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The project-based method to promote competence-based education. A case study in teaching computer science in Italian secondary school

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Abstract

Many researchers and institutions in the field of education are striving to align the different levels of the education system to the growing needs and requirements of society. A meaningful part of these attempts has been concentrated on a systematic introduction of the competence-based education approach. Some countries adopted it and reshaped the school systems accordingly. Introduced in Italian secondary schools in 2010 by the Ministry for Education, the competence-based approach has been only partially adopted in classes. Our research aims at investigating solutions to support its adoption for teachers in Italian secondary schools. As student projects are frequently proposed in computer science classes, the project-based learning method was identified as a potential solution and investigated in an empirical study including two parts: (a) An action research training course on project-based learning; (b) A collective case-study involving six student projects. The empirical study highlighted some critical issues to be dealt with to foster the adoption of the competence-based teaching approach. Results confirmed a weak commitment of teachers to the competence-based approach, but also that exploiting student projects towards the project-based learning method may encourage teachers to adopt a competence-based approach, provided the projects are carefully designed and subsequently managed. To this end the paper offers a schema to check if a project is compliant with the project-based learning approach and some guidelines to support teachers in their activity during the student projects.

KEYWORDS: Competence-based education, Project-based learning, Active learning, Teaching method, Student project, Key competence, Subject-specific competence.

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1. Introduction

The competence-based approach to teaching has been supported by educational research (Winterton, 2009), and by international institutions.

Research has clarified that the concept of competence mainly refers to individual aspects and, as individual development takes place primarily at school, the concept of competence deserves to be respected as an important part of educational study (Weinert, 1999). At the same time, other researchers proposed a holistic model of competence, introducing a comprehensive vision of the competence-based approach (Delamare Le Deist & Winterton, 2005). International institutions have attempted to define the key competences necessary for a successful life and a well-functioning society (OECD, 2005). European institutions recommended member states to adopt the key competences defined in the European reference framework for lifelong learning (EU Parliament & Council of the EU, 2006), recently renewed by the Council of the European Union (Council of the EU, 2018), as well as advocating national strategies and a more comprehensive approach (Eurydice, 2012). An ongoing project for defining competences is that of IEEE (2021).

Nevertheless, the practical adoption of the Competence-Based approach to Education (CBE) has

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not been carried out homogeneously. Some countries have reshaped their school curricula in order to conform to it. Germany is one of these countries: in 2003 and 2004 educational standards were introduced, which defined the core learning outcomes in terms of competences for grade 4, and for the lower secondary education at grade 9 or 10 (Köller & Parchmann, 2012). The involved subjects were Biology, Chemistry, English, French, German, Mathematics, and Physics. For Computer Science (CS), a proposal for lower secondary education has also been published by the German Informatics Society in 2008 (Linck et al., 2013), and in the USA by the CS Teachers Association in 2011 and 2017, enforcing CS competences throughout primary and secondary schools. When the process of building a curriculum consistent with the competence's definition is put into place by educational institutions, it is referred to as the institutional way (see for example the case of Austria (Micheuz, 2016).

In Italy, the reform promoted by the MIUR (Ministry of Education - MIUR, 2010) prescribed the institutional adoption of the competence-based approach, subsequently introducing the lists of competences for technical schools (MIUR, 2012a) and for vocational schools (MIUR, 2012b). The learning outcomes for each discipline and different course years are defined in terms of competences, contents, and skills. However, the reform does not suggest any practical solution for integrating competences in the class (Ronchetti, 2017). As a consequence, schools and teachers have to design and create their own procedure for integrating these competences into their curricula.

The operationalisation of CBE, i.e. moving from theory to practice, is a complex procedure, and it is not popular in classes (Mulder, 2017; Bottani, 2007). This gap between an official requirement to use CBE and the actual situation prompted the present search for practical support for CS teachers in Italian secondary schools.

As student projects are frequently proposed in CS classes, the project-based learning (PBL) method (Kilpatrick, 1918; Kingston, 2018) was identified as a potential solution and investigated in an empirical study including two parts: (a) An action-research training course on project-based learning; (b) A collective case-study involving six student projects.

