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Learning inquiry-based science education in the context of a continuing professional development programme for biology teachers

Abstract

The purpose of this study was to examine if teachers who participated in a continuous professional development (CPD) programme were able to develop an understanding of inquiry-based science education (IBSE). The CPD programme was designed to present inquiry-based science education (IBSE) in both formal and informal, Learning Outside the Classroom (LOtC) contexts, to discuss its role as a tool to improve pedagogic practises in science teaching and to explore the application of the method in teaching biodiversity and climate change. A qualitative design using pre- and post-programme questionnaires was used to investigate teachers’ understanding and classroom implementation of inquiry. Evolution of teachers’ practises were also evaluated during the different steps of CPD course and served as a checking and a remind of what is really an authentic scientific inquiry. The results of two year independent courses suggest that the CPD programme appeared beneficial in resolving teaching misconceptions about IBSE. Teachers were able to experience, evaluate and reflect on their own practises. At the end, they developed new approaches to apply scientific inquiry while teaching biodiversity and climate change in the context of their own classrooms.

Keywords: inquiry, science education, learning outside the classroom, biodiversity, climate change.
Abbreviations

EU - European Union
IBL - Inquiry-based learning
IBSE - Inquiry-based science educations
ISCED - International Standard Classification of Education
LBG - Lisbon Botanic Garden
LOtC - Learning Outside Classroom
PISA - Program for International Student Assessment
OECD - Organisation for Economic Co-operation and Development
TIMSS - Trends in International Mathematics and Science Study
Introduction

A basic understanding of science is one of the major endeavours of Europe, being considered a necessary skill for every European citizen, according to different international surveys. Critical thinking and problem solving, effective communication, collaboration and team building, creativity and innovation have been identified as important skills that enable students to improve their understanding of science and, consequently, their further citizenship action (AMA 2010). Many international reports identify shortage of human resources in key scientific professions and call for the need of a continuing professional development of teachers to improve the quality of science teaching in schools (EACEA 2011). The initiatives developed all over Europe actively pursue the renewal of science education and the implementation of inquiry-based methods (Rocard et al. 2007). Inquiry-based science education (IBSE) has proven to be effective with all kinds of students and to promote students’ participation in science activities (Boaventura and Faria 2015, Tavares et al. 2014, Tavares, Silva, and Bettencourt 2015).

Inquiry teaching and learning has been the focus of many European projects during the last years, to reach the education targets for Europe 2020 Strategies (Kapelari 2015). One of these projects, INQUIRE (Science-In-Society-2010 nº 266616), focused on improving the professional development of science teachers by implementing effective teacher training interventions using IBSE methodology. The European project INQUIRE involved 17 partners from 11 countries, including 14 botanic gardens, which were offering IBSE training and support to science teachers. One of the partners was the Lisbon Botanic Garden from the National Museum of Natural History and Science (LBG), in Portugal. In each of the partners’ countries, a Continuing Professional Development (CPD) programme was created and implemented, focusing on inquiry-based learning methods and assessment techniques, in the subjects of biodiversity loss and climate change, using botanic gardens as learning outside classrooms institutions (LOTc). These CPD courses were targeted to science teachers from the 5th to the 9th grade of the basic and secondary education (ISCED 2 and 3). Within this training we intended to involve teachers in designing, applying and assessing scientific inquiry lesson plans in order to cooperatively generate a theoretical and practical founded understanding of their own learning process. Teachers had to be able to evaluate and reflect on their own practises so that they could develop new approaches to apply scientific inquiry in the context of their own classrooms.

European Context

In Europe, the proportion of students who do not have basic skills in science is an indicator of inadequate education quality and equity (Commission 2013b). The lack of such skills may hinder their full participation in society and the countries’ economy (EACEA 2011). For economy to grow, to promote excellent science and industry
competitiveness, each country in Europe need to invest properly in people and put education at the heart of economic and social policy (Commission 2015). There is, thus, an urgent investment in education’s quality and particularly education in science (Commission 2013b).

Within the different measures already pointed out by the European Commission (Commission 2013a), some deal with the relationship between students motivation and teachers competences. Aware that the quality of teaching and their competences are a determining factor, the European Union recommended that the teaching career should be seen as a key element in promoting high-quality education that can adapt to today's requirements (Commission 2015, Council 2013). Improving teachers' academic and professional training, through the development of continuing professional development programmes and making the career more attractive to young people, are becoming vital issues in European recommendations (Council 2014). High quality of teaching is dependent on schools’ autonomy and support to continuing professional development of teachers (Commission 2013a). Professional development opportunities need to be designed to help in-service teachers move from more traditional instruction to new pedagogical strategies adapted to the 21st century.

*The Inquiry Concept*

In order to promote students’ motivation and interest in the school curricula, the scientific contents should focus not only on the importance of the thematic knowledge but also on how the curriculum serve (or does not serve) the daily life problems society faces. The rise of place-based identity in determining our relations with the planet provides an opportunity to adopt a model of science instruction based more on learning within problem contexts rather than on rote memorisation.

