STEM Teachers' Competence Development: When Opportunities Jump over Barriers

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Abstract: In this paper we present a study, aimed to identify the main challenges teachers face when trying to implement innovative teaching methods, stressing on identifying the needed STEM teachers competence development. The overall design of the study follows the European Awareness Scenario Workshop methodology and aims to negotiate the teachers' need, policy makers decisions and other stakeholders' understanding of the resent National regulatory framework, related to the teachers' competence development. The main research activities, performed during the study, are outlined and compared with similar research efforts and initiatives. At the end systematic analysis of results achieved is performed and proposals for further improvement of the competence development of teachers were made. The extracted requirements – mode, forms, topics, etc., for STEM teachers' competence development are valuable for universities and other institutions offering teachers' professional development courses. They are a base for further design of computer supported inquiry-based education for teachers' competence development.

1 INTRODUCTION

The ***Enhancing Learning In Teaching via e-inquiries (ELITe)*** Erasmus+ project aims to provide computer-supported learning opportunities for secondary teachers' competence development, which stands as a priority of the "Education and Training" EC policy agenda. The main project goal is to support computer-based teachers' professional learning for competence development, targeting specifically in-service educators in the STEM (Science, Technology, Engineering, and Mathematics) domain. We need to use conceptual, methodological and domain specific perspectives, in order to form specific requirements for the software tools to be used in the project. This is related to the first specific project objective: to ***deepen understandings on the requirements for STEM teachers' competence development at national levels***, as conceptualised and expressed by policy makers, policy mediators and practitioners. In this paper we present the methodology how this analysis to be performed, and describe the design, conduction and delivery of specific tailored for Bulgaria event used for this purpose. We also present the main results from this analysis - the main conclusions regarding domain specific aspects of STEM teachers' competence development in Bulgaria.

There are many challenges faced from all the stakeholders in Bulgaria – policy makers, policy mediators, teachers' trainers, STEM teachers, and broad society. Our main research goal in this paper is to clarify main opportunities and barriers, as they are seen by each stakeholder's group, and to find a way to negotiate the possible ways for their extended use (opportunities) and solving or removing problems (barriers). The extracted analysis and resume will be used as input for further inquiry-based learning model development and the respective software tools, and the design and implementation of specific computer-based learning scenarios for STEM teachers' training.

2 RELATED WORK

The work of the Thematic Working Group 'Teacher Professional Development', which comprised experts nominated by 26 European countries and stakeholder organisations, resulted in a document named "Supporting teacher competence development for better learning outcomes" (European Commission, 2013). This important report was grounded on various

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policy documents on teacher training of the European Commission (2007, 2010, 2012a, 2012b, 2012c), Caena (2011a, 2011b), the European Union (2006, 2007, 2008, 2009) and other research studies. On the base of examples of the policy approaches used in Europe, this document explores and highlights the concepts of teacher competences and competence frameworks, discusses ways of development and assessment of teacher competences, and "*defines the key factors that lie behind successful policies*" (European Commission, 2013, Chapter 5). The document acknowledged that "*The process of bringing stakeholders together to discuss these issues can, in itself, be beneficial, especially if it leads to an increased sense of ownership of the results and a commitment to their implementation.*" (European Commission, 2013, p. 43).

A major study of teachers' related policy was conducted during the 2002-2004 period by OECD in collaboration with 25 countries (OECD, 2005), aiming to explore, systematise, and present issues and effective policies with respect to the activities, related to developing effective teachers. Its methodology is to some extent similar to the methodology of the study, presented in this paper. It addresses 4 key issues, related to the topic. The study methodology included the preparation of countries' background reports (based on a predefined set of questions and requirements), organising workshops in different countries and disseminations of their results, implementing national visits of experts groups, writing paper reports on the basis of the different visits to detect issues, collecting rich sets of data and performing specific data analysis, and describing the main results in the policy report (OECD, 2002).

