CREATIVELAB_SCI&MATH: WORK DYNAMICS AND PEDAGOGICAL INTEGRATION IN SCIENCE AND MATHEMATICS

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Resumo

O CreativeLab_Sci&Math é um projeto do Departamento de Ciências Matemáticas e Naturais da Escola Superior de Educação de Santarém que visa a inovação das práticas pedagógicas no ensino superior. Através do envolvimento dos estudantes em atividades interdisciplinares que integram os conteúdos e os processos de construção do conhecimento da Matemática e das Ciências Físico-Naturais, pretende desenvolver competências como o saber científico, técnico e tecnológico, o pensamento crítico e criativo, o raciocínio e a capacidade de resolução de problemas. Este processo de integração curricular assenta num forte trabalho colaborativo entre os docentes das duas áreas. Neste artigo apresentam-se as dinâmicas de trabalho, as dificuldades e as mais-valias que este processo colaborativo trouxe para a aprendizagem dos estudantes, as práticas didáticas dos docentes e para o seu desenvolvimento profissional, assim como os desafios futuros.

Palavras-chave: Ambientes educativos inovadores; Ciências Físico-Naturais;

Inovação; Interdisciplinaridade; Matemática.

Abstract

CreativeLab_Sci&Math is a project of the department of Mathematical and Natural Sciences of the Higher School of Education of Santarém that aims the innovation of the pedagogical practices in Higher Education. One main objective is the involvement of students in interdisciplinary activities that connects content and processes of knowledge construction of Mathematics and Physical-Natural Sciences. Those activities aim to develop competencies in students such as scientific, technical and technological knowledge, critical and creative thinking, reasoning and problem-solving skills. This process of curricular integration is based on a strong collaborative work among the teacher educators of both areas. This article presents the work dynamics, difficulties and benefits that this collaborative process has brought to students' learning, our didactic practices and professional development, as well as future challenges.

Keywords: Innovation; Innovative learning environments; Interdisciplinarity; Mathematics; Science.

Introduction

Science, Technology, Engineering and Mathematics (STEM) competencies are crucial "to foster economic development, while occupations are among the highest paying, fastest growing, and most influential in driving innovation. STEM graduates enjoy low unemployment rates as well" (Horta, 2013, p. 2). For that reason, in the past decade in Portugal, government and education policy leaders have been concerned to promote STEM education to:

> *1) increase the proficiency of all students, as well as teachers in STEM in order to improve the ability of students and teachers to address increasingly complex problems, employ STEM concepts and apply creative and innovative solutions to their daily lives; and 2) increase the number of students who pursue STEM careers and advanced studies by raising awareness of the importance of STEM and by raising interest in STEM subjects* (Horta, 2013, p. 2).

According to Ríordáin, Johnston and Walshe (2016), to meet these challenges it is important to develop a curriculum that effectively integrates Mathematics, Science and Technology and to improve teacher education. School curricula usually compartmentalize knowledge into isolated disciplines in basic and secondary education. In higher education, and especially in the Portuguese teacher education programs, the compartmentalization is even stronger because the curriculum is divided in seven formation areas: General education; Teaching area – Portuguese; Teaching area – Mathematics; Teaching area – History, Geography and Science; Teaching area – Expressions; Didactics; and Initiation to the Professional Practice.

This subdivision of areas is a huge obstacle to curriculum integrative approaches. In fact, this rigid boundary between the school subjects do not exist in the real world, where professionals and researchers use Mathematics and Science in closely related ways (Baxter, Ruzicka, Beghetto & Livelybrooks, 2014). However, with the teacher educators' engagement and collaboration it is possible to construct an integrative curriculum. This is the main purpose of this paper, to present how a group of teacher educators of the Department of Mathematics and Natural Science of Santarém School of Education work together to create and develop an innovative and integrated approach for connecting the teaching of Science and Mathematics, named CreativeLab_Sci&Math. The CreativeLab_Sci&Math is an effective innovative learning environment, encompassing a new learning space but also teacher educators that have the purpose to innovate the pedagogical practices of Science and Mathematics in Higher Education.

Difficulties and Advantages of Science and Mathematics Integration

The teacher education program of the undergraduate degree of Basic Education of Santarém School of Education is highly compartmentalized in the seven scientific areas (Table 1).

This results in a dispersion of courses of different scientific areas through the six semesters of the program. This dispersion can be an obstacle to a curricular integrative approach and to collaboration within teacher educators of different scientific areas.

