Chapter #18

DEVELOPMENT OF INTERDISCIPLINARY INSTRUCTION USING INQUIRY BASED SCIENCE EDUCATION

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ABSTRACT
The task of the current educational system is to give all pupils competences they will need to prosper in the global economic competition. However, pupils very often consider learning content to be useless for their everyday life. In the context of natural sciences, this is not only about the choice of learning content but also about how science subjects are taught. Pupils are not usually able to connect knowledge from individual natural science subjects and to solve interdisciplinary problems so typical for everyday life. This could be one of the essential reasons for the lack of pupil interest in the study of natural sciences. An interdisciplinary approach to teaching could be the way to solve this situation. However, teachers usually lack training in interdisciplinary instruction, and they do not know the appropriate educational methods supporting interdisciplinarity. It is vital to educate them on how to carry out interdisciplinary instruction to satisfy pupil requirements. This study introduces inquiry-based science education as a suitable educational strategy for efficient interdisciplinary instruction. Research findings confirming the effectiveness of pre-service teacher education in interdisciplinary instruction using inquiry-based science education are presented.

Keywords: interdisciplinary instruction, inquiry-based science education, teacher education.

1. INTRODUCTION

Education plays a vital role in developing and improving the quality of human resources. Therefore, the current educational systems of developed countries have many tasks depending on the priorities of individual countries, and the demands on them are evolving fast. However, the main ones include providing all pupils with the competences they will need to prosper in the global economic competition during their professional life and to equip them for solving everyday problems (Csapó, & Funke, 2017). Scientific knowledge develops and grows very quickly, and subsequently, scientific progress influences the everyday lives of people. Natural sciences are an essential discipline which significantly affects people in many aspects.

Contrary to this fact, natural science educators, especially in Europe and USA, face a decline of interest in the study of natural science and technology (OECD, 2006; Kires & Šveda, 2012). Educational experts and researchers attempt to find reasons for this phenomenon (Bolte, 2006; Dostál, 2015). Unsuitable educational methods appear to be one of the main factors leading to this situation (Rocard et al., 2007). According to the PISA findings, only 15% of European pupils are satisfied with the quality of natural science teaching/learning in schools, and nearly 60% of them state that natural science teaching/learning is not attractive for them (Ministry of Education, Youth and Sports CR, 2010). One of the significant reasons for pupils' lack of interest in the study of natural sciences could be traditional educational strategies which very often prioritise acquisition of separate knowledge such as data, formulas, equations, and theories, which pupils only

memorize without understanding and forget them very easily (Ministry of Education, Youth and Sports CR, 2010).

Another reason for lack of interest in natural sciences may be that pupils consider natural science subjects to be useless. Based on our research findings, even though pupils think natural science educational contents are essential for society, on the other hand, they consider them unnecessary for their everyday lives (Trnová, 2012). The cause could be the way of teaching, which lacks an interdisciplinary approach. Pupils are not usually able to connect knowledge from separate natural science subjects and to solve interdisciplinary problems typical for everyday life. This situation suggests that there is a gap between how science subjects are taught and how they are perceived in society (e.g., on television and in other media). There is also an argument for the need to implement into science subjects contemporary teaching/learning methods that can reduce this discrepancy (Osborne, 2007). Therefore, it is necessary to look for innovative teaching/learning methods that will lead to more effective science education and an increase in pupil motivation for science. According to research findings (Trna & Trnová, 2014) inquiry-based science education (hereafter IBSE) is appropriate for interdisciplinary instruction of natural science subjects.