Around the world, policy documents and curriculum materials were developed based on the idea of inquiry-based learning as the way to improve science education (Abd-El-Khalick and Lederman 2000, Valente, Fonseca, and Conboy 2011). Although inquiry-based science education (IBSE) has been recommended since 1996 (Morrison 2008), it is often viewed as a body of knowledge, rather than a process in which a better understanding of the world can be obtained. In Europe, it was only after the Rocard report (Rocard et al., 2007) that schools have been advised to adopt IBSE as a methodological approach towards the improvement of students’ interest in science (Osborne & Dillon, 2008).

Learning science through inquiry improves students’ understanding, participation and motivation in relation to scientific activities and, above all, contributes to improving general interest in learning (Osborne and Dillon 2008). Through engaging in the processes of scientific inquiry, students are able to acquire a general understanding of the importance of science, the nature of scientific investigation and the evaluation and interpretation of evidence (Kapelari 2015, Osborne and Dillon 2008, Osborne 2013). Accordingly, for students acquire a basic
interest in science, school’s science teaching pedagogy must change from mainly deductive to inquiry-based methods.

Since the late 1980s, and using the learning cycle approach, Roger Bybee developed the 5E instructional model, that falls within the theories of constructivist teaching model (Bybee 1997). Already in the current century, different discussions and policy documents both in North America and Europe have helped to define inquiry in terms of what it means for teaching and learning (Barrow 2006, Duschl and Grandy 2008). Five steps were described and advised to be followed (Barrow, 2006): (1) students are engaged for the creation of scientifically oriented questions; (2) students collect evidence in real contexts to answer the questions; (3) students develop explanations based on evidences; (4) students evaluate their explanations and may include alternatives that reflect scientific understanding; and (5) students communicate and justify the proposed explanations, that follows the previous 5E proposed model. As a whole, students are encouraged to form, reframe, and improve questions as they gather information and adjust their thinking in response. Under such model students are not passive recipients but as active participants in their own process of acquiring knowledge (Costa and Araújo 2018). The value of these features or models is not to be used as a checklist, but as a guide to science learning process (Bell et al. 2010). Within the IBSE approach teachers need to shift from “what we want the students to know” to “what we want students to be able to do” (Duschl and Grandy 2008). This means that teachers should know how to structure a lecture in order to promote student orientation activity and student participation in classroom planning. This implies a close interaction of teachers with students within the whole class (Kapelari 2015).

**The Need of Continuous Professional Development Programs**

More than ever, there are advantages in engaging teachers to develop and evolve on their quality practises, facing the present society changes (Saroyan and Trigwell 2015). This means that teachers should be involved in professional development programmes where they learn how to support students learning. Learning is here defined as the process where teachers are perceived as active in the learning process (Postholm 2012). Hence, it is important that they continually look for ways to improve and continuously change. Continuous Professional Development programmes (Kapelari 2015) is a concept that means learning from actions in the classroom, learning from theory and practise, so that teaching can be continuously adapted and effective.

But teachers’ views of what constitutes effective teaching and learning, influences their choice of instructional strategies (Lotter, Harwood, and Bonner 2007). This is particularly evident when we observe that science teachers teach at different educational levels, they are often educated in different science subjects and possess different cultural backgrounds (Council 2013). On the other hand, teachers from each country, with each cultural tradition and social settings, have different ways to approach and develop learning processes (Kapelari 2015).
Teachers may simply follow inquiry tasks, conducting laboratory work followed by a detailed protocol, that despite its simplicity, allows a minimal engagement of the students to science reasoning (Chinn and Malhotra 2002). For most of those teachers, scientific experiment is reached more through a protocol hands-on approach in the school laboratory than in a visit to the field, museum or other institution. To know how to change to a group-based pedagogy or to foster a learner engagement with science (Duschl, Schweingruber, and Shouse 2007) teachers need help in the form of professional development programmes. Recent research has emphasised the importance of learning with practise-oriented work outside school (Dillon et al. 2006), including developing methods of critical thinking, collecting evidences, to promote a metacognition knowledge on how to self-regulate their own learning process (Postholm 2012).

Many studies have been published that acknowledge the importance of CPD programmes on teacher’s improvement of their teaching practises (Postholm 2012, van den Bergh, Ros, and Beijaard 2015), even to use scientific inquiring with or without informal learning spaces (Chinn and Malhotra 2002, Dillon et al. 2006, Dillon 2013). Results from PISA (Program for International Student Assessment ) 2015 strengthens the evidence at the EU level to share knowledge about good practises on high quality teaching (Costa and Araújo 2018). This implies a continuous teacher professional development, meaning course activities and processes that teachers should engage in to ameliorate their way of learning.

However, the outcome of the courses can be influenced by teachers previous scientific knowledge, the environment or the approaches of the CPD programme (Postholm 2012, van den Bergh, Ros, and Beijaard 2015). INQUIRE project was designed to reinvigorate inquiry-based science education (IBSE) in both formal educational systems and Learning Outside the Classroom (LOtC) spaces throughout Europe. Within this project a continuing professional development programme (CPD) was designed to help teachers from each participant country to move from more traditional pedagogies to strategies incorporating inquiry, particularly focused on teaching biodiversity and climate change.