Our strategy to overcome this obstacle is by making connections between the mandatory syllabuses of the Mathematics and Science courses that occur in the same semester. That happens between Introduction to Number Theory and Chemistry and Physics (1st year / 1st semester) (Table 2), Statistics and Probabilities and Human Biology and Health (2nd year / 1st semester) (Table 3), and with Mathematical Modelling and Earth and Life Sciences (3rd year / 2nd semester) (Table 4).

Table 1 - Scientific areas of the curricular structure of the undergraduate teacher education program.

Scientific area	**Acronym**	**Credits**	
		Compulsory	Optional
General Teacher Education	GTE	20	
Formation in the Teaching Area – Portuguese	FTA-P	27	5
Formation in the Teaching Area – Mathematics	FTA-M	32	
Formation in the Teaching Area – Natural Sciences, History and Geography of Portugal	FTA-NSHGP	27	5
Formation in the Teaching Area – Arts	FTA-A	32	
Didactics	D	16	
Introduction to Professional Practice	IPP	4	12
Total		158	22

Table 2 - Curricular structure of the 1st Year /1st semester of the undergraduate teacher education program.

Courses	**Scientific area**	**Type**	**Working hours**		**Credits**	**Observations**
			Total	Contact		
Introduction to Number Theory	FTA-M	Semiannual	135	TP-60	5	Connections
Portuguese Language Communication	FTA-P	Semiannual	162	TP-72	6	
Chemistry and Physics	FTA-NSHGP	Semiannual	135	TP-60	5	
Art Education - Drama	FTA-A	Semiannual	162	TP-72	6	
Curriculum Management and Professional Ethics	GTE	Semiannual	108	TP-48	4	
Psychological Foundations of Education	GTE	Semiannual	108	TP-48	4	
			810	360	30	

Table 3 - Curricular structure of the 2nd Year /1st semester of the undergraduate teacher education program.

Courses	**Scientific area**	**Type**	**Working hours** Total	Contact	**Credits**	**Observations**
Statistics and Probabilities	FTA-M	Semiannual	162	TP-72	6	Connections
Reading and Writing	FTA-P	Semiannual	135	TP-60	5	
Human Biology and Health	FTA-NSHGP	Semiannual	135	TP-60	5	
Arts Education – Music	FTA-A	Semiannual	162	TP-72	6	
Physical Education II	FTA-A	Semiannual	108	TP-48	4	
Introduction to Professional Practice II – Option b)	IPP	Semiannual	108	TP-36; E-40; OT-4	4	
			810	392	30	

Table 4 - Curricular structure of the 3rd Year /2nd semester of the undergraduate teacher education program.

Courses	**Scientific area**	**Type**	**Working hours** Total	Contact	**Credits**	**Observations**
Mathematical Modelling	FTA-M	Semiannual	135	TP-60	5	Connections
Contemporary Portuguese Literature	FTA-P	Semiannual	135	TP-60	5	
Language, Cognition and Multilingual Education OR Portuguese as Foreign Language	FTA-P	Semiannual	135	TP-60	5	
Earth and Life Sciences	FTA-NSHGP	Semiannual	162	TP-72	6	
History	FTA-NSHGP	Semiannual	162	TP-72	6	
Digital Educational Resources	GTE	Semiannual	81	TP-36	3	
			810	360	30	

This strategy was also used in the Ríordáin et al. (2016) research. These researchers recognized that the content of Science and Mathematics to be integrated would have to be based on making connections between the centrally compulsory syllabuses of the two disciplines, as teachers are unlikely to adopt integrative strategies that will not address directly to the concepts students have to learn for subject-specific examinations.

Some comprehensive studies show that Mathematics and Science integration could be prejudice by poor teacher content knowledge and pedagogical content knowledge, teachers' beliefs and attitudes and lack of time for planning with other teachers (Czerniak, Weber, Sandmann & Ahern, 1999; Frykholm & Glasson, 2005; Meier, Nicol & Cobbs, 1998). In our case, we have the advantage of being specialists in Physics and Chemistry (Correia), Natural Sciences (Cavadas and Linhares), Science Education (Cavadas, Correia and Linhares), Mathematics and Mathematics Education (Mestrinho and Santos). One advantage of that specialization is that we have confidence about teaching Mathematics or Science, one gain also stated by Munby, Russel and Martin (2001). However, the fact that we are subject specialists brought us the disadvantage that we were not totally comfortable to integrate alone the language, methods, concepts or content of another scientific area, a problem also specified in Ríordáin et al.'s (2016) research.