2. BACKGROUND

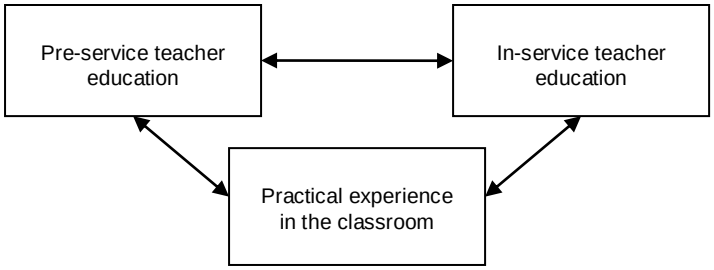
Teachers are a significant factor affecting pupils´ learning outcomes (Darling-Hammond, 2000; Osborne, & Dillon, 2008). Therefore, it is crucial to pay attention to their education, beginning in pre-service education and ongoing throughout their continuous professional development (hereafter CPD). It is necessary to educate them on how to carry out interdisciplinary instruction to satisfy pupil requirements for linking teaching/learning to everyday life. They are not often aware of educational strategies suitable for interdisciplinary instruction, or they are not able to implement them into natural science instruction. Teachers sometimes struggle with the design of interdisciplinary instruction. The first step, understanding what interdisciplinary instruction is, can be difficult, let alone designing activities that support interdisciplinarity. Inappropriate application of interdisciplinary attitudes into science instruction may not produce the expected positive results, and the disappointed teacher goes back to the traditional style of teaching (Darling-Hammond, 2000). To avoid this and to make interdisciplinary instruction effective, teachers must have the professional competence to apply this way of teaching/learning, so they should acquire a set of specific skills.

Teacher professional competences have to be created through three main parts: pre-service education, in-service education, and practical school experience (see Figure 1). The high educational level of the three components mentioned in Figure 1 and their linking are necessary conditions for quality teacher education. Teachers take part in this educational system in five possible roles: teacher as a learner, teacher as a teacher, teacher as a reflective practitioner, teacher as a leader and teacher as a researcher. The role of teacher-learner is typical for teacher candidates. This role is often underestimated and neglected during continuous professional development (CPD); however, it is vital. According to experts, teachers are strongly influenced by their own school experience as learners, and many teachers have minimum experience with interdisciplinary teaching/learning from their schooling.

The role of teacher-teacher is connected with the teacher's classroom practice, and university students (pre-service teachers) go through this role during teacher training at schools. The role of the teacher-reflective practitioner is based on experience and it is expected within CPD. Teacher-leader is involved in teacher training management.

Experienced teachers or education specialists (e.g., an expert in didactics, educationalist) usually fulfill this role. The role of teacher-researcher has gained importance recently based on the popularity of research in this field. Researchers from our University have been engaging in-service teachers (some pre-service teachers as well) in action research as much as possible. This is beneficial for both sides - university experts and teachers.

Figure 1.
A diagram of systematic teacher education (Trna & Trnová, 2014).



2.1. Interdisciplinarity

Interdisciplinary instruction is generally defined as the integration of two or more disciplines. The term "interdisciplinary" is applied to a variety of curricular arrangements and has a variety of synonyms (thematic teaching, integrated learning). The degree of integration and what will be integrated is important to consider. Relan and Kimpston (1991) arrange interdisciplinary approaches to the curriculum along a continuum of operational schemes, indicating the degree of integration. Thus, one extreme of the continuum would be structuring the curriculum plan around each separate subject, with the opposite extreme being an "eclectic" or "problem-oriented" approach. Techniques such as the intermingling of disciplines (sometimes called "multi-disciplinary") or the integration of across-the-domain skills like problem-solving or writing across the curriculum are between these opposite poles.

It is necessary to understand that interdisciplinary instructions affect pupils and teachers differently. Teachers face challenges to cover knowledge from various subjects. For improvement of the interdisciplinary approach, teamwork among all involved science teachers is beneficial to develop a quality interdisciplinary curriculum (Jones, 2009). The interdisciplinary approach requires the knowledge of didactics of particular subjects whose contents are integrated to prevent pupils from incorrect learning processes. Also, knowledge of pedagogy is required to implement the interdisciplinary contents into the educational procedures correctly. Pupils are called to be successful in an interdisciplinary approach; thus, they need carefully structured experiences and instructional support from teachers. Also, pupils often need to understand the learner-centred attitude; they have experienced only the traditional way of teaching in which a teacher maintains the leading role.

