A Pedagogical Framework To Form Scientific Competencies In Bachelor Students By A Specialized Course

Stanka Hadzhikoleva, Zhelyazka Raykova, Emil Hadzhikolev

Abstract: Forming research skills and scientific competencies in students is an important task which has a key role to define the education quality of the students and their training for successful professional realization. More and more educational institutions make purposeful efforts in that direction. In the present article, our experience of conducting a specialized course in a bachelor program has been presented as being part of students' training like researchers with the necessary scientific competencies. In the course of the specialized training, the students took part in learning activities related to conducting a scientific research; preparing a short scientific article; reviewing a colleague's scientific work; editing an article in accordance with reviewer's instructions; making a presentation and presenting it in front of colleague students as well as making assessments and giving opinions of their work. In this article, a pedagogical framework to form scientific competencies in students based on our experience is presented. It could be used as a base to create specialized scientific courses in different scientific areas. Special components of it might be integrated in classical learning courses according to the curriculum.

Index Terms: forming scientific competencies in students, a training to form research skills in students, pedagogical framework to form scientific competencies.

1. INTRODUCTION

One of the European higher education area priorities in the recent years is the task to attract young people for professional realization in science and developing their creative potential. Encouraging the interest in young people and society to scientific research and its application in the business area is an important factor to achieve smart, sustainable and inclusive growth, which is a strategic purpose of the Europe 2020 program. A part of the strategy for researches and innovations of the European commission is creating a European research area, which provides the opportunity to build effective national research systems, international and transnational cooperation, an open labour market for researchers, and optimal circulation, access to and transfer of scientific knowledge. The successful implementation of Horizon 2020 is a strong motive for its continuation. The new program Horizon Europe is much more ambitious in terms of maximizing the scientific researches and innovations and it has a bigger budget. In 2017, the European commission has assigned to an independent high level group to form a vision for future researches and innovations in the EU and make strategic recommendations to increase the future EU programs' influence for research and development activities (Lamy et al., 2017). In the presented report the role of quality education to conduct quality research has been mentioned. There is an emphasis on the necessity of fundamental changes, which are related to systematic integration of innovations and entrepreneurship in education; stimulation non-formal cooperation between universities; new methods of training and supporting the career development of researchers; modernization and better provision of the education. A bigger support should be provided for talented researchers and innovators, including people returning to EU country from another country. In the report, it is said that the pursuit to Open science and open innovations suggests mobilization and involvement of citizens in scientific and research activities, for example by identifying and defining problems, by discussing and following the progress of the work, participation in commissions, testing new innovative solutions, presenting feedback, etc. Involving stakeholders, end-users and citizens in different scientific and research activities will stimulate a bigger usage of innovative products and services as well as better understanding of social changes.

A strategic document, which popularizes scientists' role is the European Charter for Researchers. It contains a number of common principles which define the frame of roles, responsibilities and the rights of the researchers. The document includes all the stages of scientists' career in all the areas of scientific researches. Various roles of the researchers have been described into it – not only those, which are strictly related to conducting scientific research, but also the people who do supervision, mentor, managing and administration related activities. All of the requirements of the modern society are described in the document, related to professional qualities and skills, ethic principals and professional responsibilities of the scientists. According to the European Charter, senior researchers have to be active in the role of mentors and supervisors of young scientists, leaders, heads of projects, etc. They have to build a constructive and positive relation with the young researchers at an early stage, to create conditions for efficient knowledge transfer, to assure support for their creative development as well as for their successful career advancement. Forming basic scientific competencies and attracting young people to a scientific career should be an object of special attention when training students in higher education. It is necessary to conduct a purposeful learning process by offering specialized courses, which develop key scientific competencies as well as prepare

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and motivate bachelor degree students to continue their education in conducting future scientific and research activities.In our view, the skills which build scientific competencies should be formed in a purposeful way and this could be efficient within a suitable training course. In this article, a pedagogical framework is offered to form scientific competencies in students by training in a special course in a bachelor program. The skills, which should be acquired are described as well as activities appropriate to their achievement. Our practical experience from the conducted training is described, including the training topics, assigned tasks, students' achievements and their opinion of the training course.

