Connectivism and Teacher Constructivism in Science and Technology Education Focusing on Inquiry-based Science Education

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Abstract

Connectivism as a new pedagogical theory was recently born as a response to the fast ICT development. All students and young teachers are already members of the NET-generation. Teachers build up their pedagogical content knowledge, skills and competences using their own experience from teaching and thus connecting pedagogical theory and classroom practice, which can be defined as teacher constructivism. Inquiry-based science education is an appropriate innovative educational strategy based on student and teacher constructivism. This study presents the results of design-based research on the influence of connectivist factors on science and technology education, with an emphasis on teacher constructivism.

Keywords*:* connectivism; ICT; inquiry-based science education; science and technology education; teacher constructivism.

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Introduction

According to experts (Darling-Hammond, 2000) the quality of teachers strongly influences the quality and effectiveness of science and technology education (hereinafter STE). It is therefore obvious that teachers must be very well prepared for their profession, in both in-service and pre-service teacher education. Teaching is a profession which is characterized by the necessity of continuing education and continuous professional development (hereinafter CPD). Teachers must learn all their lives because they have to alter their teaching methods in accordance with the changing needs of students and society. They must be able to analyse, plan, experiment, synthesize and evaluate documented field experience and on this basis to apply new knowledge and skills. Working conditions for teachers are significantly complicated due to a number of factors, which include a sharp increase in ICT and its influence on the behaviour of students and their parents. Teachers should be not only well prepared for the current situation and future challenges in education but they should have adequate conditions for their work.

Currently, teachers have a very important task: they have to motivate and prepare students for lifelong learning and work within a situation of global economic competition (Osborne and Dillon, 2008). Society puts higher demands on the skills and knowledge of teachers of Science, Technology, Engineering and Mathematics (STEM) because it needs a workforce with generally high levels of literacy for all students, as well as a sufficient number of highly gifted individuals (Bybee and Fuchs, 2006). Teachers are looking for innovative educational strategies to meet these challenges. Inquiry-based science education (hereinafter IBSE) has been proved to be a suitable educational strategy because it motivates students and provides a suitable space for the development of science and technical literacy. In order to achieve quality outcomes in teacher education so that teachers exercise the acquired knowledge in practice, it is necessary for education to be based on constructivism and respected new theories such as connectivism.

The main goal of this study is the identification and description of connectivist factors influencing constructivist STE, with an emphasis on teacher constructivist education, which can be called "teacher constructivism". This research was conducted in training courses on the implementation of IBSE within the PROFILES project (Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science) funded by the FP7 programme of the European Commission (PROFILES, 2016) over the years 2012-2015. It should be borne in mind that the connectivist factors are combined with other factors affecting teacher education. Some factors have newly emerged and their meaning has increased, while others factors have become less important. After identification and determination of the factors affecting the effectiveness of teacher training it is necessary to develop effective teacher educational methods.

Rationale

To ensure the quality of teacher education and all CPD it is necessary to respect many factors. Active engagement of teachers in education is very important in order for them to overcome their resistance to changes and to transfer the knowledge and skills into their practice for innovation of teaching (Magoon, 1977; Richardson, 1998). Because all learning is filtered through teacher pre-existing experiences and knowledge, for these and other reasons, it is appropriate to base teacher training on the theory of constructivism (Richardson, 1997). The fact that all pupils, students and young teachers are already members of the NET-generation (sometimes called Millennials, generations Y or Z) should also be considered. This NET-generation has specific personal characteristics, especially learning styles, and in the case of teachers also teaching styles. That is why it is necessary to incorporate the findings of connectivism (Downes, 2012; Siemens, 2005; Oblinger and Oblinger, 2005) into teacher education.

It must be remembered that the main reason why teachers want to study is that they are trying to find appropriate strategies for the education of the current generation, which differs from the previous ones, because teachers want to achieve high-quality educational outcomes. According to experts, IBSE is a suitable strategy for this (Rocard et al., 2007; Osborne and Dillon, 2008). But teacher training in IBSE should comparably reflect new theories aimed at education to be successful, especially constructivism and connectivism.