The goal of the action-research training course was to investigate how the application of the PBL method is driven by the CBE and motivating teachers to adopt this approach. Furthermore, we analysed student projects activities usually performed in schools to verify if they were compliant with PBL.

The empirical study is part of a large multi-year project on e-Learning methods and platforms, focusing on CBE. This paper describes the main results of the study. Related sub-projects are described to an extent that allows the reader to understand how the study addresses and answers the research question.

The structure of this paper includes the following sections. Section 2 defines the context, the research problem, the research question, and the research methods used to address the research question.

Section 3 describes the empirical study. Section 4 gives the results of the empirical study. In section 5, we draw the conclusion examining possible impact of the research and describe future implications and open questions.

2. Materials and Method

2.1 The context and the research problem

MIUR provided a formal and nationwide prescription of CBE for secondary schools. In order to understand if and how the CBE approach is adopted by secondary school teachers, we focused on the Trento province, in Northern Italy: a region having autonomy in the education system management.

Our research project used data and opinions collected from teachers by two sources. Firstly, the results of a project called eSchooling and meant to support teachers in the adoption of CBE (involving 120 teachers in two workshops, and 300 teachers in a survey) gave us the opportunity to look into teaching methodology and related issues (Chiozzi et al., 2015).

Secondly, in an initiative called "Conversation on the Competence-based approach to Education", we interviewed CS teachers to observe how accustomed they are to using the CBE approach and related terms (Giaffredo et al., 2017).

Data collected in these initiatives highlight some critical aspects. Teachers described the "lack" or "fuzziness" of the guidelines to the adoption of the competence-based approach, declaring also a low level of trust in the competence proponents (Giaffredo et al., 2015). Data also suggest that the institutional framework of the competences was scarcely used as a practical reference for teaching activities. Moreover, the formal definition of the set of competences issued by the MIUR does not make their use in the class compulsory. Hence, most teachers prefer not to adopt CBE at all, and as a result CBE is present in Italian secondary schools only in very limited way (Ronchetti, 2017).

2.2 The research question

CBE requires activating a learning process in which knowledge, skills, and abilities of the learners can be applied, developing competences according to the constructivism principles. Such a learning process can be activated by inductive teaching methods (Hazzan et al., 2011), which set up "experiences that induce students to construct knowledge for themselves, when necessary, adjusting or rejecting their prior beliefs and

misconceptions in light of the evidence provided by the experiences" (Prince & Felder, 2006, p. 125).

Our research aimed to discover solutions able to support the adoption of CBE for CS teachers in Italian secondary schools. During our interviews, all CS secondary school teachers claimed to use student projects in their classes because students are directly involved in the educational process: they are more interested and more active. Student projects share relevant aspects of the PBL.

Hence, we focused our study on the following research question: are CS secondary school teachers induced to adopt the CBE approach when they are applying the PBL method?

2.3 The research methods

In order to answer the research question, we planned and designed two empirical case studies.

The first one was an action-research course on the PBL planned for CS secondary school teachers. This kind of course aims to motivate the teachers in their direct action in classes, alternating the teachers' instruction and their activity with students (Cohen, 2007). In this way, the teachers receive an incentive to rapidly put into practice the main notions suggested during the instructional part of the course. At the beginning and at the end of the course we submitted a questionnaire on PBL and on CBE approach. It was designed to pick up on possible changes in attendees' teaching practices. During the course, attendees used a web platform called OPLÀ (Ronchetti & Valerio, 2016), aimed at supporting PBL activities in a CBE framework. OPLÀ supports teachers in planning, designing, and implementing different educational activities, including PBL activity. After the initial settings of basic data, including competences with related contents and skills, teachers can define their teaching activities. A sort of Gantt diagram can help the planning phase, with a choice of different time granularity. Focusing on PBL, the project could involve different teachers, whereas students from different classes could be grouped. A competence rubric details the quality level of the final product and can be defined for each of the competences chosen in the project. Assessment features include discipline-specific competences, chosen by teachers, and general competences, defined at school level.

