

Using CHAT to Address the Nature of Scientific Knowledge Aspects on a PD-Program for Greek Science Teachers as a Cycle of Expansive Learning

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A Science Teachers' Professional Development (PD) Program on Nature of Scientific Knowledge (NOSK) aspects is designed, implemented and evaluated, based on the cycle of expansive learning. A needs analysis showed that NOSK is not explicitly included in Greek Science classes and its integration might be a solution to students' indifference towards them (questioning phase). A relevant literature review highlights three approaches to teach NOSK: through History of Science (HOS), Scientific Inquiry (SI) and Socio-scientific Issues (SSI). The PD-program includes all three, in that order, to provide the 49 participant-teachers alternative paths to embed NOSK in more school science units, designed according to the community of trainees' Cultural-Historical characteristics and the Principles of Adult Education (analysis and modelling phases). Teachers examine and test the new model (4th phase) through a voluntary assignment to design and present a lesson plan to the plenary. The implementation phase consists of teaching in the classroom and a 5th meeting, finishing with a 6th meeting (reflecting phase). Arisen contradictions are dealt to evolve the whole activity system. Works for evaluation are included in all phases. Results to that point show that the PD-program is successful.

Keywords: Cycle of Expansive Learning, Nature of Scientific Knowledge, Continuing Professional Development, Secondary School.

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Introduction

The importance to include Nature of Science (NOS) aspects in science teaching is acknowledged among all researchers. The arguments for this are: a) better understanding of the limitations of science, b) increase interest in the classroom, c) achieve better understanding of scientific knowledge and d) achieve scientific literacy (related to citizen education) [35; 34]. Scientific literacy is widely adopted worldwide in science curricula [4; 33]. However, even though researchers and curricula designers agree that NOS needs to be taught – and specifically in an explicit way [34; 35], there is no consensus on a common list of NOS aspects [35; 39; 9; 3; 37; 17; 50].

As for Greece, even though there is academic work in the field [40; 41; 49; 25], a survey [28; 30] showed that NOS is not included in the Greek secondary education and graduates have naïve views on it.

In the present work, the design, implementation, works for evaluation and initial results of a Professional Development (PD) program on teaching NOS aspects to 49 science teachers are presented. We prefer to use the term “Nature of Scientific Knowledge” (NOSK), to communicate more accurately what is meant by NOS [35], by referring to the characteristics of scientific knowledge that are inherently derived from the manner in which it is produced (Scientific Inquiry) and are suitable for K-12 students to learn about.

We adopt Cultural Historical Activity Theory (CHAT) [14; 16] as a guiding framework for the design and analysis of the PD-program, which is in agreement with Roth and Lee's view [45]: “*adopting CHAT as a guiding framework allows for a questioning of the structural determinations of current educational practices*” and has been used by many other researchers in the field of Curricula design and teacher training, in science and other fields [26; 27; 44; 22; 10].

Education is a complex, multi-parametric activity system, that interacts in network relations with other systems, via the conceptual tools it has developed [14], where they merge as “*a constellation of two or more activity systems that have a partially shared object*” [16]. CHAT was selected so that we can deal with the complexity of education’s activity system. For example, the analysis of the interaction between the trainer and the trainees, using tools (educational means) to teach an object (a common ternary relation) is not an analysis of the activity system of education. The framework of Activity Theory suggests that the excess of the directly visible dual and ternary relations among the nodes of the system define the way in which the other nodes are present and influence the examined condition [27].

Nature of Scientific Knowledge (NOSK) aspects

For the past 100 years, the definition of Nature of Science (NOS) and its aspects has been a matter of constant debate between philosophers/historians/sociologists of science and educators. Still, there is no consensus among them, but they all agree that it is necessary to be included into Science teaching [34; 41]. In the present work, we prefer to use the term “Nature of Scientific Knowledge” (NOSK) to refer to the characteristics of scientific knowledge that are inherently derived from the manner in which it is produced (Scientific Inquiry). Those characteristics are [34]:

(A1) Scientific knowledge is empirical, observations and inferences are different

Scientific knowledge is based on/derived from empirical data. Observations are descriptions of natural phenomena that are directly accessible to the senses, or an expansion of them. They are subject to limitations of existing equipment and the dominant theory, but observers usually reach consensus on what they see-hear-feel etc. Inferences are the explanation of observations and same observations could lead to different inferences, according to researchers’ background.