**Study Goals**

This paper aimed at understanding if the CPD course on inquiry-based science education developed in the Lisbon Botanic Garden would lead teachers, as learners, to develop a reflective practises of their own learning process with a correspondent development of inquiring focus in their teaching practises. Our research hypothesis is that the design of CPD course providing theoretical background, as well as practical experiences both in Botanic Garden and in their classrooms, able teachers to better understand IBSE pedagogy applied to biodiversity and climate change teaching.
A previous programme developed in Portugal has shown that after the development of a multidisciplinary inquiry-based activities learning processes were different between teachers (Boaventura and Faria 2015). An international analysis, Portugal included, about teaching methodologies to develop scientific literacy within students, according to OCDE definition, has shown that IBSE practises tend to have a low impact on students' achievements (Valente, Fonseca, and Conboy 2011). However, another Portuguese study has shown that environmental education inquiry-based methodologies was able to promote the students' ecological self-identity, the personal norm and pro-environmental practises (Barata, Castro, and Martins-Loução 2016). With this course we expect that learners, independently of their experience or age, create their own learning in relation to the teaching course artefacts through a truly reflective practises.

The specific research questions addressed in this study were:

a) What prior knowledge do teachers have concerning the epistemology of inquiry science education on their own reality in the classroom?;

b) To what extent teachers have shown useful the introduction of LOtC as informal education places to support IBSE practises?

c) To what extent teachers have a better understanding about the key concepts of IBSE practises in classroom after the CPD course?

Methods

The site: Lisbon Botanic Garden

The Lisbon Botanic Garden of the National Museum of Natural History and Science (LBG) is fully committed to biodiversity conservation and to environmental education. It has an important living collection (c. 1 500 plant species) within 4 ha, as well as a herbarium (> 250 000 exsiccates) and a seed bank (> 3 300 seeds, 50% of the threatened Portuguese flora), which together represent an important and effective way of conserving threatened plants. The science research behind this valuable garden is mainly focused on studying the ecology and taxonomy of vascular and non-vascular flora towards in situ and ex situ conservation.

In 2003 LBG launched the education service and since then has been assumed as the ideal place for students to take part in scientific activities specifically designed accordingly with the national curricula: more than 8 000 students, every year, visit the LBG to attend educational programmes and develop learning activities. In 2009 two new areas of research arose from this educational service: environmental education and science promotion and communication.

Continuing Professional Development Program
The Continuing Professional Development (CPD) course (2.4 credits), entitled “The IBSE method as a tool for teaching biodiversity conservation”, took place in LBG from January to May, during two consecutive years. This CPD programme was certified by the Education Central Direction in Portugal and it was designed to science teachers from the 5th to the 9th grade of the basic and secondary education (ISCED 2 and 3). Program sessions took place on Saturdays, out of teaching hours.

The programme aimed to present the IBSE method, to discuss its role as a tool to improve pedagogic practises in science teaching and to explore the application of the method in teaching biodiversity and climate change, using botanic gardens as LOTC institutions. Although it was designed within the collaborative INQUIRE project and followed the project aim (Kapelari et al. 2014) each partner was free to organise its own CPD programme, according to their own criteria and facilities. In LBG we developed a programme where teachers could have four modules: 1) theoretical knowledge; 2) practical experiences; 3) community of knowledge with peers; 4) evaluation and feedback. An overview of the programme and its distribution over time is shown in Figure 1. A total of 60 hours were distributed during five months. This took into account large periods where teachers trained within their classes what they have learn, preparing and planning lesson plans focused on biodiversity and climate change.

During the first module, theoretical seminars were given by specialised researchers on the topic. Guided visits to LBG, and IBSE lesson plans, already applied in the LBG by educators, were explored. These particular lesson plans were used as exemplars of the ones teachers had to develop during the course with their students. According to INQUIRE project and previous experience in LBG, the lesson plans were taught to be divided, in general, into three phases: a pre-visit, in classroom, where students were engaged with the subject and raised their own questions and hypothesis; a visit phase developed in the botanic garden, where students had to follow their own investigation plan and explore the garden’s resources; and a post-visit where students were able to draw their own findings and discuss them with their colleagues, as well as to communicate their conclusions to other students within their school. Through all these phases, the teacher had a key-role in guiding and helping the students, having always in mind the stimulation of students’ curiosity, critical thinking and autonomy. A great emphasis was given to the use and meaning of outside spaces, namely schoolyards, gardens and parks nearby schools and botanic gardens, as LOTC spaces, where teachers and botanic gardens’ educators can develop pedagogical activities.

Practical exercises were done both through the development of IBSE lesson plan each teacher had to present to the course colleagues and individual garden exploration with or without environmental guidance, according to teachers need. After the optimisation of each lesson plan, each teacher had to apply it to his/her own students, throughout the three-phase approach: pre-visit, visit to the botanic garden or other LOTC spaces and post-visit.
The community of practises were stimulated through the promotion of round table discussions to test whether the teachers internalised all the contents, peer review and discussion about the lesson plans’ proposals as well as internal dialogue during coffee breaks and small meetings of reflection.

Evaluation was continuous during all CPD programme. Teachers were examined during round table discussions in terms of opportunity of response, type of words used, and scientific content of their answers as well as during the presentation and discussion of lesson plans. When teacher-learners visit the garden with their students, teachers were evaluated to see whether they were able to apply all the pedagogical approaches defined by an IBSE lesson plan. Through all these phases, the teacher had a key role in guiding and helping the students, having always in mind the stimulation of their curiosity, critical thinking and autonomy. At the end teachers had to present a portfolio with their individual lesson plans, that was developed with their own students, including all the comments on what went well and what should be improved. Thus, participants had the opportunity to discuss how their own pedagogical resources and activities have been changed in order to become IBSE.