The action-research course included three different kinds of activities:

- *Plenary meeting*, with the whole group of trainee teachers attending to short interventions or sharing experiences and ideas about student projects or the PBL method.
- *Individual project meeting*, in which the researcher met the teacher to observe and support planning, designing, and implementing the student projects.
- *Individual teacher on-line education, supported by the web platform*, which partially guides the trainee in the PBL activities.

The second case study was a collective study, in which we investigated student projects in technical secondary schools, observing teachers' activities, and conducting initial and final interviews. For over the six months we met the teachers in different situations, including individual meetings and their lessons in class or laboratory. Teacher interviews were individual even when different teachers were involved in the same project. We collected data and details on the project design: data related to competences to be developed by students during the project, and data about how students were going to be assessed. Since not all student projects were PBL compliant, we defined a schema with the characteristics needed by a project to be a PBL activity, and we applied the schema to the student projects.

We used a software system (a web platform) to document the PBL activities, for three reasons: the quantity of data to manage, the communication needs, and the need to have a consistent management of the educational work.

The initial phase of didactic design in the PBL activities dealt with identifying the competences for all involved disciplines and creating an explicit scale of competence achievements.

Data were available to teachers involved in the same PBL activity, and at the school's convenience all resources used or produced by a PBL activity could be shareable among all school's teachers.

Timetable and deadlines, as well as definitions of competences and related rubrics, needed to be consistent during the students' project implementation with what was planned in the design phase.

3. Results of the empirical study

3.1 The Action-research training course

In the first study, we designed and performed an action-research training course on PBL and CBE. The intention was to let the most learning-effective aspects of PBL emerge, and to find possible links to CS competences. The target were CS teachers, including those teachers who already planned to apply the PBL method in at least one class during the schoolyear. Seven CS teachers enrolled in the course. They worked in three different technical schools of two different sectors (economic and technological), offering a rich variety of pedagogical environments to observe.

As the course was on PBL, course attendees were asked to plan their activities for a project to be developed in class. Details on the project plans were collected during individual project meetings, as well as during visits to schools and classes involved, forming mixed teams of

teachers and researchers with focus on a single project. Mixed teams reflected on results, in order to plan the project steps and tune the activities to be implemented, realising the *self-reflective spiral* for each project. Individual projects were discussed also in group with all attendees, for a reflection on the various project issues.

We collected data at the beginning and at the end of the course, to investigate possible variations occurred after the action research course. To measure the impact of the training course, we introduced two tools: the mentioned OPLÀ web platform, designed and implemented as an on-line guide, and a worksheet called "Plan for a Project-based Activity" (PPA) (Giaffredo, 2018): an Italian reduced version of the Patton Project planner (Paul Hamlyn Foundation, 2012) meant to help planning and summarizing the plan. The sheet requires defining the learning goals, in terms of contents or skills, adding assessment criteria.

Of the twenty-eight learning goals gathered with the sheet, 15 related with contents and 13 with skills. Two blind evaluators teams, respectively of University of Milan and of University of Trento, checked the classification to validate it. Results highlighted problems in 4 out of the 15 content objectives, which had to be classified as skills (Giaffredo et al., 2017).

In another step of the learning activity, we checked if teachers changed their projects plan for future classes.

The milestones of the course were three plenary meetings. After a review of the most important aspects of the PBL method, in the first meeting we shared some characteristics of the student projects which the teachers were going to plan. The attendees filled in the PPA twice, related to the PBL activities delivered in the past, and to those to be delivered during the schoolyear, as required by the "action" component of the course. We also introduced the teachers to the use of OPLÀ, into which the plans for the projects were uploaded.

Four PBL activities were planned, all of them concerning software development. Details about them are reported elsewhere (Giaffredo, 2018).

In the second plenary meeting the main characteristics of the PBL activities were shared, and data collected in the first meeting were analysed. Some peer-critique techniques were introduced, inviting teachers to use them in their PBL classes.

The third meeting was a discussion related to the usefulness of the PBL activity. Using PPA we collected new data about the planning of PBL activity, focusing on future, possible activities to deliver to their classes.