An interdisciplinary approach has many advantages, as well as disadvantages (Jones, 2009; Cai, & Sankaran, 2015). Based on our long-time experience, we specify the essential advantages of interdisciplinary instruction:

(i) Motivation.
(ii) Greater curriculum understanding to connect findings from various subjects.

(iii) Development of competences which are necessary for everyday life (problem-solving, critical thinking, forming conclusions and their defence).

(iv) The possibility of an individual approach to solving problems based on the abilities of pupils in particular subjects.

(v) The saving of time in the curriculum of particular subjects.

Teachers in the Czech Republic were recommended to utilize the interdisciplinary approach and not implement the same learning content into several subjects. In the end, this intention did not move forward because of lack of experience of teachers in how to create the required interdisciplinary curriculum. To form the interdisciplinary curriculum is hugely time demanding, which is one of its disadvantages. There are also higher requirements for teachers (also for pupils) than the teaching of particular subjects. Nevertheless, this way of teaching brings high-quality outputs in the way of understanding and utilizing necessary competences. Based on our experience, the requirements increase with the curriculum difficulty, thus, with the requirements on expertise.

In the Czech Republic, pre-service teachers are educated in two separate subjects of their choice, and interdisciplinary instruction is not involved in the university curriculum. However, the current interdisciplinary paradigm of natural science education requires an integrated approach. The Faculty of Education, Masaryk University in Brno is solving this deficiency in the pre-service teacher education by establishing the course Didactics of Natural Sciences, which aims at interdisciplinary instruction. Students (teacher-candidates) acquire educational strategies appropriate for interdisciplinary instruction. First, they get to know them theoretically and they then apply them in practice at schools.

2.2. Inquiry-based science education (IBSE)

IBSE is one of the strategies which is relatively new in the Czech Republic, and therefore students (teacher candidates) and teachers have usually minimum experience with IBSE instruction, and they have to gain it. According to research findings (Trnová, 2012) teachers can implement IBSE in an appropriate way when they acquire it in both roles (teacher as a learner and teacher as a teacher) under supervision. Afterwards, they can develop their acquired professional skills in further roles. However, it is necessary to show teachers how to develop interdisciplinarity within IBSE. Not every IBSE learning content includes an interdisciplinary dimension. Interdisciplinarity places demands on teachers not only in the field of didactics but also in other sciences that they do not have in their teaching qualifications. Teachers themselves must understand the interdisciplinary issues that pupils should learn through IBSE. Teachers must learn to collaborate with colleagues to prepare interdisciplinary instruction using IBSE. Teamwork is essential for quality interdisciplinary teaching/learning, and it enriches all participants in the educational process.

To develop interdisciplinarity with the use of IBSE, teachers need to master this innovative educational strategy. IBSE is an excellent motivation for all different types of pupils, those who are talented and also those with special educational needs, as well as for teachers. The most critical motivational element of this method is the connection between the curriculum and everyday life (Trna & Trnová, 2014). Nevertheless, it is logical that IBSE is age-specific when applied to science education. Application of IBSE needs a large ensemble of activities that constitute “doing science.” These activities include conducting investigations, sharing ideas with peers, specific ways of talking and writing, mechanical, mathematical, and computer-based modelling, and development of representations of phenomena. This type of science education involves active learning, and it takes advantage of children's curiosity by increasing their understanding of the world through

problem-solving. To develop skills in natural science, pupils have to gain the opportunity to participate in this full range of activities. It would be wrong to assume that young pupils in primary science can conduct scientific research independently and from the beginning as do pupils in secondary science courses, or even as real scientists do. The teacher needs to develop individual skills gradually and systematically and lead the pupils to some extent according to their abilities, even in IBSE. Banchi and Bell (2008) defined four IBSE levels (see Table 1) according to the degree of the teacher's guidance (help in the process, asking guiding questions and the formulation of the expected output).

Table 1.
Four IBSE Levels.