Many studies (Lederman, 1999; Powers, Zippay, and Butler, 2006; Richardson, 1998) justify the close relationship between teachers' beliefs and their classroom practice. To accept changes, teachers need to be theoretically familiar with an innovative method and also need to test these innovations in their classroom practice. The gap between theoretical teacher education and teaching practice is a significant issue that limits the development of teacher professional competences (Korthagen, Kessels, Koster, Lagerwerf, and Wubbels, 2001). Teacher constructivism is a good way to support teacher beliefs and to bridge this gap. Another important factor which influences the change of teachers' beliefs is teamwork in training through close discussions with colleagues (Richardson, 1998). According to our research, the creation of a net-environment where teachers share their experiences and opinions (network), and the inclusion of other connectivist elements increase the shelf life of the knowledge of teachers and help them put it into practice (Downes, 2012). Basic concepts that emerge in this study are connectivism, IBSE, and teacher constructivism. These concepts and their relationships need to be concisely addressed.

Connectivism

The new pedagogical theory of connectivism was born as a response to the invasive ICT development and its impact on society (Downes, 2012). Siemens laid down the foundations of the theory of connectivism. According to Siemens, (2005, p. 4), "learning (defined as actionable knowledge) can reside outside of ourselves (within an organization or a database), is focused on connecting specialized information sets, and the connections that enable us to learn more are more important than our current state of knowing." It is necessary to take into account "connectivism: a learning theory for a digital age". Educational strategies implemented in the education of "NET-students" and also "NET-teachers" have to respect these aspects. STE educators must focus on creation and implementation of connectivist elements into STE, but also into teacher development, because current students and young teachers are already members of the NET-generation. Learners use digital tools to create content, not only to be passive consumers of knowledge. In accordance with specific personal characteristics, this new generation requires a "connectivist" way of learning/teaching (Oblinger and Oblinger, 2005).

Inquiry-based science education

Teachers need to be equipped with new competences and educational methods. One such educational strategy is IBSE, based on constructivism. It is an instructional learner-centred approach that integrates theory and practice on the basis of inquiry, and develops knowledge and skills for a solution to a defined problem. Research results (Rocard et al., 2007) prove that IBSE brings the required competences to society, it is effective and increases students' interest, and also stimulates the motivation of teachers (Dostal, 2015). The core principles of IBSE are the involvement of students in discovering natural laws, linking information into a meaningful context, developing critical thinking and promoting positive attitudes towards science. IBSE based on constructivism provides teachers with the possibility of building up their pedagogical competences using their own experience from teaching and thus connecting pedagogical theory and classroom practice, which can be defined as teacher constructivism (Magoon, 1977).

Teacher constructivism

Constructivism as a pedagogical theory is preferably applied to the education of students (student constructivism). Teachers also learn for the whole of their lives, so it is therefore possible to assume that the constructivist approach can be applied to teacher education. It is logical that teachers also construct knowledge and skills through experiencing teaching and reflecting on their experiences (Pajares, 1992). Teachers compare new ideas with their previous experience and thus they connect pedagogical theory and practice (Magoon, 1977). In this active formation of new knowledge, skills and beliefs teachers are more open to finding new ideas, inquiring, and evaluating. This approach should be at the core of teacher constructivism. However, it is necessary to take into consideration that teachers are adults and to respect the learning principles of andragogy. According to the Canadian Literacy and Learning Network (2013), for the effective education of adults some stated principles of adult learning must be respected. The majority of them are a different way of motivating and linking to practice - adults "learn by doing".

Research questions, sample and methodology

This study presents the solution to the research problem of how to identify and to determine connectivist factors influencing science and technology teacher constructivist education, which can be defined as teacher constructivism. The basic research questions were phrased as follows:

How do connectivist factors influence science and technology constructivist education, with an emphasis on teacher constructivist education (teacher constructivism)?

Design-based research (hereinafter DBR) in a web-based environment was used as a core research strategy and it was completed with specific research methods such as tests, questionnaires, observations, interviews, students' and teachers' portfolios, etc. (Pulpan and Kulicka, 2015). The choice of DBR was justified by its close connection to school practice. DBR is development research. This research differs from other types of research (Reeves, 2006) and consists of four stages:

(1) Analysis of practical problems by researchers and practitioners: identification of connectivist factors for teacher constructivism in IBSE.

(2) Development of solutions with a theoretical framework: analysis of connectivist factors and determination of their impacts on teacher CPD; development of teacher educational methods for teacher constructivism in IBSE implementation.

(3) Evaluation and testing of solutions in practice: testing and evaluation of the adapted teacher educational courses for support of teacher constructivism.

(4) Documentation and reflection to produce "Design principles": identification and description of characteristics of connectivist factors and methods for the support of teacher constructivism.

The core of this DBR is a focus on the creation of a new product and close connection with educational practice.

Fifty Czech science (physics, biology, chemistry) teachers from secondary schools who were teacher-participants in the PROFILES project (see Table 1) formed the sample for the DBR, which was investigated over the years 2012-2015.