2 APROACHES AND MODELS TO DEVELOP SCIENTIFIC COMPETENCIES

Many scientists and educators support the idea that forming scientific competencies should start in school education. Since an early age, children have to get involved into science by games, and feel the joy of studying natural phenomena and technological applications as well as feel the power of applying scientific achievements in life.A research conducted in the USA by the National Research Council aims at setting new standards in K-12 science education. It is based on the vision that all the students should be trained in science and engineering, and providing basic knowledge for those students who will become scientists, engineers, technologists, etc. A framework has been created, which recommends science education in grades K-12 to be built on the base of three major dimensions – „scientific and engineering practices; crosscutting concepts that unify the study of science and engineering through their common application across fields; and core ideas in four disciplinary areas (physical sciences; life sciences; earth and space sciences; and engineering, technology, and applications of science)". In order to conduct efficient training, these dimensions should be integrated into standards, curriculum, instruction, and assessment. The academic community in California works in the same direction. In order to overcome the high requirements of the scientific education, scientists and educators from California colleges and universities form basic scientific competencies, which have to be acquired by the future students (Rutan et al., 2016). They are described in Statement on Competencies in the Natural Sciences Expected of Entering Freshmen and approved in 2016. The document revises California scientific standards, approved by California Department of Education in 2013. It is focused on 9 concepts, which are common for all scientific and engineering disciplines - Uncertainty and weighing evidence, Systems and system modeling, Structure and function, Stability and change, Energy and matter, Scale and proportionality, Synthesis of information and how it contributes to the "big picture", Visualization of data, Human and global impact. All of these concepts have been reviewed in details in the context of 4 specific scientific disciplines - Chemistry, Earth & Space Sciences, Life Sciences, and Physics.Yarullin and a team proposed a methodology framework for efficient training in scientific competencies at a university level (Yarullin, Bushmeleva & Tsyrkun, 2015). Four interrelated components are defined for research competencies - cognitive, motivation-goal, activity-evaluation, and communicative. Cognitive component includes theoretical and methodological knowledge of the students, observation skills, analysis and judgement. The motivation-goal component contains understanding the meaning of that knowledge for professional activities as well as the general meaning of the science in this direction. The activity-evaluation component presents the ability to use scientific knowledge to solve practical problems, generating ideas, original thinking, etc. The communicative component encompass teamwork skills, cooperation, coordination and communication. Different experiments to form research and scientific competence have been conducted in universities. An interesting experiment in order to form research competencies by project-oriented training is described by Yarullin and a team (Loginov & Kovalev, 2017). The students work on different projects to construct scientific and educational small satellites under the supervision of industrial partners. The results show that the experimental groups are doing better than the standard training way in the three basic activities – planning, analysis and research. Kulikova and a team make an experiment to form scientific competencies in students by practical training (Kulikova & Kulikov, 2014). It required 4 pedagogical conditions. The first condition is providing creative work conditions to students with the help of highly qualified educators and suitable forms for creative and practical students' work – professional skills competitions, the best report competitions, scientific conferences, grants, etc. The second condition is managing scientific and research work by simultaneously organizing practical training. The third condition is stimulating the students' research activity at the time of the practice. It includes the moral and material stimulation of the best students. The fourth condition is monitoring of the quality of the scientific and research work of the students. Each of the these conditions is related to a number of activities, which are done by students, educators and mentors as well as skills and abilities which have to be acquired and demonstrated by the students. Some authors consider that forming scientific competencies have to be integrated in undergraduate education (Abu-Zaid & Alkattan, 2013). Stouthard and Cohen offer a PhD Competence Model, which aims to assist PhD students to address their personal needs of training, which are necessary for a successful scientific and professional career. There have been defined 7 areas of competencies: Research skills and knowledge, Responsible conduct of research, Personal effectiveness, Professional development, Leadership and management, Communication, and Teaching. Each competence area includes a number of specific skills (Stouthard & Cohen, 2016). A software supplication for self-assessment of the scientific competencies has been developed (PhD Competence Model, 2017). It is free and available online as well as it is easy to use. The application supports young scientists to assess their gaps and weaknesses and referring them to the areas in which they have to improve their skills.