IBSE levels	Questions (defined by teacher)	Procedure (defined by teacher)	Solution (defined by teacher)
Confirmation	Yes	Yes	Yes
Structured	Yes	Yes	No
Guided	Yes	No	No
Open	No	No	No

(i) Confirmation inquiry: This is based on confirmation or verification of laws and theories. The confirmatory inquiry is appropriate at the beginning of IBSE implementation when the teacher aims to develop the observational, experimental, and analytical skills of the pupils. When conducting experiments, pupils follow the teacher's detailed instructions under his/her guidance.

(ii) Structured inquiry: The teacher significantly influences the inquiry at this level and helps pupils by asking questions and providing guidance. Pupils look for solutions (answers) through their inquiry and provide an explanation based on the evidence they have collected. The teacher defines a detailed procedure of experiments, but the results are unknown in advance. Pupils show their creativity in discovering laws. However, they are guided by the teacher's instructions in the research. This level of inquiry is significant for developing pupils' abilities to perform a high-level inquiry.

(iii) Guided inquiry: The third level of IBSE changes the role of the teacher dramatically. The teacher becomes a guide for pupils. He/she cooperates with pupils in defining research questions (problems) and advises on procedures and implementation. Pupils themselves suggest procedures to verify the inquiry questions and their subsequent solutions. Pupils are encouraged by the teacher much less than in the previous two levels, which radically increases their level of independence. Pupils should have previous experience of lower levels to be able to work independently.

(iv) Open inquiry: This highest level of IBSE builds on the previous three inquiry levels, and it resembles real scientific research. Pupils should be able to set up their inquiry questions, methods, and procedures of research, record and analyse data and draw conclusions from the evidence. This way requires a high level of scientific thinking and places high cognitive demands on pupils, so it is applicable for the oldest and/or gifted pupils.

These four IBSE levels correspond to different age levels of pupils and their abilities. However, it is possible to apply different levels of IBSE to the same age group during group instruction depending on pupils' abilities. Similarly, we can choose the appropriate level of IBSE according to the demands of the science course.

The education of teachers based on IBSE must be implemented in the graduate and postgraduate phase of professional preparation because the development of the ability how to choose and prepare a curriculum in the IBSE form and implement it into the teaching practice correctly requires time. During the graduate phase, teachers gain the beginning level, which includes especially knowledge and the first experience with teaching. These students are not able to implement the next level in IBSE in their teaching. Nevertheless, the students get more experience in their teaching practice and studies, so they reach the proficient level, and they know how to apply IBSE in all its levels.

2.3. Interdisciplinary instruction using inquiry-based science education

Interdisciplinary instruction and IBSE methods are demanding educational strategies which require teachers to use new approaches. However, teachers do not have enough experience and professional competences. Moreover, they do not know how to utilize IBSE. Both strategies have many advantages and also disadvantages described in published literature related to this topic (Jones, 2009; Cai, & Sankaran, 2015; Trnová, 2012). The advantages of these strategies are connected, and they intensify within the proper design of interdisciplinary introduction. Our research confirms the development of motivation and students' understanding of coursework based on practical activities of IBSE. Also, both the mentioned advantages of interdisciplinary instruction conform with the implementation of IBSE into teaching. The support of the development of competences such as problem-solving, critical thinking, forming conclusions, and their defence is typical for interdisciplinary instruction and IBSE. The four levels of IBSE enable the individual educational approach depending on pupils' abilities. (Banchi, & Bell, 2008). To eliminate the disadvantages, teachers need to identify and avoid them or at least minimalize them. High-quality pre-service teacher education is beneficial for reaching this.

At the Faculty of Education, Masaryk University in Brno students (teacher candidates) learn the necessary skills within the frame of the course Didactics of Natural Sciences. They create interdisciplinary teams; members are experts in individual natural sciences, and they collaborate in preparing quality interdisciplinary topics and design of IBSE. University teachers, experts in natural sciences, didactics, and pedagogy have the role of mentors. This interdisciplinary teaching/learning can facilitate students in learning about approaches, theories, and methodologies from various disciplines of the social and natural sciences.