**Sample**

In total, we accepted 40 teachers coming from 25 different schools, for a maximum of 20 teachers in each annual course. This number was chosen following a regulation from the Portuguese Education certification of CPD courses. With this certification teachers got a diploma that gave credits for their scholarly curriculum. Teachers came mainly from Lisbon schools but we received registrations from other schools out of Lisbon, in more than 100 km radius to the Centre and South of Portugal.

In each year a process of teachers’ selection was established, taking into consideration 3 aspects: (i) experience (never less than 2 years of teaching), (ii) origin school (we never selected more than 2 teachers from the same school), (iii) Biology/Geology graduation background (neither Physic/Chemistry, nor math teachers were selected, due to the scientific contents of the course).

Only teachers that finished the programme and completed the pre- and post-questionnaires were used for this analysis. At the end of the two consecutive years we got a sample of 34 teachers, corresponding to 85% of the initial registration. The remain (15%), independently of the year, gave up in the middle of the CPD for personal reasons such as overwork. The mean age of teachers was 40 and 82.3% were female.

**The evaluation methods and tools**

Different evaluation methods were applied to function as a self-correcting mechanism to ensure the quality of the programme. The following tools were used to validate and turn reliable the learning process:
a) Observation grids were used during group discussions, teachers’ activity with their students at the Botanic Garden and during peer review of teachers lesson plans. The evaluation during group discussions include items about teachers participation, reasoning, clear speech and speech contents within the group. The evaluator used key words, relating to each one of the mentioned items, and for each one of the participants, that were later converted into a scale from 0 “not at all” to 4 “very good”. This scaling allowed a quick evaluation on the progression of each one of the participants and about the quality of the discussions within a group. During the activity in the Botanic Garden teachers’ performance with their students the observations grids included items about the IBSE criteria and gave quick information about what was missing or what to improve.

Similar grids were used for the presentation of the final lesson plans.

All these evaluations were used to help the continuous development of teachers learning as well as to check its evolution till the end of portfolio. They served as criteria for addressing internal validity and improvement of continuous professional development, functioning as a “rigor” criteria (Morse et al. 2002) that the programme intended to pass to teachers. Then, they had to learn to apply the same constructive evaluation to their students in classrooms and LOtC visits, testing a self-learning process.

b) Audio and video recordings during group discussions and during the visits that teachers did with their students to natural contexts around their schools. These records were also used to ensure “trustworthiness” of the programme.

c) A final portfolio of evidences, presented both orally (to the entire group) and written. This portfolio should contain the IBSE lesson plan adapted to teacher classroom reality, a report about their students’ reaction and the work performed during students’ research plans, as well as a reflection on the implementation of this new pedagogical approach, within their classroom as well as in the school context.

All the above mentioned qualitative assessment methods were constructive since they served teachers to improve their learning process and learn how to support students learning, during the evolution of the course. The evaluation of the programme was measured by an anonymous pre-and post-questionnaire with the pre-questionnaire given one week before. The post-questionnaire was distributed and fulfilled at the end of the CPD.

A quantitative evaluation was done at the end of the programme according to the regulation of the Portuguese Education certification of CPD courses. To accomplish this rule teachers were classified at the end, analysing portfolio characteristics, although it didn’t serve to exclude teachers.

Data collection and analysis
Pre- and post-course questionnaires comprised different open-ended questions that were used to answer the three research questions: 1) What was the previous knowledge and experience of teachers about inquiry-based teaching; 2) The usefulness of LOtC as informal education places; and 3) Views of scientific enquiry after the CPD course. The post-course questionnaire contained a set of extra questions directed to the evaluation of the CPD programme. Since the paired pre- and post-course questionnaires were equal in both years we pooled all data obtained. From the 34 teachers that finished successfully the CPD programme at the end of the two years, only 28 finished correctly both questionnaires.

Analysis of the written responses was made after a previously established scheme that contained relevant keywords taken from the INQUIRE project and expert discussions with project partners. Then, the aim was to pinpoint descriptive keywords that emerged from this analysis. Their application to each teachers’ responses were reviewed and discussed by the authors looking for consensus. Thus, the three group of major research questions were evaluated through the responses to one or three questions present in the questionnaire, depending on the level of complexity and the number of potentially correct answers (for details, see Table 1).

Given the nature of this evaluation there was no proper wrong questions. But as much as cumulative keywords were assigned and allowed us to identify patterns in teachers’ learning. We also extracted qualitative data in the form of excerpt sentences from teachers’s responses to better explain or support our assertions.