Another well-known initiative of OECD is the Teaching and Learning International Survey (TALIS), a periodic survey, administered in 2008 and 2013, and planned for delivery in 2018. Bulgaria participated in both 2008 and 2013 surveys and will participate in the 2018 edition. This gives a very good opportunity for triangulation of the findings and results of the described by the current paper STEM teachers' competences development study with the TALIS results for Bulgaria.

Yet another big OECD current initiative is the Innovative Teaching for Effective Learning (ITEL) project. First an extensive research work was conducted, resulting in a book (Guerriero, 2017), focussing on conceptual framework of teachers' professional competence, where the teachers' competence is fed by the initial, continuous, and informal/non-formal teacher learning, consists of content & pedagogical knowledge and affective-motivational competences and beliefs, and results in teaching approaches, which lead to instruction that supports the cognitive and social-emotional student learning (Guerriero, p. 261). This competence framework was used for the development of the survey instruments of international comparative studies conducted in ITEL that investigate teachers' knowledge as a key component of teacher quality (Sonmark et al.).

There is a big number of other studies that focus explicitly on the teaching-related factors, which play as stimuli or barriers to inquiry-based learning (IBL). For example, Kang and Keinonen, (2016) commented the results of 7 small scale studies, conducted in different single countries, and summarised that the reported in these studies barriers and teacher reluctance to apply IBL may have as main inhibiting factors: the low teacher confidence and competence in using inquiry instructions; the lack of time and resources; the tight curricula; the inadequate professional development; the large class sizes, the lack of professional science content knowledge; the difficulties in developing students' ideas and in designing experiments for students' hypotheses; and the insufficient school resources (Kang and Keinonen, p. 32). Authors pointed out the "teachers' confidence in teaching science and their collaboration to improve science teaching" as important factors for implementing IBL (Kang and Keinonen, p. 44). In another study of 34 IBL early-adopting Australian teachers, the participating teachers pointed out as the most important barriers to IBL-teaching "*the extreme time restrictions on all scales, the poverty of their common professional development experiences, their lack of good models and definitions for what inquiry-based teaching actually is, and the lack of good resources enabling the capacity for change.*" (Fitzgerald et al.).

In a successful effort to cope with the counted above barriers, the IBL-in-Science focused EC project "weSPOT" formulated prerequisites for successful IBL in schools, based on earlier research results, namely: "*change teachers' attitude and provide stronger support to students (at micro level); provide schools management support; enable teachers to share experience and best practices; provide the needed ICT support (at mezzo level); provide constant training for teachers and a rich set of resources based on ICT infrastructure (at macro level).*" (Nikolova and Stefanova). The weSPOT researchers then developed a reference model for inquiry skills, and a diagnostic instrument to measure the individual performance on inquiry skills. In this way the project "*provided teachers and learners with*

efficient support and the technology tools to reach competence, progress and to become able to find the optimal inquiry level to match their needs" (Mikroyannidis et al.)

Another important research program of EC related to improving innovation in education is eTwinning. An excellent overview of the best efforts related to preparation and training of STEM teachers in this program is given in (Papadakis, 2016).

3 METHODOLOGY

The ELITe consortium has performed a detailed analysis of the situation in four European countries, including Bulgaria. On the base of this analysis a comprehensive research report called "Policy envisions and requirements for STEM teachers competence development in Greece, the Netherlands, Bulgaria and Spain" was developed. This report was used in order to design multiplier national events, aimed to communicate and negotiate the main outcomes from this analysis with policy executives, policy mediators and practitioners,, and to identify systemic opportunities and challenges to implement training activities for STEM teachers' competence development.

The ***European Awareness Scenario Workshop (EASW)*** methodology was used for the implementation of such event in Bulgaria. This methodology relies on dividing event's participants in varying compositions groups, depending on the specific goal to be addressed. In such a way, working in groups and in a plenary was used to develop scenarios on the workshop topics, to name barriers, and to propose strategies and steps for realising the goals and overcoming the barriers. Working on concrete "scenarios" or various problems, it invites working group members to think about realistic challenges rather than dreaming about unlikely problems and how to solve them. Such a workshop follows three phases - the critical analysis phase, the visionary phase and the implementation phase – "to create a basis for local action". The EASW setting *allows for interaction between stakeholders* - rather than a static one, in which presentations are provided to participants, and *aim for consensus building rather than instructional approach.* One disadvantage of EASWs is their reliance on stakeholder balance, which might never be reached realistically. However, targeting a certain number of distinctive stakeholders is a good starting point to make "bringing together a broad range of interests" a little more concrete.