Table 1. Sample selection

Subject taught	N	Gender of teachers	N	Teaching experience of teachers (in years)	N
Total	50		50		50
Physics	16	F	41	0-5	6
Chemistry	16	M	9	5-15	19
Biology	18			more than15	25

These teachers-participants were chosen on the basis of their interest in being involved in the project. More data on the PROFILES project can be found in PROFILES (2016).

Results and discussions

The important DBR outcome was the result that connectivist factors have a significant and growing position in STE, including IBSE. An important issue is the relationship between connectivism and constructivism (Downes, 2012). This research has confirmed that there are a number of links between these two pedagogical theories in STE. The main connectivist factors which influence the development of teacher constructivism have been identified as follows:

Dynamic creative work and willingness to change

The connectivist approach raises and requires teachers to actively "learn by doing". Active participation is especially important to adult learners in comparison with children. In our PROFILES CPD courses teachers were spontaneously interested in being actively engaged in presented IBSE activities, testing and modifying them in practice. The activity of teachers, however, is fundamentally conditioned by the quality of the course, i.e. its objectives, content and methods.

Research confirmation (from the case study of a female teacher, Nada): She is a lower secondary school teacher at a village school with almost twenty years of experience. Her specializations are mathematics, chemistry, physics and ICT. Here are some excerpts from her case-study diary corresponding to dynamic creative work and willingness to change:

"As I understand the context of work in the PROFILES project, one of the CPD principles is the need to create independently and adapt the discussed curriculum creatively. It is important for us teachers to have theoretical methodological information, motivation and a model. Then most of us are capable of working independently and creatively."

"I learned to think about motivating students and about making them reflect on a given topic and learn by themselves. It is probably the biggest benefit of participating in the PROFILES project for me."

"I usually do not accept offered didactic or methodical materials unchanged. To be able to work naturally with "suitable" texts, I almost always perform minor modifications."

Teamwork in teacher education supported by web-environment

Teachers change their own beliefs more easily through discussions and collaboration with colleagues face-to-face and also increasingly through web communication.

Research confirmation:

In the international project PROFILES Portuguese and Czech teachers collaborated when preparing teaching. Their collaboration took place within the net-environment. The teachers recorded their insights on cooperation in their diary. The following text is the record of the Czech teacher about creating worksheets demonstrating the teamwork in teacher education supported by the web-environment:

"The worksheets informed me not only about new content but also about the way of teaching as well. It was very interesting to follow them. I will use them in my teaching in the future. It was important and comfortable for me that teachers' versions were prepared. It was not necessary to look for information."

Obtaining practical information from web databases

The crucial reason why a teacher starts a CPD course is practical application of obtained knowledge and skills. Since the acquisition of practical solutions is one of the main characteristics of connectivism, this is the significant factor in the current teacher education. This educational need of teachers is necessary to meet appropriate educational databases and networking in the frame of CPD. Therefore the content of the PROFILES CPD course was very pragmatic: development and implementation of IBSE modules into science teaching/learning (Trnova and Trna, 2015; Trna and Trnova, 2016). Teachers-participants collaborated using action research and created their own PROFILES modules.

Research confirmation:
The teachers-participants in the third phase of the DBR tested and evaluated the PROFILES modules in their classroom teaching and carried out self-reflections, which were studied through interviews, questionnaires, portfolio analysis, and case studies. A part of a teacher self-assessment questionnaire on obtaining practical information is given in Table 2:

Table 2. A teacher PROFILES CPD course questionnaire (obtaining practical information from web databases)

Questions from the teacher questionnaire	*Frequency of answers: YES (%)*
I search periodically for practical information for my teaching from web databases.	*83*
The PROFILES project website gave me a lot of practical advice and information that I have successfully used in the classroom.	*96*

In their evaluations teachers-participants expressed a positive view on the PROFILES website as a source of practical information.

Entering into net-networks with experts and peers who have the necessary knowledge and skills

A very popular and effective connectivist factor was a network of communication with experts (scientists and science educators) and peers. This was arranged using the PROFILES project web portal and especially its networking part. Within teacher CPD courses it is necessary for lecturers to be science education experts who will be in continuous web and face-to-face contact with teachers-learners.