(A2) Scientific knowledge is creative

Scientific research – opposite to common belief – is not a rational and orderly procedure. It requires scientists’ creativity and imagination in all parts of research: design, data collection and invention of explanations, similar to the creation of an artistic work.

(A3) Even though objectivity is the goal, subjectivity within scientists is unavoidable

Each individual scientist is affected – during interpretation of results, observations, and research design – from his/her personal commitments, previous knowledge, training, expectations and etc. Even though through history of science, objectivity is the goal (through standard scales and precision in measurement), subjectivity is unavoidable. Science is also a social activity: Scientists are interacting with each other through scientific publications; their consequent criticism and continuous testing enhances its objectivity.

(A4) Scientific knowledge is durable, but subject to change in the light of new evidence

Scientific knowledge is reliable and durable, however not absolute and certain. There is always the chance to alter it, either due to evolution in technology and new instruments that lead to new evidence, or because old evidence is re-interpreted.

(A5) Science’s socio-cultural embeddedness

Science is a human endeavor that affects and is affected from all societal, cultural, philosophical, religious, political and economic factors.

(A6) Scientific laws and theories are different kinds of knowledge

Laws are generalized descriptions of relationships among observable phenomena and are based on many observations. They describe what happens in the (usually idealized) natural world, but never explain why. Those inferred explanations are theories.

Cultural-Historical Activity Theory (CHAT)

CHAT is a “cross-disciplinary framework to study how humans purposefully transform natural and social reality, including themselves, as an ongoing culturally and historically situated process [45]. There is a big spectrum of socio-cultural theories where CHAT was always included. Its origins are traced in the classical German philosophy (from Kant to Hegel), in the writings of Marx and Engels, and in the Russian studies in psychology of Vygotsky, Leontiev, and Luria. They saw behaviorism and analytical psychology as unable to manage the material and cultural reality which was then on the scene. The concept of activity became very important in the societal setting, and the focus was on activity as the unit of analysis. Two kinds of activity element were distinguished: the cultural-historical and the material [41]. The cultural-historical activity theory was expanded, organized, and increasingly used to create contemporary research environments with emphasis on the studies of human activity [14]. There was an increase in international interest in Activity Theory during the 1990s, while today the theory holds a significant role in many scientific fields such as psychology, work research and education, in many countries worldwide [16; 25; 43]. Furthermore, international journals and books are dedicated to cultural studies of science education, and the ISCAR.ORG international society supports a thematic section on Socio-Cultural approaches to Science Technology Engineering Mathematics (STEM) Education (<https://www.iscar.org/organisation/sections/thematic-sections/>).

In the specific field of science education, some scholars underline that teaching and learning science transcends the transmission of knowledge and facts and go even beyond participation in the community; they consider science education as contribution by both teachers and learners in an agentive, authorial, authentic and activist way, to the gist of science [49].

Learners become engaged in science activities and they use artifacts, that is, material objects or processes which are products of human activity [8] in order to deal with a scientific concept. Furthermore, they interact with one

another as well as with tools and means into the community of learners and work on the construction of knowledge with outcomes that are scientifically accurate [14].

Engeström (1987) presented Leontiev's views, using the triangle for human activity systems, (see Figure 1 [5; 43].

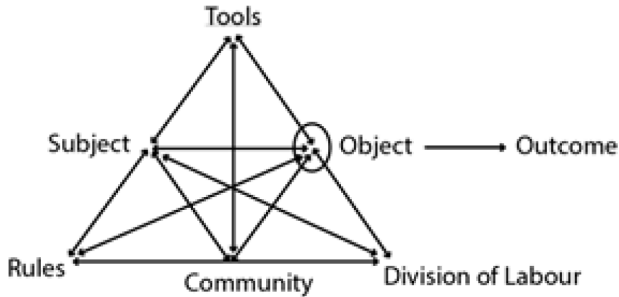


Fig. 1. The structure of a human activity system

The relations between the Subject (usually people, but lately they are also corporations that are moving towards a desired goal) and the Object (the goals of the activity) are mediated through tools, community, rules and division of labor [19]. Tools and artifacts are culturally produced means that subjects use to perform the activity. They may be material, like a magnet, a telescope, or mental, like language. Community refers to all the participants who share the same object, and shapes and directs individual actions to the collective activity. Division of labor refers to the way subjects i.e. members of the community divide their responsibilities during an activity. The triangle of the activity system refers both to the horizontal actions and interrelations between the members of the community and the vertical distribution of power, resources and relative societal or professional status [43]. The nodes of an activity system are not static and isolated to each other, but they are dynamically connected; the system is regarded as a unity [18].

