8. Papers

A key-competence approach to teaching standard topics in STEM

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1. Introduction

The European Commission has identified the urgent need to support the development of citizens' key competences (European Commission, 2019). Higher education institutions (HEIs) play a major role for this support, as they are the ones to educate future teachers. Core of STEM education at school is the transfer of fundamental subject knowledge like functions, measurement and chemical reactions. However, in traditional teaching, learners' skills and attitudes in these standard topics have not been sufficiently. Therefore in the key competence approach (COM 2019) key competences play a major role. They consist of knowledge, skills and attitudes and mathematical competence, competences in science, technology and attitudes and digital competences belong to eight key competences as highlighted by the EU. addressed in a key-competence STEM teaching approach (Maass et al., 2019). The challenge for HEIs is to learn teachers to teach key competences without neglecting subject structures needed for further study (e.g. Ploj Virtič & Šorgo, 2016).

Topics bearing controversial aspects or obvious societal relevance – such as environmental degradation or cybersecurity – require innovative educational approaches, which enable teachers to not only deliver knowledge but also foster learners' skills and attitudes. New approaches are needed to connect traditional topics to these transversal competences. This creates the need to figure out ways to allow learners to develop key competences in the scope of these traditional topics. Unfortunately, only a few materials are available on teaching STEM content

with the potential to foster the development of key competences, because these materials are often not explicitly connected with traditional curricula (Šorgo et al., 2022).

In the European STEMkey (2020–2023, Erasmus+ KA2) project, several countries collaborated to develop modules for teacher education with the aim to learn future teachers to teach standard STEM topics with a key competence approach in order to reshape the delivery of standard STEM topics with their interdisciplinary connections. STEMkey is a project implemented by the International Centre of STEM Education at the University of Education in Freiburg in cooperation with 10 partners out of 10 European countries. In the following we will outline some of the modules in order to give insight into the key competence approach.

2. Exemplary insight into the teaching modules based on the key competence approach

2.1 Teaching functions

As for many approaches to STEM education, it is essential to gain the students' interest and to show them the relevance of functions. Even though most people do not realize it, but they use functions in many all-daily situations, be it to calculate a taxi fare with fixed start price and per kilometre travelled (linear function), the trajectory of a ball (quadratic function) or the spread of a virus (exponential function). The current situation in relation to the corona virus and societal measures shows how important it is to fundamentally understand the concept of exponential growth to act responsibly. This module starts off from open realistic situations and students are asked to mathematically model them. Mathematical modelling can simply be understood as applied mathematical problem solving, and thus involves connecting mathematics and the world around us, applying mathematics and inventing mathematics to solving problems, and therefore serves sense making in mathematics education (Drijvers et al., 2019). The module discusses how to work with open and interdisciplinary tasks, and how to orchestrate the classroom activities that support students' autonomous construction of knowledge, investigation of strategies and presentation skills. Additionally, we know that different function aspects can be better understood by using different function representations, graphs, tables, rules or verbal descriptions (Bloch, 2003) and therefore students work with these various representations. This also offers obvious use of digital tools for the purpose of analysing functions and their representations.

2.2 Teaching measurement

Measurement provides answers about sizes of objects or phenomena and applies to basic physical quantities like length, area, volume, weight, time, speed, force and energy. These quantities can be primary (e.g., length and time) or compound quantities (e.g., speed). Measurement competences have become increasingly important in our current digital society and are needed in daily life and in the workplace. However, in day-to-day teaching, measurement is treated in an abstract way with a focus on conversions of measures and practicing the staircase model. The aim of this module is to provide a rich learning experience for future teachers and demonstrate the relevance of being able to apply measurement concepts and use them to solve situations in their personal and professional lives. The module also addresses a variety of qualitative and quantitative dimensions (e.g. for acid or wind) and includes attention for everyday language like micro, kilo and tetra. Measurement is addressed with modern (mobile) tools that are needed for meaningful and critical use of technology (Gravemeijer et al., 2017). Future teachers need to understand the potential of using modern technology in their classroom, and they need to learn how they can instruct their students how to use them in today's society