Our solution for that problem is teacher collaboration. Traditionally, Science and Mathematics departments work in isolation from one another and have not a culture of collaboration that leads to planning and overlapping topics in both areas. Fortunately, we have a gainful school structural factor, related to the fact of the two areas are joined together in the Department of Mathematics and Natural Sciences in our School of Education. In addition, Frykholm and Glasson (2005) had already proposed that the collaboration between Science and Mathematics teachers to explore authentic and situated connections between the two disciplines, could be a way of developing their pedagogical content knowledge for integration. Morrison and McDuffie (2009) said that the same collaboration was a way of overcoming content knowledge limitations on the other area. In fact, we noted that teacher collaboration is an efficient way of sharing and developing content and pedagogical knowledge of the other area. For example, regarding the integration between Mathematical Modelling and Earth and Life Sciences, it was clear for us that Mathematics aided to underscores the importance of careful observation, data collection, logical thinking and modelling as part of the scientific method, an advantage also stated by Hollenbeck (2007).

We are also aware about the danger of students construct the idea that Mathematics is only a tool to collect data, represent data and to be used for computational proposes (Frykholm & Glasson, 2005). In our activities, the data collected by the students are transformed in graphs, charts, equations, etc., mathematical models whose Frykholm and Glasson (2005) consider appropriate uses of mathematical principles and concepts in the context of using Science. We agree with Bosse, Lee, Swinson and Faulconer (2010), regarding their statement that Science can provide students an engaging context for mathematical work and Mathematics provides tools for making sense of Science.

With our collaborative work, we also experience the conclusion of some researchers that Science can provide students with concrete examples of abstract mathematical ideas, while Mathematics can enable students to achieve deeper understanding of Science concepts, by providing ways to quantify and explain Science relationships (Hollenbeck, 2007; Ríordáin et al., 2016). Our Jurassic Race activity is a good example of this mutual and beneficial relation, because students start from the analysis of a simulated theropodous track and use mathematical modelling to estimate the speed of the animal that marked the track. This activity included topics of both Science and Mathematics curriculum, as the study of measurements, patterns and relationships, variables and functions, leading the students to effectively appreciate how different subjects can together solve an authentic problem. As stated by Hollenbeck (2007), there can only be integration when the Mathematical skills are directly involved in the Science curriculum.

With our approach we also noted the benefits, stated by other researchers (Baxter et al., 2016; Pang & Good, 2000; Venville, Rennie & Wallace, 2004), related to Mathematics and Science integration and the improvement of students' motivation, engagement and understanding of mathematical and science concepts. As stated in OECD (2013), one major advantage of team teaching is to facilitate the learning of specific groups of learners who otherwise would risk been neglected in a whole group setting. We also agree with Hollenbeck (2007) when he states that the center of design schemes for integration of Mathematics and Science should be the learner.

Other advantages of collaborative work, according OECD (2013), are informal reflection and feedback to continually refine practice. From our experience in the CreativeLab_Sci&Math, we state that we learn greatly working together and developing common lesson plans, activities and research. For us, being in a professional learning community is a powerful tool for recording, learning and sharing good practices. This way of working has also proved being very valuable in our teacher educators' professional development.

Examples of Integrated Activities in Science and Mathematics

We agree with Hollenbeck (2007) when he argues that a solution to improve the performance of the students in both areas is to combine them into one field of study or, in our case, in common activities. Therefore, one of our main goals in the CreativeLab_Sci&Math is the implementation of interdisciplinary activities with the intention of developing different skills in students, through their involvement in tasks that mobilize connections between Mathematics and Science. For that aim, we work together in creating rich contexts and in the definition of common learning goals and specific learning outcomes of both disciplines. Some of the interdisciplinary activities that we have implemented are:

- CreativeLab_Sci&Math: A Jurassic race

  The activity starts with an outdoor activity in a Portuguese geosite related with dinosaur fossils (Lourinhã). After that, in the CreativeLab_Sci&Math space, and starting from the analysis of a simulated trackway of dinosaur's footprints, students need to answer to the problem: How fast was the dinosaur moving when it produced the trackway? To answer this question, students need to collect data from the trackway and use an animal model (the human) to collect data concerning the dynamics of biped locomotion. Furthermore, they need to use the concept of dynamic similarity and transfer the data from humans to dinosaurs, using mathematical modelling to achieve the dinosaur's speed.