We planned to have three sessions during our event – ***Raising issues*** session, ***Negotiation*** session, and ***Structuring proposals*** session. During the *Raising issues* session participants work in homogenous groups, aiming to identify the opportunities and challenges on implementing activities for STEM teacher's competence development. During the *Negotiation* session they were re-arranged in heterogeneous groups, looking for solving the conflict aspects and generating recommendations on how to take advantage of the opportunities and how to avoid / deal with the challenges. The aim of *Structuring proposal* session was, in plenary, to map the issues and recommendations in the frame of broader educational priorities.

4 IMPLEMENTATION

4.1 Setting and Context of Event

The multiplier event took place in June 2017, at the end of the academic year in Bulgaria, with the total of 48 participants. It strictly followed the EASW methodology.

According to the methodology, participants were separated in three groups:

- **Policy makers** – representatives from Ministry of Education, Regional Management Centers of Education, National Center of Information support, professors responsible for teachers' training curricula from main universities in Bulgaria, and head teachers responsible for local school policy in STEM teaching;
- **Practitioners** – STEM teachers from general and vocational schools;
- **Broad Society members** – parents, representatives of private educational centers, private companies, NGO and research centers.

In Bulgaria, since 2016, there is a new Law on pre-school and school education. We paid special attention to teachers' professional development and the way of attestation, and National requirements for 'teacher' professional qualification. They stimulate teachers' professional development by regular trainings, participation in research activities and experience exchange events. The new students' national educational standards and curricula for STEM education also is a challenge in front of the teachers and teachers' educators. Another important initiative of the Ministry of Education and Science, called *Innovative school*, is providing innovative vision, development strategies, and teaching

approaches to all interested schools, and stimulating the school managers to involve the pedagogical staff at schools in activities, enhancing their academic, pedagogical, administrative and communicative competences.

On the base of these specific facts and the issues described in the preliminary analysis research report, we formulate the main topics for the multiplier event discussions:

- What teacher competences are needed to design Inquiry-based learning (IBL) activities in class;
- What kind of support is needed for teachers for IBL day-to-day application;
- What content should be provided and how, in order to spread widely the IBL approach;
- What are the challenges in schools management related to strategy, curricula and teaching approaches;
- What are the opportunities and challenges in using training for building teacher competences.

4.2 Structure of the Event

The raising issues section started with a presentation, which provided detailed information in relation to project description and aims, and main results from the analytical report of national policy documents on policy envisions and requirements for STEM teachers' competence development. All participants were divided into three homogenous groups and were given a list with topics prepared in advance.

Figure 1: Homogenous groups' SWOT analysis.

Policy makers were engaged with national standards on teachers' qualification, trainings topics for teachers, how to receive feedback from teachers and society, how to assess (in advance and post-event) relevance and quality of particular teaching training course and/or teachers' training provider.

Practitioners discussed administrative issues, the need of relevant environment for STEM teaching (textbooks, simulations, and specialised labs), the new subjects in the curricula, the new summative exams and how they correspond to national standards of education, the teachers' attestation process and related carrier development, salary, penalties.

Broad Society members were invited to discuss the results of teachers' work, the possibility of earlier graduating of students and joining the labour market, the lack of motivated and qualified teachers in STEM disciplines, the new requirements for school-parent communication and sharing responsibilities.

The moderators conducted and managed the discussion in each group. They also wrote down strengths, weaknesses, opportunities and treats related to the new regulatory framework, as identified in each group, creating the ground for performing the SWOT analysis. After that all participants joined together, and the issues identified in relation to the SWOT analysis were presented from representatives of each group. After a short discussion, all participants voted in favour of different statements of the SWOT analysis. The statements which gathered most of the votes were used to identify the set of issues to be negotiated during the second session.