The course Didactics of Natural Sciences is taught for 2 hours per week during one semester (24 hours in total). However, students (pre-service science teachers) work not only during lessons but also outside of these lessons. They create proposals for topics and designs of interdisciplinary instruction using IBSE. During the period the research described below was carried out, students prepared the interdisciplinary topic "water", which corresponded with the Czech curriculum and was suitable for interdisciplinary instruction using IBSE. In the first stage (12 hours during the course and around 10 hours outside of it), they worked on the design of the teaching/learning to meet the curriculum requirements and the IBSE and interdisciplinary approach. University teachers were mentors at this stage. In the second stage (approximately 10 hours), the students prepared the school environment for interdisciplinary education using IBSE. Experienced school teachers who were supervising teachers for the students' teaching practice had the role of mentors. In the third stage, the students taught the selected topic "water" in the form of interdisciplinary instruction using IBSE at school (5 hours). University teachers and experienced school teachers observed the process of interdisciplinary instruction using IBSE. In the last stage (approximately 3 hours) university teachers and experienced school

teachers gave feedback to the students (pre-service science teachers) and these students performed self-assessment. This last stage was very important for correction of possible inaccurate or inappropriate procedures. The pupils (participants of interdisciplinary instruction using IBSE) gave feedback to the students (pre-service science teachers) in the form of a questionnaire on their views on the completed lessons. The students (pre-service science teachers) were satisfied with the course Didactics of Natural Sciences and considered it to be very useful for their practice.

3. METHODOLOGY

The research aimed to verify the development of interdisciplinary instruction of natural science subjects using IBSE. The research was focused on education of in-service teachers, pre-service teachers, and pupil educational outcomes. It is necessary to take into consideration the limited scope: this study presents only research findings connected with the education of pre-service teachers. Therefore, the research question is:

How does IBSE implementation in pre-service teacher training influence the development of interdisciplinary instruction?

The research sample was composed of 36 students (pre-service science teachers) from the Faculty of Education, Masaryk University, the Czech Republic. These students were preparing for interdisciplinary instruction using IBSE in the course Didactics of Natural Sciences. During this course, students gained experience with interdisciplinary instruction using IBSE first in the role of learners. This means they carried out the inquiry, and fulfilled the tasks as pupils in order to be able to better imagine the feelings or learning problems of children. In this role, they also acquired the necessary pedagogical knowledge and skills for teaching. After that, the students in the role of teachers undertook interdisciplinary instruction using IBSE under the guidance of experienced teachers during their teaching practice at schools. Pre-service teachers built up their pedagogical knowledge, skills, and competences using their own experience from the role as learners and after during their teaching practice at schools as teachers, they connected pedagogical theory and practice, which is known as teacher constructivism (Magoon, 1977). The university teachers of natural science subjects had the role of teacher-leader and teacher-researcher.

There was used a research-method of triangulation (semi-structured interviews, questionnaire, and analysis of teachers-candidates' products) as a specific method to answer the above mentioned research question. First, semi-structured interviews were carried out with all (36) research participants and questions were focused on the professional competences connected with the development of interdisciplinary instruction using IBSE. Based on the answers of the research participants, items of the questionnaire were created using a Likert scale (Půlpán, & Kulička, 2015). The verification of the research findings was completed using the analysis of educational products created by the research participants. The collected data were analysed. The research was carried out in the period 2016-2017.

4. RESULTS

As mentioned above, the questions in the semi-structured interviews were focused on the competences of pre-service science teachers connected with interdisciplinary instruction using IBSE. The research participants stated what professional competences connected with interdisciplinary instruction using IBSE they had acquired during the course. In the next

research tool – questionnaires - research participants expressed their subjective assessment of the extent of acquired professional competences. To determine the level of acquisition, the 5-point Likert-type rating scale was used (1-Very weakly, 2-Weakly, 3-Normally, 4-Strongly, 5-Very strongly) to measure the development of their professional competences. Table 2 provides an overview of the leading professional competences mentioned by pre-service science teachers. Subsequently, analysis of teachers-candidates' products and verification of collected data were performed.