3 A PEDAGOGICAL FRAMEWORK TO FORM SCIENTIFIC COMPETENCIES IN STUDENTS

In our researches, we consider the scientific competence as a skill to practice the complete cycle of steps in the process of scientific research. Its basic structural elements are:

- Research of the scientific literature;
- Conducting a scientific experiment;
- Making a scientific publication;
- Reviewing a scientific publication;
- Revising a scientific publication in accordance with the reviewer's instructions;

- Presenting a scientific work in front of audience.

Each of the components above is presented by a wide range of skills, which purposeful forming is to be achieved by specialized training courses. In order to conduct a successful training, the educator should periodically observe, correct and assess every activity in the process of the students' work (fig. 1).The first basic activity, which is of great importance to conduct successfully scientific and research activity, is to research the scientific literature. It aims to get the learner acquainted with the problem in details and to gather enough information for its solution. He has to research the state of the problem, what possible solutions have been offered by other researchers, their strong and weak points, to become familiar with the methods and means to solve the problem used by other researchers, etc. The students have to acquire skills of how to work with scientific database, search for information following specific criteria, collect, systemize, analyze, make a selection, and summarize information, forming conclusions and tasks.Conducting a scientific experiment starts with the development of a research methodology. Depending on the specifics of the scientific area, it might include different activities such as planning observations and measurements, choosing and providing the necessary tools and equipment, etc. The measurements could be direct, indirect, static or dynamic. In many cases, a mathematical model of the researched object and the studied process is made. Analysis and interpretation of results are performed. Students have to demonstrate knowledge depth of the field they have been researching. They need skills, which are to be assigned into three categories:

- specific to the scientific field – the student has to demonstrate accurate and in-depth knowledge in the specific scientific field in which they are being prepared as a professional, which is important in order to be able to assess the used literature, to define scientific questions and hypothesis;
- interdisciplinary skills and knowledge;
- research skills – it includes skills to construct research experiment, collecting and using data and analytical methods, critical interpretation of text and data, analyzing results, providing reports.