Figure 2: Votes for Negotiation issues.

For the second session (negotiation session) participants were divided again into three but heterogeneous groups, with equal number of representatives from policy-makers, practitioners and broad society members. The next task for the participants was to focus on differences, to look for reasoning and negotiating a solution. As a result from this session, each group had to find a compromise vision for STEM teachers' professional development and Inquiry-based learning. The final outcome was a list with ideas, suggestions and possible actions agreed in each group. At the end of this session representatives from each group presented and justified their findings in a general plenary meeting and discussion with all participants. A summary and conclusions on the main needs and considerations in relation to STEM teachers' training was the final result from this session, forming an extended list with the requirements for effective and efficient teachers' trainings – topics, logistic, delivery, specific activities, etc.

The final session – structuring proposals – was performed in a week after the end of the face-to-face workshop event. SWOT analysis was performed a

few days after the multiplier event by the organisers by using the open questions of the questionnaire, participants' feedback during the event, collection of the results during each session work, and how they evaluate the participants' activity and quality of work. It presents strengths, weakness, opportunities and threats in relation to planning and implementation of the multiplier event, the effect of networking, and quality and relevance of outcomes. The details of the main results are outlined in the next section.

4.3 Evaluation of the Face-To-Face Workshop

All participants filled in anonymous questionnaires just before the closing of the event. They were asked to evaluate the organisation of the event in terms of content / thematic, process and venue, background materials, process / methodology of the event, and overall satisfaction from the event. The evaluation questionnaire was filled in by 40 participants. They found background materials – initial information and presentation, relevant to the event topic and their personal professional interest.

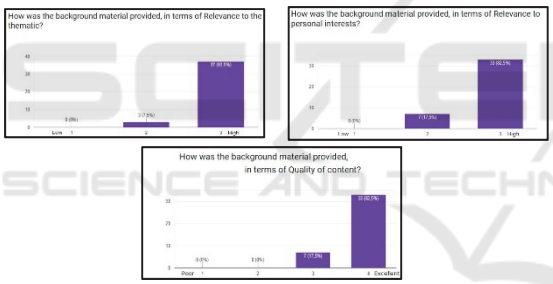

Figure 3: Workshop materials evaluation.

Evaluation of the process and methodology shows only one person with thinking that the event should provide more opportunities of interaction, one person with opinion that there were no enough opportunities of gaining new ideas, and two participants with relatively low level of satisfaction of the event outcomes.

Regardless of these very few moderate comments, the huge majority of participants provide high scores of the methodology and process of implementation of the event. 90% (36 persons) show high level of overall satisfaction of the event. The participants' comments share the feelings of satisfaction, and expectations this workshop to be followed by other similar events.

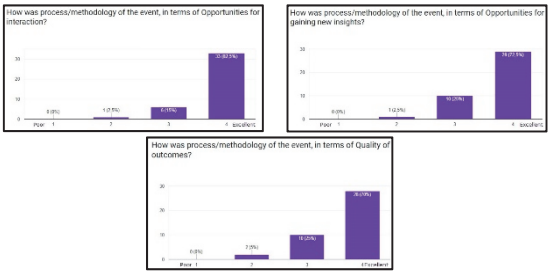

Figure 4 Overall satisfaction level.

5 MAIN OUTCOMES

The outcomes of the Raising issues session were summarised and presented as a SWOT analysis result, as shown in Table 1:

Table 1: SWOT analysis of the National regulatory framework in accordance with teachers' competence development.

(S)TRENGHTS
1. STEM teachers are free to present new subjects and to use new teaching methods and innovative training
2. Qualification program is well regulated with good opportunities for STEM teachers
3. Opportunity for STEM teachers to participate in training outside the country (e.g. CERN)
4. The new regulation gives opportunities for differentiation of the education after 10th grade
5. Clear and transparent system for the assessment of STEM teachers
6. New regulation provides clear directions for STEM teachers with detailed work goals
7. The Inclusive Education provides new opportunities for STEM teachers
(W)EAKNESSES
1. Lack of clear links and dependencies between attestation of STEM teachers and their salaries and career development.
2. Lack of choice for professional qualification
3. Reduced number of hours in the science subjects leading to problems how to satisfy standards.
4. The standards for learning content are slow to follow the rapid STEM developments
5. Lack of flexibility in following the learning program leads to low motivation and high level of absences of students (including talented and gifted students).
6. Long time period between teacher attestations prevents rapid development of STEM teachers.
7. Lack of high qualified teachers
(O)PPORTUNITIES
1. STEM teachers have more opportunities for innovative practices through the school curricula.