At the end, teachers have to organize a final portfolios, was made presentation to all group of teachers together with all the previous grid observations during group discussions and garden visits were used to grade teachers (1 to 10). Portfolio evaluation was based in the following criteria that teacher-learners have to show: (i) application of IBSE method to teaching biodiversity and climate change; (ii) creation of new approaches and examples during classes; (iii) developing complete lesson plans; (iv) acquisition of new perspectives on how to approach scientific subjects with students, advantages and difficulties encountered; (v) creation new assessment methods to apply during development of lessons. The grades were dispersed from 6 to 10. Those that did not present a full understanding of the method, present a portfolio with the minimum evidences but without any care put on it and only showed few IBSE practises with their students when visiting LBG, scored 6. The ones that present an understanding of the method but only showed few IBSE practises with their students when visiting LBG, scored 7. Those that showed a full understanding of the method and showed consistent IBSE practises with their students when visiting LBG, scored 8. Those that showed a good commitment and were exceptional in knowledge acquisition, improvement of pedagogical practises with their students, but didn’t show a particular innovation on lesson plans, scored 9. The exceptional and innovative ones scored 10. These grades functioned as a measure of teachers’ knowledge acquisition of IBSE due to the CPD course.
Results

Previous epistemological knowledge

Epistemological knowledge was measured by open-ended questions in a pre- and post-questionnaire design as well as in teacher’ observations during CPD programme. Open-ended questions were used to show the opinion of teachers about the characteristics of an effective teacher of science.

Before the programme teachers considered that a good science teacher should mainly promote students’ motivation (19/28), be self-confidence on their own scientific knowledge (18/28) and promote students’ critical thinking (14/28). For example:

“A successful science teacher is one who: can make each lesson a different time; can motivate students to discipline and know how to engage students on the curiosity for science”.

After the programme, reflecting on their own educational practises (from 3/28 to 15/28), was considered an important issue (Table 2), as it is illustrated in this testimony:

“A successful science teacher is one who innovates, reflects critically and constantly on his educational practises and push students for the survey of problems’ answers.”

As a whole, the great majority of teachers knew about IBSE although they had a lot of doubts concerning its real implications within their teaching practises. Many considered that by developing practical laboratories (12/28) and research through a guiding protocol (6/28) activities (“hands-on”) were applying scientific inquiry in their teaching practises. During the programme, the dynamics of the discussion groups created an enriched community of practises. It was possible to see that teachers were not only keen in discussing themes related to teaching biodiversity and climate change through IBSE, but they were also aiming for the opportunity to discuss with their peers all the limitations they have in their professional career. At the end of the programme, the great engagement of all participants in experiencing IBSE, allowed a self-confidence improvement to apply IBSE methodologies within teachers’ classroom context (Table 1).

Introduction of LOtC as informal education place

The use of LBG as a LOtC place to discover “new ideas about plant diversity and climate change for classroom lecturing” was considered an important asset between teachers testimonies at the beginning of the programme. Some of the teachers were already using the Lisbon University Botanic Garden as a LOtC institution, but only as a place where they could mainly perform a guided tour by the end of a curricular module. Throughout the course, teachers were able to realize how a botanic garden or even a park nearby their schools can be of great
support to engage students in a scientific investigation, allowing them to actively explore, hypothesise, learn and get enthusiastic about natural sciences and aware about biodiversity conservation and climate change.

In the pre-questionnaire, the majority of teachers felt sometimes useful to visit LBG or other LOtC places, though without any previous planning visit, just as a beautiful place to show plant diversity. Whereas in the post-questionnaire teachers confirmed (18/28) the importance of LOtC as informal education places (Table 1). At the end of the programme “the contact with the real context to collect evidences about those issues in botanic garden” have been systematically affirmed as relevant to approach difficult subjects such as biodiversity and climate change. Also, teachers referred that “we have found new pedagogical resources to complement our botanical lessons and a beautiful place to bring students”. Nevertheless, there were some (8/28) that at end considered very difficult to leave school due to “logistics and financial problems of schools”, but learned to use schoolyards or parks nearby schools, particularly focused on themes such as biodiversity and climate change.

Changes of Views of scientific inquiry

The comparison between pre- and post-course questionnaire’s results about the teachers’ perception of efficacy of IBSE teaching biodiversity and climate change showed that after the CPD course they experienced changes of their understanding on how to use inquiry-based learning (Table 2). Previously, teachers considered that they followed (as much as possible) an inquiry pedagogic practises, since they promoted students’ motivation (16/28) and developed practical experiences, within or outside school. Different testimonies showed the type of confidence teachers had on IBSE application:

“In the school garden limit a space, per group and search the number of living species.”

or

“A guided experimental activity, in which students could draw conclusions”.

These type of arguments showed that teachers, although worried with students motivation and saying they perform research activities, they followed instead practical guided experiments and not planning research activities based on a defined question/problem.

At the end of the programme teachers changed their opinion towards the use of IBSE in classrooms. They understood better the importance of starting with a research question (from 8/28 to 17/28), students’ critical thinking (from 5/28 to 16/28) and students’ work planning (from 10/28 to 14/28). In different testimonies they referred:

“now we have a better reflection on educational practises and know how to make a better workload planning”.

“I have been trying to be less expositive. Through current problems I have tried to question the students, making them think and reflect on it.”

Others considered positive the ability they acquired to “question the pedagogical methods used so far.”

Also, teachers reported to perform hands-on (laboratory protocols) practises more often before the course and reported to perform problem/questioning activities more often after the course. They did understand the difference:

“In teaching practises this IBSE method becomes part of a new way of being. Sometimes we only realize it later.”

“Whenever possible, I begin by motivating students with a "dissent fact" and lead them to formulate their own questions even though they may not always be able to follow a complete research....”

These examples indicate that teachers consider that, after the course, they were able to engage students in research activities (collecting data, interpreting and developing critical thinking), rather than simply execute an experimental protocol. The CPD programme was considered very useful since:

“We were able to share knowledge, experience a reflective practises within the group and to acquire scientific competences to motivate and evaluate the knowledge evolution of our students”.