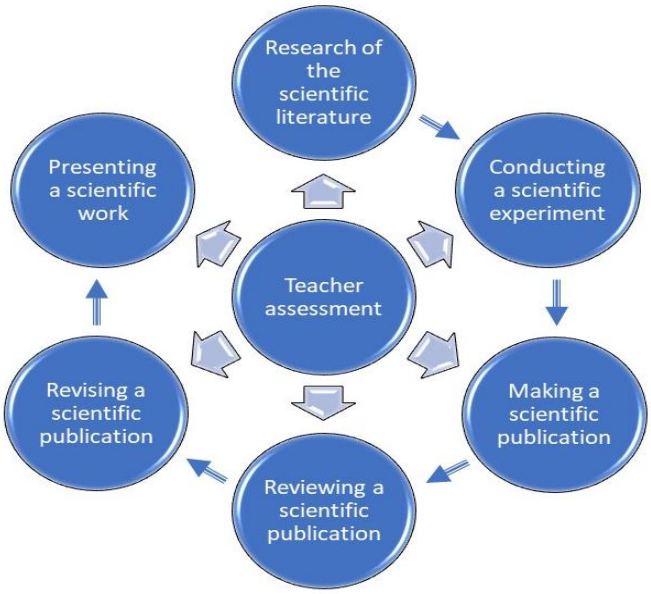

Fig. 1. *Framework to form scientific competencies in students*

The availability of research skills implies that students can perform the following activities: formulation of research questions and hypothesis, performing measurements with specialized equipment, preparing research plans and protocols; table, graphic and analytical description of the results, creating mathematical models of objects or processes, interpretation of the gained results, etc. For science development, the scientific achievements have to be popularized. This very often happens by making a scientific article and its publication in a suitable edition. As a result of that, the students have to know the essence of scientific writing. They should be able to write in accordance with different formats, theses, project proposals, scientific publications, etc. A suitable assignment would be to write a scientific text and adapt it to the requirements of a scientific publication. In order to be more realistic, they might format the publication by the requirements of a specific conference or scientific journal. The students have to gain knowledge for the different types of scientific works as well as their purpose and structure, for the citation standards, to acquire skills for writing a short abstract, to write a scientific publication, form bibliography, and format a scientific article in accordance with a given template. Reviewing a scientific article is a specific activity, which needs proficiency skills – analysis, critical thinking and assessment of scientific work written by another person. In order to train this skill, each student should be assigned to review any of his colleagues' work. Assigning the reviews might be arbitrary i.e. the students don't choose themselves whose work to review. In this case, a "blind" review could be made. A good idea is to give students a form, which contains detailed indicators for a grade, and assessment with points. The students should gain knowledge about the world system for reviewing, indexing and assessment, the essence of the scientometric indicators, and types of reviewing. They have to be able to prepare a critical review of a scientific work and motivate their remarks. The following important activity is correction of a scientific article in accordance with the reviewer's instructions. This involves getting acquainted with the review and removing weaknesses and mistakes indicated by the reviewer. The students should gain skills to correct and prove their own statements and conclusions. Presenting a scientific work in front of audience includes making the presentation itself and then presenting the scientific work. There are a number of specialized programs to make multimedia presentations. Besides, the students should have studied them and be able to work with at least one application. The educator should clarify the specific requirements to the students in order to create and present scientific presentations. The students' skills to present thoughts, ideas and facts in a comprehensible way for the people have a crucial role in their training as professionals and researchers. Graduate students are expected to demonstrate skills for interpersonal communication, for presenting and listening as well as work with the media. It is important for them to be able to participate in professional conversations in an active and efficient way, to be familiar with the verbal and non-verbal rules of communication, and to be able to have self-control during presentation. The students should acquire skills for structuring, making and formatting a scientific presentation. They have to be able to present their work within a specific time, which is usually 10-12 minutes, by briefly presenting the problem they have been working on and gained results. In case, they have been asked additional questions, they have to

be able to get concentrated and give a reasonable answer. If a question has been asked unclearly, they should ask for further explanations. Forming scientific competencies involves a number of specific activities. In order to have a successful learning process, there should be periodic educator's assessment. The assessment itself is complex – the educator has to observe the students' development and correct performance of the tasks assigned, to direct and correct the students as well as encourage them.

4 OUR EXPERIMENT

In order to approbate the efficiency of the suggested framework, a training course „Formatting and presenting of thesis and scientific work" has been conducted. The foremost aim of the course is to build scientific competencies in the students by forming appropriate knowledge and skills for scientific research and communication. The training course is elective and it includes 40 academic hours. It is aimed at students of all specialties in the Faculty of Mathematics and Informatics at the Plovdiv University, which are being trained in the educational qualification degree of bachelor, full-time study. The participants are trained in the professional areas of "Mathematics", "Informatics and computer science", and "Pedagogy of training in mathematics and informatics".

The basic topics, which are studied in the course, are:

1. Science. Definition, purpose. Basic terms.
2. Scientific research. Stages and methods of the scientific researches.
3. Scientific work. Types. Visibility of scientific work.
4. Thesis. Planning and conducting the research.
5. Structure of thesis, style and technical formatting. Software for writing and formatting a thesis.
6. Scientific article. Purpose, content and structure of a scientific article.
7. Scientific journal. Citation standards. Bibliography.
8. Scientific database. Scientometric indicators. World system for reviewing, indexing and assessment.
9. Presenting a thesis and scientific publication. Making a presentation.
10. Presenting a scientific work: structure and content. Software to format a scientific presentation.
11. Professional scientific networks. Building a public image. Scientific communication. Scientific networks.

After finishing the training from this course, the students should know:

- the basic stages to conduct scientific research;
- methods of scientific research;
- structure of the scientific work;
- citation standards;
- basic scientometric indicators;
- how the world system for reviewing, indexing and assessment works.
- basic rules for conducting scientific correspondence, etc.

The students should acquire the following skills:

- work with scientific literature – searching in scientific database and making a research of scientific sources;
- critical reading and analysis of a scientific text;
- research and reasonable presentation of the actual statq of a specific problem – by researching, collecting and citation scientific sources;
- making personal researches, studying models, concepts, frames, etc.;
- interpretation of scientific knowledge and facts, and using them in the context of an assigned task;
- summarizing scientific knowledge and facts, creating new knowledge and presenting it through a scientific resume or an essay;
- creating a bibliography;
- conducting scientific research;
- analysis and assessment, constructive criticism and reviewing a scientific text;
- structuring a scientific article and formatting it according to a specific template;
- making a scientific presentation;
- presenting scientific work in front of an audience, reasoned defense of a personal hypothesis, analyses, conclusions, etc.