Then, Engeström [14] moved beyond the barriers of one activity system, including minimally two activity systems that interrelate, promoting multiple perspectives, dialectics, and networks for collaboration (see Figure 2, [14]).

Contradictions and tensions that might appear would play a crucial role as the most important motive for development of human actions, transforming both the activity and the outcome [43]. Engeström's suggestions could be summarized in the following five principles:

an activity system a) is the unit of analysis, b) is multi-voiced, c) its problems and potentials can be understood against their own history, d) contradictions are the driving force of change and e) through the cycle of expansive learning it is possible to study the transformations of the activity system, while it is reconceptualized to embrace a radically wider horizon of possibilities than in the previous mode of the activity [14].

Engeström and Sannino [16] give an ideal-typical sequence of actions in an expansive cycle, which is presented in detail, because the whole PD-program was designed and implemented based on the cycle of expansive learning:

- The first action is that of questioning. Participants in an activity system are criticizing or rejecting some aspects of the accepted practice and existing knowledge. Primary contradictions appear, within each and any of the nodes of the activity system.
- The second action is an analysis of the situation to identify systemic tensions or contradictions within and between activity systems. Secondary contradictions appear between two or more nodes, e.g. a new object and an old tool.
- The third action is that of modeling, to construct an explicit, simplified model of the new idea that explains and offers a solution to the problematic situation.
- The fourth action is about examining and testing the model to establish its potential and limitations
- The fifth action is implementing the model by means of practical applications, enrichments, and conceptual extensions. Tertiary contradictions appear, between a newly established mode of activity and remnants of the previous mode.
- The sixth and seventh actions are those of reflecting on and evaluating the process and consolidating its outcomes into a new stable form of practice. Quaternary contradictions appear, between the newly recognized activity and its neighboring activity systems.
- The above are illustrated in Figure 3 [16].

The process of expansive learning should be understood as construction and resolution of successively evolving contradictions. In expansive learning learners are involved in constructing and implementing a radically new, wider and more complex object and concept for their activity and implement this new object and concept in practice. It is worth mentioning that all strategic actions presented in Fig. 3 are an indicative series of steps and not a "universal formula" that follow each other automatically. Some steps might be skipped [43; 16].

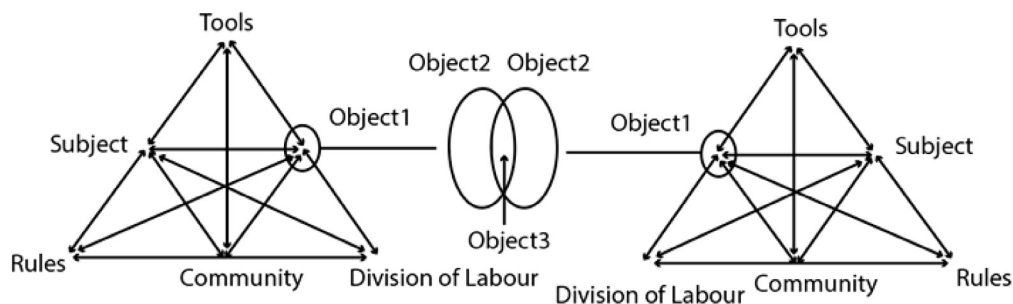


Fig. 2. Two interacting activity systems [14]

The process of expansive learning should be understood as construction and resolution of successively evolving contradictions. It is worth mentioning that all strategic actions presented in Fig. 3 are an indicative series of steps and not a “universal formula” that follow each other automatically because any step might be missed [43].

Design & Implementation of the PD-program

The PD-program was co-organized with the 4 Lab Centers (EKFE) of Thessaloniki. Forty-nine science teachers participated voluntarily; their average age was 50 years old and they worked in education for 10–30 years. It took place in twilight courses and during mornings teachers followed their regular program at school: that was deterring for a long-lasting program. It was decided to have four 3-hour meetings, one per fortnight. The first one took place on April 2018. At the end of the 4th meeting, teachers asked for a 5th meeting, which took place on December 2018 and lead to another one, on May 2019. The first writer, after the required permission, observed 9 of the above teachers in their classrooms during the school year 2018–19. The PD-program was designed, implemented, and took its final form and presented as a cycle of expansive learning (see Fig. 3).