“My students turn to be active due to their involvement in planning, presenting and discussing the work in the classroom”.

Above all, most of the teachers have understood that inquiry-based science education is more related to their own reflective practises rather than just a new pedagogical method. In practical terms more than 87% of teachers showed a full engagement during IBSE programme and created interesting lesson plans reflected in the final portfolio delivered at the end of the programme (Figure 2, marks 8 to 10). From this group, 54% were able to show innovative lesson plans (marks 9 and 10), a huge involvement during the CPD programme and have declared that “the most important aspect they learnt was the perception of learning how to learn”. New and totally innovative lesson plans were delivered only by 26% of teachers (Figure 2, mark 10).

Teachers emphasised that the knowledge acquisition on IBSE led to a significant change on their own educational practises, more focused on students. Generally, all teachers, from both editions of the CPD programme said that the added value of this course was “the possibility to share knowledge, to acquire scientific competences and to promote a reflection practises”. Interestingly, teachers with the highest grades (54%), also mentioned that these sharing practises are much more easy outside school than among their peers at school.

Discussion
The analysis of our findings shows that, according to our work hypothesis, the designed CPD programme was suitable for teachers develop a reflective practises of their own learning process with a correspondent change of teaching practises, using IBSE approaches. This was possible because the CPD course was designed to provide theoretical background, practical experiences, time for teachers to discuss and exchange ideas with other peers, practises on how to make a continuous evaluation, as well as time to practises in their own classrooms the IBSE pedagogical resources. One important change that has had significant implications for the understanding of inquiry in teaching science concerns the realm of scientific observations (Duschl and Grandy 2008). The organised structure of this course allowed teachers modify their understanding about the meaning of IBSE practises in school context and learn how to use that knowledge on classroom contexts. Similar results were observed in previous studies where teachers have followed academic year workshops on inquiry (Lotter, Harwood, and Bonner 2007). At the end of the course all teachers came away with an increased enthusiasm to further incorporate more inquiry-based practises into their classrooms and started looking to inquiry lessons as a good method for further use.

According to Postholm (Postholm 2012) teachers are able to develop a metacognition process when they perceive themselves as a learning and thinking person. Practicing inquiry learning in this CPD course made teachers realise that starting from general pedagogical reflections and science standards allowed them to promote a new culture of teaching in the classroom where students in groups engage in self-regulated learning activities. These results were already experienced by other authors (Bell et al. 2010, Demir and Abell 2010) and emphasised the need of a focused course on both theory and practises where teachers, as learners, are able to reflect their own knowledge and to adopt a more complete perspective on the interaction processes in the classroom to deal with expected and unexpected inputs (Postholm 2012). Also, learning from teaching through inquiry across the professional developmental programme in synergy with practical experiences in LOtC (Dillon et al. 2006), reinforced teachers’ ability to evaluate and adapt to inquiry-based materials and lesson plans. Ultimately, these teacher-learners benefited from their intellectual exchange in posing critical questions, searching for answers and seeking alternative viewpoints on various matters during the practicum CPD.

Within the INQUIRE project, each partner developed their own CPD course model, including both theoretical and practical aspects, linking the formal with informal education developed in LOtC areas, preferentially in botanic gardens (Regan et al. 2014, Tavares et al. 2014, Tavares, Silva, and Bettencourt 2015). The balance between theory and practises in synergy with LOtC experiences as it has been offered in this CPD course reinforced teachers’ ability to evaluate and adapt their inquiry-based materials and lesson plans (Egg et al. 2014, Gano and Kinzler 2011, Martins-Loução et al. 2012).
With this CPD programme design (Fig. 1), all teachers were asked to take part in group discussions on how they could translate their knowledge into practices opportunities that incorporate inquiry methodologies, forming a community of practices. They were also invited to behave as peer reviewers of the other teachers’ lesson plans, using an open process of free and informal discussion. Teachers need to become competent at implementing effective instructional approaches to promote their students’ understandings of scientific inquiry (Crawford 2000, Osborne 2013). During the CPD programme, teachers’ performance was differently evaluated through observational grids during reflective exercises to serve their own evolution and understanding about pedagogical strategies. These procedures promoted great thinking on teachers’ practices and influenced all their conceptions of inquiry. The majority of teachers attending the course already heard about the method, but it turned out to be very important to learn and discuss on how to put it in practices. Besides, when they applied for the course they expected a more scientific knowledge-based programme rather than an IBSE practices (Barata et al. 2013). Research on this area has shown that teachers’ beliefs are related to their use of inquiry teaching practices in the classroom (Duncan, Piliotsis, and Piegaro 2010), since they depend on their instructional scientific epistemological views (Lotter, Harwood, and Bonner 2007). Since this course in Portugal was run both in Lisbon and Coimbra Botanic Garden (Tavares et al. 2014, Tavares, Silva, and Bettencourt 2015) with great enthusiasm from the teachers, this means that during these 3 years project we were able to reach more than 50 teachers at national level. Teachers felt more motivated and able to share their experiences and practicing in a true reflective practices, within a professional learning community, as it was recommended by the INQUIRE project (Kapelari et al. 2014, Kapelari 2015). These experiences were facilitated through an online platform/forum created to support these practices as well as the activities in LOtC institutions. At the end of the project the advantages and drawbacks of IBSE practices at school have been debated in a national conference where different teachers, within and outside these CPD programmes, leaders of schools, educational authorities and national parents associations, were able to discuss and present their different experiences. From this meeting a full commitment was established within the community of teachers and parents’ association in order to be present to Education Ministry (declaration in annex).