- CreativeLab_Sci&Math: Earthquakes and human constructions

  The activity begins with an approach to the huge earthquake that occurred in Lisbon in 1755. In response to the devastation caused by that earthquake, the Prime Minister of that time, Marquês de Pombal, ordered the reconstruction of Lisbon with anti-seismic rules. One of the main achievements of the anti-seismic constructions of Lisbon was a structure known as "pombaline cage". Using a model of a seismic surface made of jelly, students need to inquire the mathematical properties that make this structure so strong. Afterwards, they are involved in an inquiry activity in which they have to make different constructions and test their capacity to resist to an earthquake.

- CreativeLab_Sci&Math: The charming Pitchuko

  The activity aims to explore Mendelian inheritance and probabilities. For that purpose, it uses an imaginated animal, the Pitchuko, that has a pool of dominant and recessive characteristics. Students have to produce different generations of Pitchukos throughout the activity, generating gametes with aleatory combinations of genes, selected from the genotype of their progenitors', through the launch of a coin. In the meantime, students must solve problems involving Probability.

- CreativeLab_Sci&Math: Creative seeds

  This inquiry activity starts from the problem: What characteristic should a seed have to travel the largest distance possible in the air? From this starting point, students place hypothesis related to the characteristics of seeds that they think will influence the travel in the air, construct models of the seeds with different materials, throw them from a platform, measure flight's parameters, such as distance reached or duration, and collect other data concerning the flight dynamics. After that, they need to improve their model in order to travel farther.

- CreativeLab_Sci&Math: Statistics of healthy eating

  In this activity, students measure biometric data, such as height, weight, age, type of activity (sedentary, mild, moderate), daily calorie needs and basal metabolic rate (BMR). After a collective share of data, students, using the software Tinkerplots®, have to establish possible relations among those variables. The activity continues with the elaboration of a healthy menu and the comparison of the mean values of fat, fibers and calories of the menus produced by all groups.

- CreativeLab_Sci&Math: Statistics of lung capacity

  In this activity, students measure the perimeter of their ribcage during inspiration and expiration. Afterwards, each one of them fills a balloon with air in one breath and calculate its approximate volume. They also register if they smoke or not. Following the collective share of all data in Tinkerplots®, students establish possible relations among those variables, developing their knowledge of scatterplots. Throughout this activity, students use the Khan Academy platform to develop and assess their understanding of scatterplots and the establishment of relations between variables.

- CreativeLab_Sci&Math: Bad plastics

  This activity aims to raise students' awareness about the problematic of ocean plastic and empower them to contribute for the resolution of that ecological problem. In an outdoor activity, students must collect different sizes of plastic in a 10 x10 m area of a beach, register their quantity and identify the materials that originate them. After that task, in the lab, they have to weigh the plastics and identify microplastics in a sample of the sand collected in the beach, trough microscope observation. To empower students and the community, they also have to produce a digital resource to alert about the ocean plastic.

- CreativeLab_Sci&Math: How to program the moon phases?

  In this activity students explore the software Scratch® to explore a science topic: the moon phases. The main goal is for students to create their own original project, using Scratch®, exploring the content associated with the moon phases. To accomplish this goal, students go through some activities to explore the software, exploring different projects. They start with a complete project where they explore the programming commands. Then, students are given projects with errors to identify and correct them. Afterwards, they must complete an unfinished project and, finally, create their own. With this approach, they are given more autonomy with time and accordingly to their experience with the software. When programming, students are always developing mathematical topics, including logic and geometry concepts.

OECD (2013) claims that team teaching opens different and more varied options than when the learning environment sticks closely to the conventional format of one teacher for each group of learners. Aware of the importance of collaborative work among teachers, some of our activities are implemented in the CreativeLab_Sci&Math with two teacher educators, one of Science and one of Mathematics, simultaneously. This strategy is very important because teacher educators can provide more feedback to students and give them additional help in the realization of the different tasks.

Use of the 7E Instructional Model and Inquiry-Based Learning

The previous activities were structured according to the 7E instructional model that includes the following moments (BSCS, 2006; Kähkönen, 2016; Linhares & Reis, 2017): Engage, Explore, Explain, Exchange, Elaborate, Evaluate & Empowerment. We think that the 7E instructional model approach provides us the path for guiding students through rich ant integrated experiences in Science and Mathematics.

