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Open Project-Based Learning for Dynamic Adaptability of IT Education

Ruben Tous and Felix Freitag[1]

Abstract

The pace of technological change is accelerating, the duration of the trends is becoming shorter and the number of technological alternatives to solve IT problems grows quickly. Keeping IT higher education course curricula up-to-date becomes more and more challenging. This paper presents an empirical study that aims to assess whether an open-statement and open-solution methodology in an IT-related project-based learning (PBL) course led to the adaptation of the skills learned by students to the trends of the main IT technology domains. The study analyses data from more than 90 projects by students from eight academic years of the course "Project on Information Technologies", carried out by students in the last year of the Bachelor of Science in Informatics Engineering at the Barcelona School of Informatics. Our results identify a high correlation between the technologies chosen in student projects and technological trends, which shows that the methodology encourages students to incorporate the latest technological innovations in their project work plan.

Keywords

Project Based Learning, Information Technology, professional skills, curriculum adaptation

Introduction

Today, project-based learning (PBL or PJBL to distinguish it from problem-based learning) is an essential component in the education of bachelor's and master's degree candidates in Information Technology (IT) related degrees[1–4]. This methodology involves many different aspects (project statement and solution openness, group management, class organization, etc.) for which there are different possible configurations, and it is being applied in multiple ways in IT related courses.

The project statement and solution openness are two of the most relevant parameters to decide[4]. One possible design of a project-based course is for the instructor to propose a single project to the students. These narrowly defined projects are generally designed in a way that focuses on leveraging the technical knowledge acquired by students in previous courses, and/or acquiring knowledge about a predefined set of new technologies. This approach has some valuable features: Once the projects are finished, all the students have faced the same challenges, and therefore, they have gone through the same learning process, leading to a homogeneous progress among the students in the acquired skills[5].

A different design of a project-based learning course is to let the students define, or co-define with the instructor, the objectives of the project and the technologies to be used. This study assesses the extent to which this open-statement and open-solution approach leads to an adaptation of the skills learned by students to trends in the main IT technological domains. The study presented in this article analyses the data from more than 90 student projects obtained over eight academic years of the course "Project on Information Technologies", taken by the students in the last year of the Bachelor of Science in Informatics Engineering at the Barcelona School of Informatics.

Background

courSe description

The study presented in this paper was conducted in the context of the semester-long course "Project on Information Technologies" (PTI), of 6 ECTS credits (around 150 hours) and from the last year of the Bachelor of Science in Informatics Engineering at the Barcelona School of Informatics (FIB) of the Polytechnic University of Catalonia - BarcelonaTech (UPC). The study comprises eight academic years, from 2012/2013 to 2019/2020.

The curriculum of the course includes technical competences related to information technologies, computer networks and distributed applications, and non-technical transversal competences such as teamwork, project design and management, and oral and written communication. The development of a project in groups of 3-5 students is the main objective of the course. The project lasts 15 weeks (half an academic year) and is active from the beginning.

[1]Universitat Politècnica de Catalunya (UPC), Barcelona, Spain

Corresponding author:

Ruben Tous, Universitat Politècnica de Catalunya (UPC), Barcelona, Spain

Email: rtous@ac.upc.edu

Related work

Many studies have proposed project-based learning as a suitable methodology for achieving effective competence-based education[6,7,7–10]. Some works have studied its effectiveness in higher education, with a special emphasis on engineering[11–15]. In the study of De los Ríos et al.[11], the authors describe two decades of applying project-based learning in higher education engineering in the context of the final years of the undergraduate programme of the Technical University of Madrid, Spain. One of the conclusions of this work is that project-based learning strongly improves the link between university education and the professional world. The work of Ruikar et al.[12] explores the links of project-based learning with industry engagement. The study of Stewart[13] puts the focus on the relationship between self-directed learning readiness and project-based learning outcomes. Gibbes and Carson[14] applied activity theory analysis to study project-based learning. The authors report mixed results in learning outcomes because of contradictions found in the activity system (e.g. inequitable divisions of labour or perceived lack of time due to community obligations). There are many other studies reporting particular experiences of project-based learning in higher education (e.g.[15–19]). Most of the studies are based on a qualitative assessment of students' behaviour and accomplishments, and do not always allow to establish a clear causal link between project-based learning instruction and positive student outcomes. Several works study the specific application of project-based learning in higher IT education. In the work of Sindre et al.[2], the authors study the suitability of project-based learning in the IT context in general, and with respect to the curriculum guidelines from the ACM/IEEE Task Force on Computing Curricula in particular. This work concludes that this methodology properly adapts to the rapidly evolving needed skills for future IT professionals. Fioravanti et al.[3] report an experience that integrates project-based learning and project management in a Software Engineering course.