2.3 Human anatomy and physiology with smartphones

Human anatomy and physiology is part of almost all primary and secondary school curricula in the world. Most of the time it is taught as a part of life science subjects, but basically every teacher, regardless of the subject, sooner or later comes across questions that connect traditional topics from his/her subject with human beings. To illustrate, we can look at the flow of energy that connects physics and chemistry to metabolism, all in social, societal, technological, and environmental contexts. Thus, teaching and learning on these topics can be seen as challenging. The search overarching principles and transversal key competences is expected to be a preferred avenue for finding connections. This module provides activities that can be used in the classroom or outside the classroom based on observation, counting, and measurement using tablets or smartphones. The hands-on activities have been tested with students - prospective biology teachers - as part of the regular curriculum in biology didactics and will be transferred to a course. So far, in addition to the introduction (know your smartphone), three activities based on observation (smartscope), counting (smart heart), and measurement (coagulation of proteins) have been tested and protocols have been established. It was shown that the introduction of such activities in the courses for prospective teachers has the potential not only to improve knowledge, experimental and practical skills, but also to enhance competences like creativity, critical thinking, problem-solving strategies and to support positive attitudes.

2.4 Teaching the periodic system

To science educators the periodic system is an invaluable tool that facilitates a succinct organization and understanding of building blocks of chemistry. Indeed, the compressing of chemical knowledge that the system offers, once initiated a transformation in teaching, from forcing students to cram brute facts – as was the fashion in the 19th and early 20th centuries (Kaji et al., 2015) – to learn by studying relationships between elements and trends in chemical properties across the table. In this module, we offer a context-based approach to introducing the periodic system to teacher students which at the same time might inspire their own future teaching about the subject in lower secondary school. A context-based chemistry teaching requires that students connect canonical science concepts with a real-world context, a connection that makes chemistry meaningful to students (King, 2012). The module includes sorting activities using Lego bricks, an introduction to the historical development of the periodic system, hands-on interaction with samples of elements, as well as socio-scientific issues related to the extraction and use of chemical elements in technological devices. By selecting elements that the students might know from their everyday lives and disseminate about their applications in society— including ethical issues– we connect the "inhabitants" of the periodic system, and thereby the system itself to real-life contexts.

2.5 Moving from theory to experience - Teaching material cycles

Learning about material cycles – and the carbon cycle in particular – bears the potential to unite different STEM subjects across the curriculum and to provide interdisciplinary learning opportunities. Curricula of various subjects highlight the importance of material cycles. In physics classes students shall learn about the water cycle and in geography and economy classes students shall encounter different cycles that are relevant to our geo-ecosystem, including the water and carbon cycle. It is crucial that (future) STEM teacher are capable to teach the ubiquity by (a) creating learning environments that allow for interdisciplinary learning instead of multidisciplinary learning of isolated pieces of knowledge, and (b) helping learners to integrate single pieces of knowledge to gain a systemic understanding of the carbon cycle. This module shows future STEM teachers how to teach material cycles in a real-world context using practical activities, which increase learners' perceived relevance of the topic (Zeyer & Dillon, 2019). This is important, because teachers typically ask learners to reproduce knowledge on the different systems, chemical compounds, and chemical reactions of material cycles and explain graphics given in textbooks. Future STEM teachers need to experience how they can support learners to apply knowledge on material cycles in real-world contexts and develop critical thinking, which is one "of the requirements to navigate our increasingly complex world" (European Commission, 2019, p. 3).

Critical thinking results when knowledge, skills, dispositions (or attitudes) and norms, values and emotions interplay when dealing with a subject or an object to take a position, make a decision and/or act and this process is controlled by intellectual standards as well as self-regulation (Rafolt et al., 2019).

2.6 Teaching chemical reactions

Chemical reactions are a standard topic in chemistry education and therefore initial teachers need to be prepared for it. However, in traditional science classrooms this topic is often treated by showing one example and then by treating chemical equations without direct connections with experimental activities. The aim of this module was to develop an innovative teaching material on the topic Chemical reactions with rich learning experiences for school students which also nurture the development of key competences. Chemical reactions are introduced in concrete examples from everyday life and in supporting of sustainable development (industry, agriculture, transport etc.). Our focus is to introduce future teachers into ways of transforming standard "content" into tasks which give student an active role, which use real-life contexts, connect different disciplines and take into account students' diversity. Experiments support the understanding of mutual transformations of chemicals where material cycles are associated with significant colour changes in substances, changes in the reactant state and variety of reaction types (Kolář et al., 2018). These experimental activities require creative and critical thinking, and aim at enabling future teachers to teach the basics of chemical reactions in an innovative way.

3. Summary

This paper gives exemplary insight into modules for future STEM teacher education with a focus on supporting not only the the acquisition of facts but on the key competence approach. The materials are available online under https://icse.eu/international-projects/stemkey/.

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