Individual support was also available for trainees on demand. 5 out of the 7 teachers asked for such support. In other meetings we agreed on specific techniques to apply in classes. For example, the *gallery critique protocol* (Paul Hamlyn Foundation, 2012, p. 99) was applied to an activity. Some classes were observed, documenting the relevant steps, some of them by video recording. Teachers have been met individually or, more frequently, in pairs, when they were working in the same class and on the same project. Even though the planning feature of OPLÀ was not used during the course, some teachers accessed the platform as a guideline and as an inspiration for initial competence choices and rubrics.

Two PBL activities completed the design and the implementation phases: they were compared in the last plenary meeting.

3.2 The collective case study: Students projects

The collective case study had the goal to observe some student project activities in two secondary schools. Ten teachers proposed different student projects in six classes, involving 121 students. Classes had 17 to 24 students each. The projects lasted 6 months. Observed teachers used the OPLÀ platform.

Details about the projects are reported elsewhere (Giaffredo, 2018):

The projects were quite different in many aspects, as summarized in the following:

- The product to be realised, the final exhibition and the possible effects outside the schools.
- Contacts or feedback from the commissioner, in case of commissioned projects.
- Criteria used to form the working groups and the group assignment.
- Working methods and standards.
- Individual students' assessment.
- Researcher's presence during the projects.

All projects but one involved only the CS domain. Each project had the goal to develop a software application; one of them was a website. Out of these, all projects but one realised a custom product. Four projects were commissioned by different subjects, external to the school. The commissioners had frequent contacts with two classes; in the other two classes, the teachers directly kept contacts with the commissioner. Three of the commissioned projects were officially delivered in a public session, also attended by the researchers.

Working groups, divided into subgroups, were formed in four projects. In two cases the working groups were created by the teachers, in a third one each student decided which group to join, and in the last working groups were often reshuffled. In two projects, each working group had a leader.

Data analysis and design of two projects were developed with all the students of the class. Two projects had people documenting the class activities.

Objectives and deadlines were clearly defined in two projects. In one project, detailed assignments for sub-groups and individual students were given by the teachers. In two cases progress was reported and presented to the class by each working group, while in a third one it was directly monitored by the teachers,

and in another by each single student. In one project, the 3 group leaders had daily short meetings.

Standards were defined in three projects: in two cases they were related to the application forms; in another, students defined only the most useful development standard.

Teachers of three projects assessed the students only by direct observation. In one of them an assessment grid had been initially defined but was never used. In one project, both the self-evaluation of the learning diary and the student relation were used as input to assess the students. In a project three different assessment grids were defined and used: one for the short and individual presentations, one for the workload assignments and the homework and the last for the final presentations.

The researchers met the teachers and all classes several times. In two cases also the external commissioners were met.

Working on this study, we realised that the observed student projects were usually planned, designed, and implemented with limited attention to the formalisation of the various project steps. Similarly, projects paid little attention to the main characteristics of the PBL method. Consequently, we analysed to what extent these projects can be defined as PBL. To this goal we first defined a schema, and then we applied it to the projects.

From the criteria proposed in literature (Thomas, 2000; Paul Hamlyn Foundation, 2012) we extracted the main characteristics of a PBL activity. The set includes:

- organisational aspects, like plan and design;
- contents choice and learning design, instantiated in driving questions and learning goals, in a constructive investigation, and in the requirement of realism;
- an attitude to autonomy both required to the students and developed with them.

We made it more explicit by defining a series of requirements:

Plan and Design. A clear timeline has to be defined for the student project, and milestones have to be announced to students.

Centrality. Projects must focus on questions which are part of the curriculum, and questions must drive towards central concepts and principles of CS discipline.

Definition of learning goals. Curriculum content and skills which students will learn in the project need a formal definition.

Assessment of learning goals. This includes self-assessment by the students; school assessment, usually done by the teachers; external assessment, by people outside the school, e.g., citizens, professionals, experts.

Constructive investigation. Students have to actively be involved in "doing with understanding" (Barron et al., 1998), also called learning when or by doing.

Realism. Projects must simulate a realistic activity, primarily engaging students in obtaining a product required or useful to someone.

Autonomy. Students are required to show products of their projects. Exhibitions are usually planned. A successful exhibition is a proof of autonomy.