The assessment of students' achievements has been made by making a presentation a thesis. This assessment way needs from the students to be really active and do various activities and it is extremely useful to form proficiency skills. Each of the students' works on a project, which was random picked from a list offered by the educator. The students have been given the following tasks:

- To conduct a scientific research on an assigned topic.
- To make a short scientific article and format it according to a given template. The template includes standard components such as title, author, abstract, keywords, main text, and references.
- To make a review of a colleague's article – a colleague student, who is randomly picked. The review is made by a given assessment sample, which contains a number of points. The final grade is formed by calculating the points.
- When the student receives their reviewed article, they edit it by making the necessary corrections.
- To make a presentation about the scientific research and present their work in front of colleagues i.e. co-students.
- To listen to the presentations of the colleague students, to express an opinion and give an assessment for their work.

In order to get feedback from the students about the training course and their attitude to making a scientific research, they were given an anonymous questionnaire at the end of the course. This questionnaire, by itself, is kind of a scientific research, which was organized, carried out and analyzed by two students. They made the questionnaire together with an educator, who helped them when analyzing the results from it. The results from the questionnaire have firmly shown the students' satisfaction from the course. All of the learners have stated their contentment from the contents and worth of the course. The participants in the questionnaire are satisfied with the acquired knowledge and skills to make a scientific article – 56% are extremely satisfied and 44% are satisfied. The students evaluate the task to make a scientific article as useful. 87% consider it has helped them improve their skills for critical thinking, analysis and synthesis of scientific information. All students have given a high assessment of the possibility to make a presentation and have shown satisfaction

from the acquired presentation skills. An important aspect of scientific competencies is the ability to communicate with colleagues form the community as well as with non-specialists. Making reviews is one of the activities which scientists do. Thus, they have to be trained for that. As a part of the training, each of the students could be in the role of a reviewer by assessing their colleague's work – a colleague student. 28% of them are extremely satisfied, and 67% are satisfied by doing this activity and the skills they gained; 5% haven't expressed their opinion. 80% from the questioned students consider that it has been a good idea students to make a review of their articles, and 20% do not agree with them. As a result, we can say here that every student received an article to review, chosen randomly. The reviewing process was not "blind" i.e. every reviewer knew the names of the author whose work has been assessed. A big part of the students learnt who has reviewed their article at the moment they received their reviews. All the students, with no exceptions consider that the reviews they have made are objective, correct and appropriate. All that raises the question of the lack of self-criticism in the students, which gives us a motivation for future researches in in this direction. All the details for the conducted course and its results have been published in (Semova, Nedyalkova & Hadzhikoleva, 2019).The results from the questionnaire have confirmed our certainty in the efficiency of the proposed educational content and its suitability. They prove the fact that practical tasks are of extreme importance in order to acquire specific research knowledge and skills.

4 CONCLUSION

Our opinion is that the training of specialists having higher education (bachelor and master degree) has to include specific knowledge of how to make a scientific research. A purposeful training is necessary, which aims at forming skills in order to prepare young people to do scientific work. This is a way for them to be motivated to choose professional realization like scientists and researchers, which is in accordance with the Vision of Europe 2020 for intelligent, sustainable and incorporated growth by building economics based on knowledge and innovations. The described framework in the article aims to propose a model for designing specialized courses, which are due to involve a number of activities typical when doing a scientific research. It could be adapted into different ways depending on the scientific area of the training course. Constructing a learning course and carrying out a training to form scientific competencies of the students is a step forward to building proficiency skills in the students (transfer of knowledge and skills, critical thinking, solving problems, etc.) and preparing them for future researchers and specialists. Our experience of running a specialized course to form scientific competencies and the results of the questionnaire among the students have shown that they highly values the given opportunity for purposeful training in this direction and they are satisfied by the various activities and the acquired knowledge and skills. Here, we have to mention that one of the students' works has been offered to participate in a scientific conference. The article was approved, reported and printed in the conference book.

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