There are not many works that focus on the project statement and solution openness of project-based learning courses. Hulls et al.[4] describe the evolution of a (part of) traditional C++ programming course (first years of Mechanical and Mechatronics Engineering at the University of Waterloo, Canada) into an open-ended project-based learning course. The work focused on motivational aspects and concludes that the approach resulted in a significant increase in student enthusiasm. One interesting aspect of this study is that students were faced with the possibility to select between pre-defined projects (a Roomba-like robot, an alarm clock which could hide from the user or a maze-solving robot) or with their own project proposals. The authors describe how the number of students choosing their own ideas increased over time, until becoming the majority at the end.

Materials and methods

Data acquisition

This study required the analysis of the final deliverables of the projects realized by PTI attendees within the course during eight academic years, from 2012/2013 to 2019/2020. A total of 91 projects, involving more than 300 students, were analysed. For the processing of the data, the project descriptions which the students publish in a Wiki* as part of their final assignments were used. For each project, a summary with its focus (e.g. "mobile-app"), application field (e.g. "sport"), programming languages (e.g. "Java"), all the involved technologies, and all involved project management tools, was generated. Project summaries were manually formatted in a machine-readable JSON format.

A tool was developed, programmed in Python, that aggregates all the JSON summaries and automatically calculates the frequency of the different technological ingredients over time. Relative frequencies are used (e.g. "the 50% of projects of the first semester of 2012/2013 used Java") instead of absolute values because not all the courses have the same number of projects. The resulting numeric values are stored in a set of data files in gnuplot format, for further graphic processing.

Data analysis

In order to observe the changes in technologies between the years in which projects were carried out, we present the evolution over time of the technologies used in student projects from 2012/2013 to 2019/2020. In addition, to analyse the relationship between the timing of these changes and that of real-world trends, we use external resources, such as Google Trends[20] and Stack Overflow Trends[21].

Results and discussion

Through the following subsections the results of the study are reported. For each aspect of the projects a bar chart is given, showing the relative frequencies of the different student choices over time. As PTI is a semester-long course, each time interval comprises one semester (20xx-1 refers to the first, autumn semester and 20xx-2 refers to the second, spring semester).

Technological project scope

Figure 1 shows the evolution of the global technological focus of the projects. Four main focuses are identified:

- *web-app*: projects whose main workload is dedicated to web application development. Typically, this kind of projects involves client-side web technologies (e.g. HTML, Angular, etc.) and server-side web technologies (HTTP servers, application servers, etc.).
- *mobile-app*: projects whose main workload is dedicated to mobile application development. Typically, this kind of projects involves client-side mobile technologies (Android SDK, iOS SDK, Unity, React Native, etc.) and server-side technologies such as Web APIs.
- *iot*: projects whose main workload is dedicated to Internet of Things (IoT) related technologies (e.g. Raspberry Pi, Arduino, webcam, sensors or actuators).

*Publicly available at https://mwiki.fib.upc.edu/pti/index.php/Categor%C3%ADa:proyectos

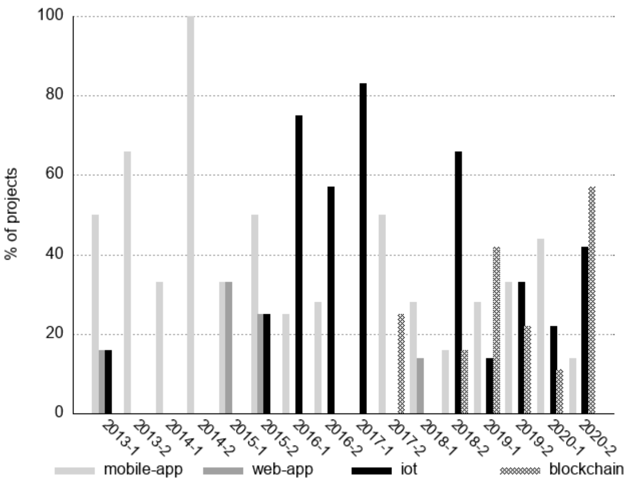

Figure 1. Bar chart showing the evolution of the overall technological focus of the projects

