – or level of particular components of meta-competencies – is evaluated according to the results of students implementing four creative tasks.

For a successful execution of the first three tasks – "Structure and the main contents of MWI/EDWI/QFWI" – students need not only to possess theoretical knowledge on the corresponding branch of physics, but also to demonstrate sustainable skills at analytical-and-synthetical components of cognition for logical reflection of cause-effect relationships of the physical knowledge. Implementation of these tasks is targeted a formation of a set of important informational components of meta-competencies – the increasing role of systemic cognition, management of available information and regulation of cognitive processes, ability of self-development and self-reflection.

The fourth task – "Physical basis of modern IT-technologies" – is targeted at highlighting meta-subjectness of physical knowledge in the system of technical knowledge. For its successful execution students need not only to possess the knowledge in the branch of the science of physics, but also to explicitly imagine the structure and contents of "IT-technologies" subject area and perspectives of its subsequent development. Implementation of this task also contributes to formation of such important elements of meta-competencies for a future engineer as cognitive mobility, creativeness, criticism, and orientation towards problems as well as capability to predict and evaluate results.

Taking a principal novelty of the offered educational material into consideration, multimedia educational handbook was developed supporting the extent of learning and implementation of the offered tasks [22]. The contents of the handbook includes an incomplete version of a corresponding course of lectures, however it fully complies with the logics and the structure of the given lectures. Annexes of the handbook are briefly demonstrating general elements of physical knowledge addressing to which students can get some help implementing the offered tasks – to presents their own vision of a corresponding world image.

In our opinion, the suggested approach to development of "Special chapters of physics" educational course contents emphasizes a multileveled and meta-subject character of physical knowledge, on the one hand, and introduces students to the modern approaches in methodology of scientific cognition, on the other hand, widening educational and eruditional significance of the course.

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