The requirements set has been consolidated into a schema (Table 1).

plan and design		
driving questions and learning goals	centrality	
	learning goals definition	
	learning goals assessment	self-assessment
		assessment by school
		external assessment
constructive investigation		
realism		
autonomy		

Table 1- Criteria for a student project to be considered PBL

Such schema has then been applied to the six student projects to measure their PBL level (Giaffredo et al., 2018), as summarized in Table 2. The more a project conforms to the criteria, the more it can be considered PBL, with the following evaluations:

- A, highly conforming to criterion
- B, conforming
- C, poorly conforming
- N, not conforming.

			1	**2**	**3**	**4**	**5**	**6**
plan and design			*C*	*C*	*N*	*B*	*C*	*C*
driving questions and learning goals	centrality		*A*	*A*	*A*	*C*	*A*	*A*
	learning goals definition		*C*	*C*	*C*	*A*	*C*	*C*
	learning goals assessment	self-assessment	*N*	*C*	*N*	*N*	*B*	*N*
		school assessment	*C*	*C*	*B*	*N*	*N*	*B*
		external assessment	*C*	*C*	*C*	*C*	*C*	*C*
constructive investigation			*A*	*A*	*A*	*A*	*A*	*A*
realism			*A*	*A*	*A*	*A*	*A*	*B*
autonomy			*B*	*B*	*B*	*B*	*A*	*B*

Table 2 - PBL characteristics of the six student projects

As we can observe, only project 2 does not present non-conformity.

4. Discussion

Our two studies investigated the possible presence of a positive impact of the application of the PBL method on the adoption of CBE. The focus was on CS secondary school teachers in Italy.

4.1 The action-research training course

The results confirmed several issues: fuzziness in definitions of the set of competences; lack in teachers' competence vocabulary; limited adoption of CBE approach.

The result of fuzziness is not new. A study published in 2013 claims that even scholarly definitions of set of competences are often unclear (Magenheim et al., 2013). Similarly, institutional definitions of competences can also be unclear. As a consequence, this generates a lack of vocabulary on competences, as confirmed also by blind evaluation on plans produced by teachers in our training course.

4.2 The collective case-study

The second study focused on a collective case study, involving six student projects. Except for one project, all student projects conform to the characteristics of plan and design, centrality, and learning goals definition. Only one project had a written plan or a design. The other five projects focused on main principles of the discipline, highly conforming to the centrality criterion, but with a poor definition of learning goals.

Learning goals were poorly assessed, except for project 5 with self-assessment, and projects 3 and 6 with an assessment by the teachers.

External assessment was implicitly applied to the projects presented to the public (projects 1, 2 and 3).

The best results were achieved for the last three criteria: realism, constructive investigation and – even if to a lesser extent – autonomy.

Overall, if we were to assign a score between 0 and 3 for N to A, all projects would score between 15 and 17 out of 27, showing that their adherence to PBL was rather weak.

4.3 Comparison of the two approaches

Our two studies performed different but complementary research activities. On the one hand, they were different in impact on teachers' behaviour. The training course included sharing some basic principles with teachers, then supporting them in their practical application in classes. For this reason, a goal of the course was to modify the way the teachers practice PBL, helping them to pay attention to CBE.

With the collective case study, on the contrary, we did not try either to modify or to interfere with teachers applying the PBL in their teaching. It was an opportunity for us to observe the process in action: we did not offer any suggestions, interacting with teachers only to collect data for the research, with no intentional consequences on teachers' training.

On the other hand, the two studies provided comparable results, seen from different viewpoints. Both studies confirmed that in PBL activities teachers are especially careful to survey the social competences and meta-competences, also called transversal competences, of their students. In both studies, teachers highlighted that PBL activities support students in developing also competences other than CS competences.

The direct observation in class and the evaluation of final products provided teachers of first study with the elements, which gave them a useful basis to assess students. The PBL activity represented a useful opportunity for all students and was very positive for some of them. Teachers did not report any negative aspects, whereas they highlighted various positive ones: motivation, autonomy, enthusiasm, and no defeatism. Participating in the creation of a real product was intriguing for all students.