We also use this instructional model to develop the DeSeCo Project's skills in the students: "Use tools interactively, interact in heterogeneous groups and act autonomously" (Rychen & Salganik, 2001, p.5). Starting from the problems or situations that are placed to them, students are involved in learning tasks that lead to the development of their scientific knowledge. These tasks may involve the manipulation of diversified technical materials and instruments and the use of appropriate working methodologies to achieve an objective or reach a reasoned decision or conclusion. They also mobilize different languages and texts to express and represent their knowledge, select, analyze, and share their productions, experiences and knowledge in different formats. They are involved in problem solving scenarios to stimulate their critical and creative thinking, generating and applying new ideas in specific contexts, identifying alternative solutions and designing creative methodologies. For that aim, they develop reasoning skills that enable to access information, understanding the results of experiences and produce new knowledge. This learning environment stimulate the development of collaborative skills, through interaction in heterogeneous groups, fostering teamwork and the ability to argue, share and work together. Additionally, it favors the personal development of students, enabling them to learn independently, to take initiative and to make informed decisions, in a process of self-regulation.

Some activities were also structured using the Inquiry-Based-Learning strategy (Hutchings, 2007; Pedaste et al., 2015). Our inquiry-based learning activities are well appreciated by prospective teachers because these activities allow them to describe objects, raise questions, construct and evaluate explanations, considering current scientific knowledge, and communicating their ideas to others, using Mathematics and Science. We think that, through the immersion of prospective teachers in this type of teaching-learning scenarios, they will be better prepared to teach in inquiry-based learning approach, and actively participate in solving social issues related to Science, Technology and the Environment (Linhares & Reis, 2017). Zhang and Shen (2015) had already shown that a student's disciplinary foundation may help or hinder his or her interdisciplinary problem-solving. In fact, Frykholm and Glasson (2005) stated that preservice teachers had rarely experienced as learners the kinds of instruction that connects Science and Mathematics, but, simultaneously, they had reported having strong beliefs that this kind of connection should happen in schools, showing the importance of embedded them in those scenarios. However, some studies show concerns about taking an interdisciplinary approach because it was harder than discipline-based science learning (Zhang & Shen, 2015).

The Importance of a Collaborative Teaching Environment

The CreativeLab_Sci&Math is organized into different spaces that relate to 7E teaching moments and students' different needs concerning the realization of the tasks. These spaces, inspired by the initiative Future Classroom Lab (European Schoolnet, 2017), correspond to different learning areas related to the development of different skills. An innovative educational environment (IEE) implies, thus, to rethink the spatial organization of the 21st century classrooms, its resources, the teaching strategies, and teacher's and students' role. In the next figures, we present the organization of our IEE.

In Figure 1, the area with the chairs is related to the Engage, Explain, Exchange and Empowerment moments. Behind the chairs, there are three areas where students can work in large groups and do, in group or individually, laboratorial activities or explore digital resources (Explore, Exchange, Evaluate). In the left side, there is an area where students can work alone or in small groups (Explore, Exchange, Evaluate).

Figure 1 - Organization of CreativeLab_Sci&Math space.

At the rear, there is a working space with lounge characteristics that can be used by students in Exchange, Explore or Empowerment moments (Figure 2).

Figure 2 - Lounge area used to Exchange or Explore moments.

The CreativeLab_Sci&Math is equipped with different types of materials related to laboratorial activities of Biology, Geology, Physics, Chemistry and Mathematics. It is provided with wireless connection and digital resources.

In the CreativeLab_Sci&Math we also have our teacher coworking space, a common library and other resources (teaching materials, etc.) that we use to prepare our classes. It is also in that space that we work together and share ideas about connecting Science and Mathematics, establish common research goals and prepare the presentation of our work in national or international scientific events.

Future Challenges

Most of our integrative activities in Mathematics and Science tend to be at the level of situated activities. This is not novelty, because Frykholm and Glasson (2005) had already recognized that the integration of Science and Mathematics is necessarily contextually based. However, one of our major challenges is to move from an interdisciplinary to an integrated approach. According to Frykholm and Glasson (2005), “definitions of interdisciplinary teaching include the assumption that the integrity of corrective boundaries will be preserved through exploration of common contexts that promote learning of both science and mathematics” (p. 130). Followingly, our objective is to make a greater integration within the curriculum of Mathematics and Science, creating strong connections between the topics and the methods of both areas.