Table 1: SWOT analysis of the National regulatory framework in accordance with teachers' competence development (cont.).

2. STEM teachers can implement new teaching methods through different research programs.
3. STEM teachers can use electronic materials and innovative software tools for labs and practice.
4. Team Buildings and STEM teacher training are encouraged under a Differentiated Model
5. Cloud technologies give new possibilities for STEM teachers for better relationships with parents
6. STEM teachers can try new forms of education like distance and blended education
7. STEM teacher competences can be assessed by independent professional organisations.
8. Innovative schools can allow STEM teachers to develop more flexible and creative curricula according to the school profile and vision.
9. Teachers' qualifications can be flexible in time and subjects and as a result to be better aligned to teachers professional needs.
(T)HREATS (from external factors and environment)
1. Low STEM teachers' salaries
2. Lack of coordination between the MES and Higher Education (HE) regulations
3. Not all STEM teachers are digitally literate
4. Lack of control over the quality of STEM teachers' training courses. Training organisations will offer low quality cheap courses to attract more teachers by easily providing qualification credits to them.
5. Lack of clear system for recognising STEM teachers professional certificates and similar rewards
6. Some institutes 'produce' STEM teachers with low quality and questionable diplomas
7. Low level of society participation and support for the STEM teachers endeavors.
8. Lack of regulated funding for STEM education environment

Some points were marked both as strengths and as weaknesses from different groups. The reason is that they were pointed from different perspectives. For example, the annual thematic plan give some possibility for teachers with common profile to collaborate in preparation of the lessons, but it also is a barrier for their flexibility to change the plan and lessons according to the student's needs. In general, both groups agreed on these two different perspectives. This was reflected in their recommendations, which are elaborated in the next Table 2. It contains recommendations on how to take advantages of opportunities and on how to overcome challenges emerged during the previous session.

Table 2: Heterogeneous group's results.

Group 1
1. To organise STEM teachers' trainings in mixed forms – online and traditional learning
2. A certain number (%) of qualification credits to be related to the specialty/subject teacher training (with academic and practical trainings)
3. The qualification courses to be based on up to date STEM subject content and teaching methodology
4. To combine knowledge and skills from different STEM subjects in the courses
5. To offer courses aligned to the STEM research methodology accompanied by practical exercises
Group 2
1. To motivate training organisations to offer rich choice of course themes and qualification courses
2. To plan methodological thematic trainings for STEM teachers in a practical and interactive way.
3. To stimulate the use of e-simulations and other relevant software tools for STEM teachers both for their trainings and how to use them in the classroom.
Group 3
1. STEM teachers' training should combine face-to-face with other relevant forms.
2. STEM teachers should have courses for the inclusion of special educational needs (SEN) pupils.
3. STEM teachers should be offered specific courses on new teaching methods for their subjects
4. STEM teachers need specific general courses on applying interactive teaching methods

It was not difficult to come with these recommendations, as the three different groups agreed on more of 70% of all issues from the SWOT analysis. There were cases of disagreement, for example teachers think that opportunities for professional qualifications are limited, while policy makers had the opposite opinion. Another point of disagreement is related to the opinion of policy makers for the lack of high qualified STEM teachers, while the teachers; opinion is opposite. Also, there were some fears among teachers from new regulations regarding teachers' evaluation.