Before the first meeting between teachers and the research group there were two separate activity systems, one

of the Greek educational system and one of the research group. Through the interaction between those two systems, we target expansive learning: both teachers and researchers participate in the design and implementation of a radically new, wider and processed object for their activity.

Each one of those systems are presented below, including the shared system of teachers and researchers through the cycle of expansive learning.

1. Activity system of a Greek science teacher

Earlier surveys [28; 30] pointed out that the Greek Science Curriculum does not include teaching of NOSK aspects. Textbooks prompt, in a small degree, to discuss only some of them and, teachers have not learned them during their studies, thus they intuitively refer to some of them, without assessment, and finally students have naïve views on NOSK aspects. Success in national exams to enter university is a major value among Greek families, therefore students’ preparation for the exams begin many years before. As a result, parents are an integral part of the community, who press teachers and students for good grades and success in tests. Teachers end up focusing on the body of knowledge (definitions, laws, equations) and solving mathematical problems, which is what is examined in the national exams. Teachers have primary contradictions with the above, because students don’t participate actively in classes, claiming that school is far from their interests.

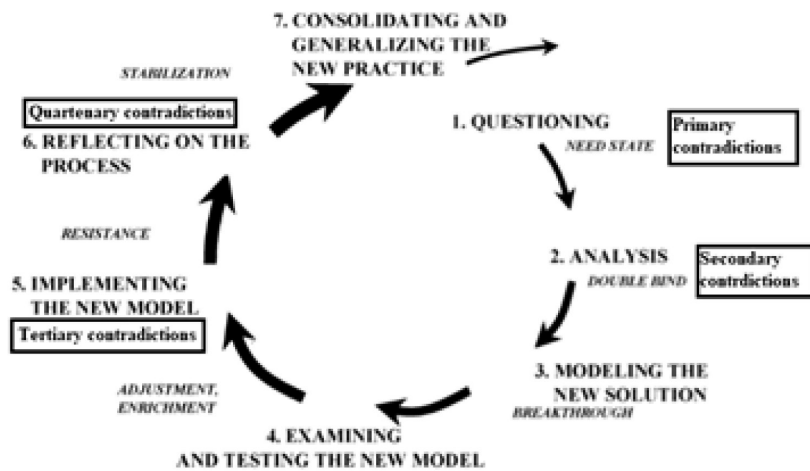


Fig. 3. Actions and corresponding contradictions in the cycle of expansive learning [16]

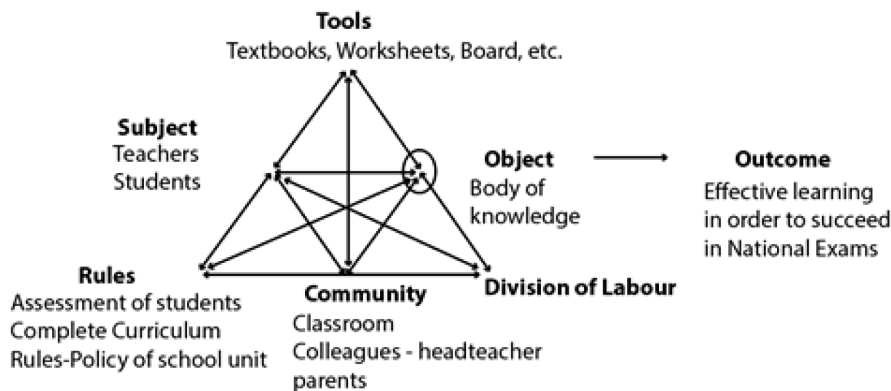


Fig. 4. Activity system of the Greek science teacher

2. Activity system of the research group

Researchers in their own activity system have recorded three approaches to teach NOSK aspects, through a) History of Science (HOS), b) Scientific Inquiry (SI) and c) Socio-Scientific Issues [33; 39]. For each approach, there are advantages (i.e. [38; 1; 47; 2; 11; 51] and disadvantages [33; 7; 4]. Allchin et al [4] claim that the three approaches used at the same time can offset each other's disadvantages, and their combined approach promotes stronger learning than each one individually, regarding NOSK. Furthermore, according to Allchin [3], all teachers do not regard each approach to be as important as another, which was also a conclusion from our interviews with teachers [28]. In our opinion, it is justified from their different cultural characteristics.