The results of the questionnaire are presented in Table 2. The collected data showed that the primary pre-service teacher professional competences for interdisciplinary teaching were developed significantly. If we consider only the highest category, very strongly, of the Likert scale, this option was chosen by more than a half of respondents for four professional-pedagogical competences necessary for interdisciplinary instruction *(to motivate pupils, to encourage pupils to solve interdisciplinary problems, include interdisciplinary topics from everyday life relevant to pupils, to develop lifelong learning skills).*

Table 2.
Questionnaire of pre-service teachers - data.

Using IBSE in interdisciplinary instruction I am able to:	(1) Very weakly (%)	(2) Weakly (%)	(3) Normally (%)	(4) Strongly (%)	(5) Very strongly (%)	Mean values (1)–(5) N = 36
motivate pupils for natural science	0	0	0	31	69	4,69
encourage pupils to solve interdisciplinary problems	0	0	0	42	58	4,58
include interdisciplinary topics from everyday life relevant to pupils	0	0	3	39	58	4,56
develop lifelong learning skills	0	0	8	36	56	4,47
develop skills of pupils to connect information from different natural science subjects	0	0	0	58	42	4,42
integrate natural science and social issues in interdisciplinary instruction	0	0	20	36	44	4,25
develop pupil interdisciplinary experimentation	0	0	8	73	19	4,11

The significant development of most of the respondents' monitored professional-pedagogical competences is even more apparent when the category is combined firmly and very resolutely. In this case, apart from “integration of natural science and social issues in interdisciplinary instruction,” pre-service teachers noted significant development of their professional competences for interdisciplinary instruction. This was confirmed by the research findings of pupil educational outcomes and analysis of educational products created by the research participants.

The research findings prove that the quality of teacher education is reflected in the quality and effectiveness of education (Pellegrino, & Hilton, 2012; Osborne, Simon, & Collins, 2003; European Commission, 2004). According to experts, teachers are the significant factor influencing the learning outcomes of pupils (Darling-Hammond, 2000; Osborne, & Dillon, 2008). Based on these facts and the presented research findings, it is possible to answer the research question: *How does IBSE implementation in pre-service teacher training influence the development of interdisciplinary instruction*? Because teacher competences were developed, it is possible to confirm the development of interdisciplinary instruction using IBSE. IBSE implementation in teaching/learning supports the development of interdisciplinarity. Our other research results (pupil outcomes and analysis of educational products created by research participants) confirmed this conclusion as well.

5. CONCLUSION

In the frame of the course Didactics of Natural Sciences the advantages and disadvantages of interdisciplinary instruction were discussed. Significant advantages are seen in Table 2. The main disadvantages are the time required to prepare this type of instruction and the limited number of suitable topics. Pre-service teachers were directed to reduce the impact of the disadvantages and to use the advantages effectively. IBSE was confirmed as an appropriate strategy for the development of interdisciplinary instruction. The text above describes the main advantages of interdisciplinary instruction using IBSE, and Table 2 lists the developed competences of teachers. It is necessary to highlight the development of lifelong learning skills that are essential to pupils' future education as well as their lives and future success and to increase pupils' ability to solve interdisciplinary problems. According to the outcomes of the course, the advantages of interdisciplinary instruction for teachers are collegial environments, high level of innovativeness, high levels of energy and enthusiasm, support for personal growth, and learning.

Considering that the quality of teachers is the fundamental factor affecting learning outcomes, it is necessary to pay great attention to their education, especially in the area of innovative educational strategies. It is necessary to implement innovations already into pre-service teacher education to increase the effectiveness of science teacher education. Teacher-candidates need to construct their professional pedagogical skills based on experience acquired first as learners and later as teachers with the support of experienced teachers and experts. This method of teacher constructivism connects teachers' experience from instruction with pedagogical knowledge and skills and creates high-quality professional-pedagogical competences.

The presented research findings confirm that a properly implemented innovative component in pre-service teacher education can improve the quality of professional competences and teachers are then not afraid of its implementation in their teaching. During pre-service training, students should have the possibility to acquire core knowledge and skills connected with innovative educational strategies, which they currently do not experience during their studies. The presented pre-service teacher education in the course Didactics of Natural Sciences could be an example of how to educate future teachers of natural science subjects.

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