However, we agree that "in contrast to the goal of integrating mathematics and science such that boundaries between the disciplines are minimized, if not eliminated, we seek to maintain disciplinary distinctions" (Baxter et al., 2014, p. 102). We do not want to blend Science and Mathematics to a point that is difficult to identify when Mathematics ends, and Science begins. As Lederman and Niess (1997), we think the nature of Science, defined as tentative and evidence-based, differs from Mathematics, which uses logic and proof to add knowledge to the discipline. We focus ourselves on Mathematics with Science and Science with Mathematics on the Huntley (1998) mathematics/science continuum, creating lessons that tend to connect Mathematics and Science, and not merging it, within a synergistic union of the two areas (Figure 3).

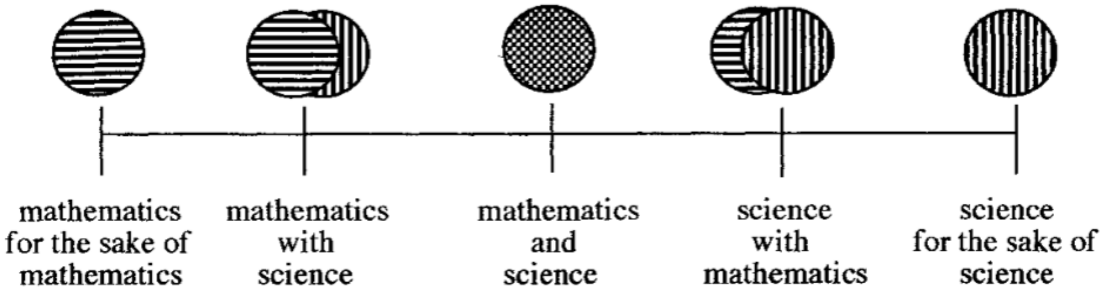

Figure 3 - Huntley's (1998) mathematics and science continuum.

This is a hard, but a challenging task. As Hollenbeck (2007) stated, courses that teach Mathematics and Science concepts together must have a clear connection for the learner. So, our objective is to implement successful integrated Science and Mathematics learning, with a strong coordination among instruction, curriculum design, and assessment of both subjects. We think the abovementioned activities have that connection because the Mathematics added in the Science classroom is strongly applicable to the resolution of the Science contextually based. As Hollenbeck argues (2007), the "effective use of mathematics in science will strengthen each discipline and allow the learners to link for themselves the language and description of the universe" (p. 80). However, the challenge is merging isolated activities into an integrated curriculum of Science and Mathematics. For that aim, we will have to continually improve our content knowledge and pedagogical content knowledge of both subjects because, we have the notion, as Baxter et al. (2014) stated, that development improves teachers' confidence in teaching those disciplines. In addition, in every attempt to achieve this integration, we collect feedback from our prospective teachers and from other colleagues/professors and researchers that help us to get better at it and more closed to the main goal: improve and innovate the higher education pedagogical practices.

Implications to Teacher Practice

Our final reflection is focused in some results of the project CreativeLab_Sci&Math that we think can contribute to teacher practice. Concerning the teacher educators involved in the project, it was clear that we developed a network of scientific and didactic knowledge and a real community of practice, looking for innovation in science and mathematics teaching. That is very important, as stated in other studies that mentioned the strong impact teachers' network can have, which is patent in the fact that teachers tend to turn primarily to their peers for professional support (Durando, Sjøberg, GrasVelazquez, Leontaraki, Martin Santolaya & Tasiopoulou, 2019).

A reflection about teacher training and Inquiry Based Science Education (IBSE) practice in Europe, done by Durando et al. (2019), mentioned that is essential that all teachers are supported by their peers, for example, through peer-support networks and by innovative teaching materials and other resources, digital, or paper based. With the aim of supporting Portuguese teachers in their science and mathematics teaching activities, we transfer our scientific and didactical knowledge through workshops and share our digital educational resources in online platforms for teachers, as Casa das Ciências®. At the end of the academic year of 2018/19 our resources added more than 20.000 downloads. This number reveals the teachers' interest and possible classroom use of those resources, many of which related with STEM and IBSE teaching practices.

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