The first conception about the nature of a good science teacher focused on the importance of student motivation, on the development of critical thinking and on their own scientific knowledge. Teachers cannot teach what they do not understand and thus, they should possess ‘adequate’ knowledge of the scientific enterprise (Abd-El-Khalick and Lederman 2000) and what inquiry involves (Barrow 2006). The second conception of teachers, when talking about inquiry methodologies at the beginning of the programme, was relating inquiry with traditional “hands-on” / protocol lab-based activities. Teacher beliefs are often difficult to change because they are based in part on their practical teaching knowledge that is learned over many years of classroom experience (Lotter, Har-
wood, and Bonner 2007). Most part of teachers that follow this programme in the two consecutive years considered the experimental procedures using a protocol lab (or field)-based activities as the most appropriate to motivate students. Also, the vast school curriculum that does not leave much time to go further and explore other themes, the big number of students per class, the short time for classes plus the financial and logistic difficulties in leaving school, were presented as big obstacles to overcome to teach through the IBSE method.

Teachers’ beliefs about what ‘good’ science education looks like, shape their conceptions of what should occur within the context of their own classrooms and ultimately guide their selection of specific content, as well as teaching methods and strategies (Smith 2005). In the present Portuguese social context, after so many different educational policies with a slight beneficial result in PISA assessments, Portugal still has a high rate of school early leaving (in spite of the steadily reduced dropout of the last decade, OECD, 2015) and low levels of school assignments (~40%). Under these social conditions, teachers’ worries are mainly focused on students’ motivation and participation in school activities. Thus, it was quite obvious that students’ motivation appeared as one of the most important core ideas of what is a good science teacher. This, together with promoting students’ autonomous work, is a true desire that all teachers have because it indicates that students want to learn and take profit of school.

During the strong evolution of Portuguese educational system in the last 40 years, teachers were pushed to present fast and positive results. The curriculum is still controlled (and controllable), ordered, pre-determined, uniform, predictable and largely behaviourist in outcome. In accordance with the ‘science for all’ goal, which today underpins science education, the most important aspect to be taken to students is to make them understand the broad fundamental ideas of science and science as a process, rather than making them accumulate a more or less heterogeneous collection of facts and knowledge. The unity of science, more often including technology, is difficult for students to grasp. The present challenges of teachers are to follow the content curriculum and look at final students’ expected competence outcomes. This would be in favor of societal needs and will favor their career progression. This view promoted a closed system of planning and practises that sits uncomfortably with the notion of education as an opening process and with the view of postmodern society as open and diverse, multidimensional and society inclusiveness. It is, thus, quite understandable that teachers’ conceptions of how to be a good science teacher did not involve the notion of communication, sharing practises or collaboration in lesson plans with other teachers. This also shows the importance of professional development programmes for teachers progression and evolution.

Although limited in teachers number and years of replication, this research suggests that to be successful, inquiry professional development programmes must not only address the training on inquiry methodologies (e.g., questioning skills, data collection techniques), but it must also promote a reflective practises within and outside
schools that benefit from discussions of their views regarding scientific subjects as well as practical development with their own students. These are important aspects that help teachers to learn how to learn and, ultimately, help them to motivate students. Also, when carefully analysing the questionnaires and the final portfolios, the data suggest that teachers stayed much more self-confident of the importance of a collaborative inquiry and a teaching efficiency more centred in the students. This requires teachers to take on more active and demanding roles than traditionally depicted (Crawford 2007).

Conclusions

This research work shows that after the CPD programme teachers developed a better perception of IBSE methodology, particularly focusing to themes such as biodiversity and climate change, that are difficult to tackle at K9 students level. Moreover, they also presented a better understanding of IBSE methodologies, reporting the steps for minds-on (inquiry-based activities) rather than considering only hands-on, protocol-based, approaches. Morrison (Morrison 2008) stated that the most effective method to introduce teachers to inquiry science is to have them actually conduct an authentic investigation of their own. Teachers were able to develop science teaching by using full inquiry methodologies.

These results go in accordance with EU recommendations in improving teachers’ academic and professional training (Costa and Araújo 2018) and give insights about what have worked well, at least in Portugal. Future research studies should investigate whether changes in teachers’ views toward more reform-based instructional strategies actually result in increased use of these strategies in their classrooms given the many external constraints (testing, content standards, school culture) influencing teachers’ instructional choices. In further studies it would also be interesting to follow teachers’ behaviour for longer periods.
References


Annexes

Lisbon Declaration
IBSE method as a tool for teaching biodiversity conservation

Theoretical knowledge
- Biodiversity & Climate Change
- IBSE Methods
- What are LOtC institutions
- Assessment Methods

Practical exercises
- Garden exploration
- IBSE questioning
- Development of lesson plans
- Testing IBSE with students in BG

Community of practices
- Internal dialogue about IBSE
- Peer review and discussion of lesson plans
- Round table discussions about IBSE