Teachers of the second study developed six student projects. We did not force teachers to strictly use the PBL method. As the application of our schema revealed, all student projects included the main characteristics of the PBL method, but the definition of learning goals was poor, and the assessment focused mainly on transversal competences rather than on CS competences. With such a weak attention to assessment, we cannot claim that the analysed projects were fully PBL. In summary, attention to development of transversal competences seems to be a result of student project activities. At the same time, more attention must be given to the definition of learning goals and on assessment.

5. Conclusions

Official indications push towards CBE, but this approach is scarcely adopted by Italian teachers. This limited adoption has been the research problem we addressed. We aimed at finding solutions to support the adoption of the CBE approach to education for CS teachers in Italian secondary schools. Our working hypothesis was that PBL can help achieving CBE.

Our preliminary evaluation confirmed a weak commitment by the teachers in the competence-based approach. Hence, we acted on two plans: in one study, we organized an action research based on a training course for teachers on PBL finalized to CBE, which we designed and implemented. In a second study, run in parallel, we observed a group of different teachers and their students while they were running students' projects as a teaching method. In this second case, we wanted to ascertain if these projects were compliant

with the PBL guidelines, and if they favoured the introduction of CBE.

Both studies reported a weak *induction-effect* from PBL activities to the CBE approach, even though some teachers showed to be interested in applying project tools to the CS competences. A problem that emerged is that project plans are usually scarcely formalised, and that student projects are not fully PBL-compliant. To address the question of the PBL-compliance, we built a schema to measure how student projects are PBL. We applied the schema to six student projects, confirming a poor plan and design formalisation, which also revealed a poor definition of the learning goals in the student projects. Our hypothesis to be further investigated is that a more formalised student project could better induce teachers to adopt the CBE approach.

Our two studies offered different investigation contexts. Action research course attendees shared some basic knowledge, principles and reflection. On the other hand, teachers of different student projects in the second case study did not plan shared activities. The course pushed teachers to enrich their PBL activities with some aspects of CBE approach, while the second study was limited to observation, without interference. To measure the impact of the action research course, we asked teachers to provide two PBL activities plans: plans of past activities, in the first meeting; plans for future activities, in the last meeting. We collected comparable data submitting the same worksheet, which requires to define the PBL activity learning goals and to identify contents and skills separately. In the final plan teachers paid more attention both to the definition of the learning goals, including social competence, and to the assessment criteria, also adding a test based on finding and fixing errors in a piece of software. One teacher included a rubric with the criteria to assess competences and skills of the students. In the last meeting we collected data from two PBL plans.

Three teachers accessed the basic functionalities of the OPLÀ platform, sharing materials and documents, but did not use those which allow managing project planning, creating rubrics for competences and products, and assessing competence. In such conditions, support systems can only have a limited impact on educational activities.

Overall, the involved teachers were keen to compare their experiences and they willingly brought the perspective of their own work into the research. Taking part in the training on PBL, they shared techniques and approaches to design and direct the activities in class. They were able to reflect on their teaching approaches, both past and present. Some of them said that they would be more confident in using teaching support systems introduced during the research. This in turn can help to support CBE.

As a result of the second study, in which we observed the project teaching in classes, we can confirm that the application of the PBL method could effectively drive the learning process, helping teachers to monitor students' activities. This could have a meaningful *induction-effect* from student projects to CBE.

CS teachers use student projects with their pupils, even though activities are not always compliant to the PBL method. Sometimes, student projects might suffer from lack of design and planning. In this case, support systems would have a limited impact on educational activities. Furthermore, some student projects do not focus on the specific competences of the CS discipline, neither by design nor in assessment. Nevertheless, we observed that student projects encourage teachers to assess social competences and meta-competences, also called transversal competences. The reason is probably that during projects students are engaged in group activities, an environment suitable to develop and observe social competences.

The schema we developed to measure the PBL characteristics of a student project could be used as a tool to support the design of student projects, helping teachers to clearly include the definition of some convenient milestones. In the first phase, teachers could apply the schema to analyse their previous student projects from the point of view of PBL. This could help them understanding which parts of the project plan need a better formalisation, achieving a clearer learning design for their future projects. This might be a way to drive an explicit adoption of the CBE approach. To contextualise results of our study, future research could compare Italian approach to CBE to European country that integrate it in the school curricula.

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