Research confirmation:
A part of a teacher self-assessment questionnaire on net-networks with experts and peers is given in Table 3:

Table 3. A teacher PROFILES CPD course questionnaire (net-network with experts and peers)

Questions from the teacher questionnaire	*Frequency of answers: YES (%)*
I use the web to communicate with peers-teachers in solving problems that arise in my teaching.	*53*
The PROFILES project broadened my communication and collaboration with colleagues and experts, especially foreign ones.	*77*

Teachers-participants expressed a positive view on the PROFILES website as a tool of net-networking with experts and peers.

Motivation of teachers by web presentation of their ideas to the teacher community

Motivation of teachers in courses CPD was a crucial issue. Teachers often enter CPD courses with extrinsic social motivation (e.g. to improve qualifications), which may be positive but also negative for them. The optimal situation is when teachers are motivated by intrinsic cognitive motivation (interest). Presenting their own ideas and examples of good practice in the teaching community with the web environment also induces strong motivation. It is comprehensive intrinsic and extrinsic motivation that supports other connectivist factors (networking, etc.)

Research confirmation (from the case study of a female teacher, Nada):

The aforementioned teacher has written a learning task with a simple experiment which is part of the PROFILES website, and shows an example of the studied motivational factor, web presentation of a teacher's ideas to the teacher community:

Carbon in organic materials:

Learning task with simple experiments: Develop a simple experiment to verify the presence of carbon in organic materials.
Solution: The presence of carbon in paraffin through the formation of soot (see Figure 1).

Strengthening of ownership through networking

One of the key goals of teacher CPD is to develop a strong "sense of ownership" (also called self-efficacy) in the teaching profession. The idea of teacher ownership can be described as leadership; self-positivism; active involvement in appropriate adaptation and development of teaching/learning methods and materials. One of the key goals of the

PROFILES project was to develop strong teacher ownership, which is a precondition for further teacher CPD. Development of ownership is affected by many factors. One of the connectivist factors for supporting teacher constructivism is networking. For teachers, it is very important to know where they can seek help and advice in their educational problems. Therefore, teachers enter into formal and informal networks (with peers, experts) that significantly operate on the Internet and utilize emerging ICT applications. Evidence on development towards ownership was obtained in this DBR through observation of the participating teachers during the PROFILES CPD; their self-reflections (reflective essays), and through interviews.

Research confirmation (from the case study of a female teacher, Silva):
Another teacher-participant, Silva, expressed in an interview the following statements about strengthening of her ownership through networking:

"Previously, I had problems in dealing with difficult educational situations in my practice. Now I get in touch with my colleagues on the network, who are able to advise me. So I'm much more confident in my teaching."

"Based on the cooperation with colleagues in the PROFILES project I gained confidence that I previously lacked. I applied for an interview at the prestigious school where I then went and where I now work. I believe that helped me enhance my ownership."

Answers to the research question were also identification of the basic principles of the development of the teacher constructivist approach.

These principles can be summarized as follows:

(1) Active learning approach
(2) Active construction of knowledge and skills
(3) Self-reflection and assessment of learning by doing and understanding

These DBR outcomes form the first step of future research into connectivist factors which influence the development of teacher constructivism. It can be expected that other factors will be found with regard to the development of educational technologies and the changing STE curriculum, the educational needs of students and teachers, etc.

It is necessary to carry out follow-up research on a larger number of teachers-respondents and to compare results from more countries. The constructivist approach in the form of teacher constructivism will require more detailed research and development, but also effective implementation. A systematic constructivist approach in science and technology teacher education is required to perform this approach systematically in pre-service training and then in in-service teacher education based on teachers' practical experience (Jeskova, Kires, Ganajova, and Kimakova, 2011). It is obvious that this approach should become part of the planning and designing of teacher training courses in CPD.

Conclusion

This study tries to identify and to determine the connectivist factors influencing science and technology teacher constructivist teacher education - teacher constructivism. Using DBR the new connectivist factors have been determined: dynamic creative work and willingness to change, teamwork in teacher education supported by web-environment, obtaining practical information from web databases, entering into a net-network with experts and peers who have the necessary knowledge and skills, motivation of teachers by web presentation of their ideas to the teacher community, and strengthening of ownership through networking.

It is obvious that the mere use of ICT does not automatically lead to an increase in the level of output CPD, just like in the education of students. A set of principles for the development of teacher constructivism was also identified: active learning approach, active construction of knowledge and skills, and self-reflection and assessment of learning by doing and understanding. It was suitable to perform this research in the context of training courses in the implementation of IBSE within the PROFILES project. It is necessary to do a more detailed analysis of these factors and the links between all elements of teacher CPD in future research. The outcomes of the research should be implemented into the education of science and technology teachers.

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