Evaluation
- Practices with their peers
- Practices with their students
- Lesson plans presentation
- Final Portfolio

Figure 1 - CPD program step descriptions along 5 months in a total of 60 hours. IBSE - Inquire-base Science Education, LOtC - Learning Outside Classrooms; BG - Botanic Gardens
Figure 2 - Portfolios marks of teachers at the end of CPD program.
<table>
<thead>
<tr>
<th>Group</th>
<th>Questions</th>
<th>Keywords</th>
</tr>
</thead>
</table>
| Teachers’ experience and views of teaching science education | 1. In your opinion, an effective teacher of science is someone who …? | • Feels self-confident on his/her own scientific knowledge  
• Knows how to motivate students  
• Promotes students’ critical thinking  
• Reflects on his/her own educational practices  
• Guides student’s learning |
| | 2. How did the teachers’ conceptions translate into inquiry instructional practices? | • Have weak experience  
• Have some doubts about its use  
• Feels confident on its use |
| Introducing LOtC in IBSE practices | 3. What effect the use of LOtC has on science teaching practices? | • Very useful  
• Difficult to go and use  
• Sometimes it helps |
| | 4. What do you understand by the term “scientific inquiry” in a school context? | • Students with more autonomous work  
• Students’ motivation  
• Students’ critical thinking  
• Hands-on methodologies  
• Research activities |
| | 5. Please describe two or more examples of how you might apply scientific inquiry in your teaching | • Research questions  
• Research activity  
• Students’ critical thinking  
• Students’ work planning  
• Use of LOtC |
| | 6. What was the biggest change, if any, that you have made to your teaching practice? | • More explanation on the use of science applied to real problems  
• More research activities  
• More educational practices centred on students  
• More knowledge on how to plan IBSE lessons |
Table 2 - Number and percentage of teachers who answered according with the selected keynotes the questions presented in the pre- and post-questionnaires. The last one was only used in the post-questionnaire.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Keywords</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. In your opinion, an effective teacher of science is someone who …?</td>
<td>• Feels self-confident on his/her own scientific knowledge</td>
<td>18/28</td>
<td>21/28</td>
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<tr>
<td></td>
<td>• Knows how to motivate students</td>
<td>19/28</td>
<td>23/28</td>
</tr>
<tr>
<td></td>
<td>• Promotes students’ critical thinking</td>
<td>14/28</td>
<td>7/28</td>
</tr>
<tr>
<td></td>
<td>• Reflects on his/her own educational practices</td>
<td>3/28</td>
<td>15/28</td>
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<tr>
<td></td>
<td>• Guides student’s learning</td>
<td>12/28</td>
<td>19/28</td>
</tr>
<tr>
<td>2. How did the teachers’ conceptions translate into inquiry instructional practices?</td>
<td>• Have weak experience</td>
<td>10/28</td>
<td>0/28</td>
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<tr>
<td></td>
<td>• Have some doubts about its use</td>
<td>7/28</td>
<td>9/28</td>
</tr>
<tr>
<td></td>
<td>• Feels confident on its use</td>
<td>10/28</td>
<td>16/28</td>
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<tr>
<td>3. What effect the use of LOtC has on science teaching practices?</td>
<td>• Very useful</td>
<td>6/28</td>
<td>18/28</td>
</tr>
<tr>
<td></td>
<td>• Difficult to go and use</td>
<td>1/28</td>
<td>8/28</td>
</tr>
<tr>
<td></td>
<td>• Sometimes it helps</td>
<td>21/28</td>
<td>2/28</td>
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<tr>
<td>4. What do you understand by the term “scientific inquiry” in a school context?</td>
<td>• Students with more autonomous work</td>
<td>13/28</td>
<td>21/28</td>
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<tr>
<td></td>
<td>• Students’ motivation</td>
<td>16/28</td>
<td>21/28</td>
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<td></td>
<td>• Students’ critical thinking</td>
<td>8/28</td>
<td>18/28</td>
</tr>
<tr>
<td></td>
<td>• Hands-on methodologies</td>
<td>6/28</td>
<td>0/28</td>
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<td></td>
<td>• Research activities</td>
<td>12/28</td>
<td>57/28</td>
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<tr>
<td>5. Please describe two or more examples of how you might apply scientific inquiry in your teaching</td>
<td>• Research questions</td>
<td>8/28</td>
<td>17/28</td>
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<td></td>
<td>• Research activity</td>
<td>25/28</td>
<td>21/28</td>
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<tr>
<td></td>
<td>• Students’ critical thinking</td>
<td>5/28</td>
<td>16/28</td>
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<td></td>
<td>• Students’ work planning</td>
<td>10/28</td>
<td>14/28</td>
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<tr>
<td></td>
<td>• Use of LOtC</td>
<td>7/28</td>
<td>8/28</td>
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<tr>
<td>6. What was the biggest change, if any, that you have made to your teaching practice?</td>
<td>• More reflection on how to apply IBSE in classroom</td>
<td>7/28</td>
<td></td>
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<tr>
<td></td>
<td>• More research activities</td>
<td></td>
<td>13/28</td>
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<td></td>
<td>• More educational practices centred on students</td>
<td></td>
<td>10/28</td>
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<tr>
<td></td>
<td>• More knowledge on how to plan IBSE lessons</td>
<td></td>
<td>8/28</td>
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