Taking that into consideration, it was decided to include all three approaches in the PD-program. As for the order of presentation: teachers' interviews showed that most of them don't regard NOSK to be as important as the body of knowledge. This can be explained from their cultural characteristics as: they were trained in science departments, without any pedagogical instruction, and the activity system they lived in – both as students and teachers – was that of the national exams, the solution of advanced mathematical problems, without tasks that include or assess NOSK aspects.

In order to change their attitude, it is important to start the PD-program with HOS, to recognize NOSK aspects throughout the evolution of scientific knowledge, and to realize that NOSK is part of science. The SI approach follows, which is within the desired culture of Greek science education and teachers like to organize inquiry-based lessons. Finally, the PD-program closes with SSI, that our previous survey showed that is the most contradictory among the three for science teachers.

Apart from that, the research group included the basic principles of adult education in the design of the PD-program: a) adults learn more effectively when they participate in the learning process, when the content is focused on their needs, their previous knowledge and experience are used and b) adults prefer to learn in their personal manner, according to their special cultural characteristics and abilities [21].

3. Cycle of expansive learning

3.1. Questioning

At the beginning of the PD-program, teachers were asked why they attended the program. Their answer was a description of the classroom activity system, similar to the one described on paragraph 1. The primary contradiction to the accepted practice was that their students don't participate actively, which makes their job tiring. They attended the program, because they were already critical towards the existing system and they seek anything that could inspire their students to be more energized.

3.2. Analysis

Teachers knew the schedule of the program from its announcement. When the lecturer informed them that

the goal was to a) learn NOSK aspects and b) be able to teach them themselves, thus secondary contradictions arose: a) in order to teach a new object they had to design new resources (tool), since there are none in the textbooks and b) there might be opposition, mainly from parents, if teaching is completely different from the standard.

Discussion led to their suggestions, some of which were based on the inclusion of all three approaches of NOSK teaching. For example, teachers who already used HOS in their teaching, could add NOSK aspects to that content. Respectively, teachers who use SI and SSI could add NOSK aspects to what they already do, based on extracts vaguely derived from the textbooks. On the one hand teachers could design lesson plans easier and on the other students would not attend completely different classes than the ones they were used to. The suggestion to include all three approaches provides more chances to teach NOSK, using the existing books in the present curricula. Finally, it was decided not to do any intervention in the 12th grade, the exams year.

3.3. Modelling the new solution

Each one of the first three meetings was dedicated to a NOSK teaching approach (HOS/SI/SSI). Their content was both original tasks and adjustments from the literature. The PD-program began with an induction to NOSK aspects.

1st meeting: HOS approach. The evolution of the concept "pressure" from 1638 to 1662 was presented. The choice was made firstly because the same phenomena are interpreted through different inferences: a) the partial abhorrence to a vacuum (Galileo), b) the weight of the air (Torricelli and Pascal), the infamous experiment on Puy-de-Dome being a crucial experiment and c) the "springs of air" (Boyle) developing the air-pump for the crucial experiment [31] and secondly because of the intense effect of the new philosophical stream (mechanical philosophy). Before the presentation, teachers were asked to recognize and note down NOSK aspects. By the end of the lesson, these aspects were summarized in a table.

2nd meeting: SI approach. Teachers participated in a black box activity [29] and recognized NOSK aspects during its solution. Black boxes' computer applications and other classification tasks were also included [6]. The meeting ended with a task where different inferences came from the same observations¹.

3rd meeting: SSI approach. The topics were a) different inferences from interpreting the same diagram for the reasons of climate change [20], and 2) advantages and disadvantages of using nuclear energy versus coal for electricity [46].

3.4. Examining and Testing the new solution

Teachers knew from the announcement of the program that they had to present a lesson plan as a final assignment, based on any school unit they wished, using NOSK aspects explicitly. The assignment was not mandatory, so that teachers with increased responsibilities were not discouraged to participate in the program.