Most of the recommendations from all the groups were related to the **content** of the teachers' training courses. The **teachers' training courses' topics** were the most discussed. The recommendations were mostly related to learning materials and activities. All groups agreed that new rapid science achievements should reflect in immediate changes in the students' curricula. Special attention was dedicated to the use of innovative software tools in STEM disciplines. There was agreement that science disciplines require more simulations of phenomena and possibilities for students to experiment, generate hypothesis and

formulate conclusions. For mathematics and computer science reasoning, the algorithmic thinking and use of interactive digital learning resources were recognised as more suitable.

All groups also recognised the importance of the **Interdisciplinary approach** – practical trainings combining different STEM subject matter and relationships, in collaboration with other STEM subject teachers. This is related to developing new learning designs, stressing on implementation and evaluation of students' achievements. Also, it is related to applying **innovative teaching methods** – interactive methods of teaching / learning, design and implementation of student's inquiry, group work management, use of innovative ICTs in education, etc., focused on STEM education.

All groups were also agreed, that abilities to **work with small well aligned students' groups** are critical for the success of STEM education. These groups need to be tailored to the specifics of the subject and the educational need – involving students with special educational needs and learning disabilities, as well as work with talented students.

Another important recommendation was related to effective communication and collaboration with parents and the involvement of parents in all aspects of the school live, so called 'school for parents'. This is related to efficient management of schools, and especially for organising STEM teaching and learning.

All groups agreed, that without efficient evaluation and assessment of educational process it is not possible to achieve high quality in STEM education.

Most of the participants agreed on the **forms** of STEM teachers' training courses. They prefer active practical learning process instead of the standard one, based on lectures and formal exams. They agreed that demonstration and participation in innovative teaching methods implementation is very important for the successful transfer of given teaching methodology to the classroom. Also, they strongly agree on the use of online training courses content and specialised software tools for support of the STEM specifics. In brief, the most important requirements, related to the forms of teachers' training courses are:

- **Face-to-face** or **blended** learning
- **Online courses** – as a current support, and as an archive for long term use.
- **Balance** between learning at **work place** (school) and out the door courses – regional, national workshops as environment for sharing ideas and experience

6 CONCLUSIONS

The multiplier event, delivered at the end of June 2017, developed a good network of policy makers, teachers' trainers, teachers and broad society members. It was the first step in identifying the requirements of STEM teachers for effective and efficient competence development with the use of relevant software tools.

The main outcomes from the Bulgarian multiplier event were very similar to the outcomes of other three such events. All outcomes from these events were summarised and used as requirements for the special inquire-based teaching software system DojoIBL system (http://dojo-ibl.appspot.com).

This system was developed by the project partner from the Netherlands and it is specially designed to implement inquiry-based methodology for learning. The application has been adapted also to the four countries' specific national requirements, and the user interface has been translated in Bulgarian, Dutch, Spanish and Greek language.

At the moment, the project is at the phase of first pilot teacher trainings, which are conducted in blended learning form, following the inquiry-based learning methodology, and using the DojoIBL software tool.

After the end of all pilot experiments, analysis of the results of trainings of STEM teachers will be performed. On the base of this analysis the project will formulate set of guidelines and requirements for STEM teachers' competence development in Europe with the use of specialised software tools.

The teachers from all four countries in the project shared their needs of trainings on the new topics in the student's educational standards and curricula. For STEM teachers, very special topic of interest is **the use of relevant ICTs**, providing interactivity that can compensate the limitations of school specialised labs (totally missing or poor of equipment). They need also practical courses related to the **interweaving of different disciplines**, providing ideas, design examples, and directions for students' achievement and the process assessments in implementation of interdisciplinary learning. They also need trainings on how to design, deliver and conduct an inquiry based learning on specific topics in specific grades.

All the stakeholders groups agreed on the need of application of **modern teaching approaches** in the classroom. Special attention is dedicated to the interactive teaching methods which still are not very popular in Bulgarian schools. For STEM learning disciplines there is a special need teachers to be

trained on how to design, deliver and conduct **inquiry-based learning** process.

Different forms of assessment and related feedback is still a problem for teachers having practices mainly on the use of open/closed questions tests but experiencing lack of skills in the evaluation of practical work, team work, or inquiry-based learning and other innovative methods.

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