¹ <https://scienceonline.tki.org.nz/Nature-of-science/Nature-of-Science-Teaching-Activities/Conflicting-theories-for-the-origin-of-the-Moon>

Even though the assignment was voluntary and occurred on the end of May, a season with increased responsibilities for teachers, 30 out of 49 teachers delivered 29 lesson plans (2 teachers cooperated). Twenty-one of them were successful. The other 8 teachers' lesson plans were either an incomplete application of the new model of activity or the old model remained. Seven of them were presented in the 4th meeting. Discussion followed each presentation between teachers and researchers. Questions, claims, different opinions and suggestions were heard. The program ended with teachers asking for a 5th meeting by next winter, after they would teach NOSK in their classes.

3.5 Implementing the new solution

Throughout school year 2018–19, the first of the writers observed 9 of 49 teachers in the classroom, in order to study how they embedded NOSK in their teaching. It was found that, in some occasions, there was disharmony between the suggested tasks for NOSK teaching and the daily school practice (tertiary contradiction). That was the theme of the 5th meeting (December 2018), where two videotaped lessons on NOSK teaching – of different character – were shown, analyzed and discussed. Through them and teachers' experience in NOSK teaching, contradictions appeared for some teachers between the object of the activity and its motive, which lead to upgrades of the activity.

3.6. Reflecting on the Process

The final 6th meeting took place on May 2019, where teachers whose lessons the first author observed, presented their experience to the plenary and discussion followed. Quaternary contradictions arose, directly connected to other network activity systems (See Figure 2), like the request to make changes in the curriculum and the textbooks. Teachers, having a first-hand experience themselves, have affected their schools and prepare for change.

3.7. Consolidating and Generalizing the new practice

We would reach that stage when the curriculum changes and NOSK aspects are included.

Evaluation of the program – results

In order to evaluate the program, participant teachers were given the following tasks: a) before the 1st meeting they completed the VNOS-D+ questionnaire (pre-test) and 10 of them gave semi-constructed interviews, b) in the 4th meeting they: i) delivered their designed lesson plan on NOSK teaching, ii) completed a post-training evaluation form and iii) completed the post-test VNOS-D+ questionnaire, c) throughout school year 2018–19 classroom observations took place on how NOSK is integrated in the Greek school reality, using a protocol (and taken field notes) d) in the 5th meeting they completed a questionnaire on the usability of the three approaches in NOSK teaching and e) in the 6th meeting they wrote a report on their activities through the whole year, any difficulty they came through, what helped them to overcome it and how they regard their results.

All the above are analyzed and initial results show that the PD-program improved their knowledge on NOSK, created a positive view towards its integration in the classroom, trained them to design their own lesson plan and teach NOSK. It is also positive that they asked for more interactive meetings, in order to exchange their views after their teaching experience.

Regarding the three approaches, they mention that a) students want variety in the tasks they are occupied with and b) more chances are given to teachers to embed NOSK aspects. Most of them mention that HOS is useful for teachers' training on NOSK, SI for students to perform tasks, and SSI is desirable for teaching to scientific literate citizens.

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Применение культурно-исторической теории деятельности для выстраивания программы повышения квалификации для греческих учителей «Основы научного познания» как цикла экспансивного обучения

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В статье описана разработка, внедрение и оценка программы повышения квалификации для учителей естественнонаучных дисциплин «Основы научного познания» (ОНП), спроектированной в соответствии с принципами экспансивного обучения. Предварительный анализ показал, что ОНП напрямую не представлены в школьном курсе естественнонаучных предметов и что их интеграция может помочь сделать предмет более интересным для учеников (фаза вопросов). Обзор литературы показывает, что существует три подхода к преподаванию ОНП: через курс «История наук», через курс «Научное изыскание» и курс «Вопросы науки и общества». Программа повышения квалификации включает в себя все три, предоставляя возможность 49 учителям-участникам выбрать из нескольких альтернативных способов интегрирования ОНП в школьные предметы, в соответствии с культурно-историческими характеристиками сообщества обучающихся и принципами образования взрослых (фазы анализа и моделирования). Учителя исследовали и апробировали новую модель (четвертая фаза) в рамках добровольных заданий по проектированию и представлению плана занятий. Фаза внедрения заключается в реализации придуманного непосредственно в классе, пятой встречи и завершающей шестой (фаза рефлексии). Возникающие в процессе противоречия используются для преобразования всей системы деятельности. На всех этапах проводится специальная работа по оцениванию. Полученные к настоящему времени результаты свидетельствуют об успешности программы повышения квалификации.

Ключевые слова: цикл экспансивного обучения, основы научного знания, непрерывное профессиональное развитие, общеобразовательные школы.

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