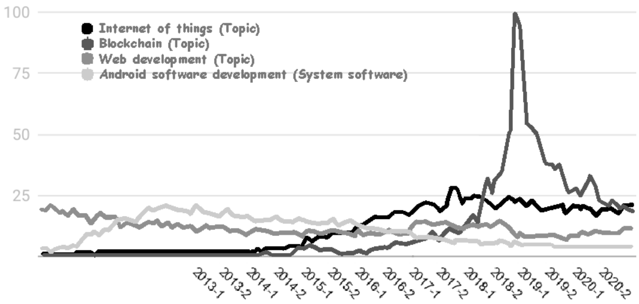

Figure 2. Search frequency in Google of the terms "web development (Topic)", "android software development (System software)", "internet of things (Topic)" and "blockchain (Topic)" (between January 2009 and March 2020)[20]

- *blockchain*: projects whose main workload is dedicated to blockchain related technologies (e.g. Ethereum, Solidity, MetaMask, etc.).

Comparing the students choices with the real technology trends in Figure 2, it can be seen that they align almost perfectly.

During a previous period (the 2000s decade), for which no numeric data are available, the typical project's technological scope evolved from no-HTTP distributed applications (e.g. using CORBA or Java RMI) to projects dominated by web-based technologies, the *web-app* focus. At the end of that decade, the projects' focus changed to the development of mobile applications (*mobile-app*). The period in which the study starts (academic year 2012/2013) was still dominated by mobile applications, but Figure 2 shows that a new trend, the Internet of Things (IoT), had started to capture the interest of the students. IoT projects were predominant around the mid 2010s, reaching their maximum share the first semester of the 2016/2017 academic year. As the period dominated by IoT advanced, the projects became more complex, and some students started to propose ideas related to robotics.

On the second semester of the 2017/2018 academic year, a first project focusing on blockchain technologies was proposed. Since then, this kind of projects, despite of their complexity, have been increasing their share (during the first semester of 2018/2019, most of projects focused on blockchain).

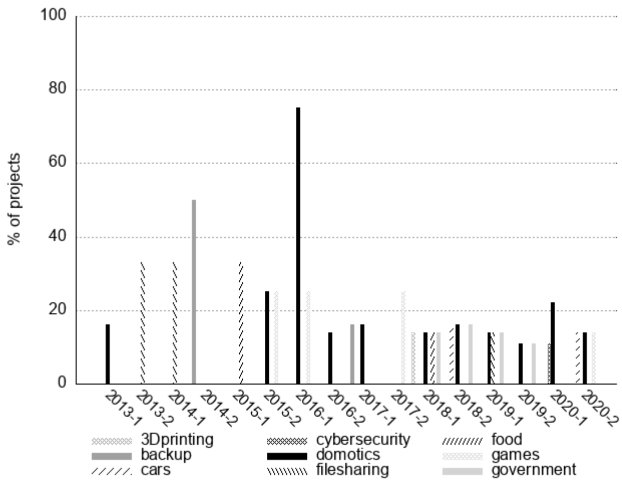

Figure 3. Bar chart showing the evolution of the application domains of the projects

Application scope

Figure 3 shows the evolution of the application domains of the projects. The analysed data show a wide variety of target application domains and the figure only includes the most relevant ones. No clear trends can be observed except for some application domains naturally linked with specific technical trends such as, e.g., domotics and meteorology (linked with IoT) or governance (linked with blockchain). Some application domains keep appearing from time to time, regardless of the technological trend, such as filesharing and games.

Programming languages

Figure 4 shows the students choice of programming languages evolution over time. If these results are compared with the popularity of programming languages in the IT community according to the % of Stack Overflow questions[21] (Figure 5), it can be observed that the programming languages used in the projects not only follow the real trends but they even allow to anticipate them. The initiative that the students have regarding the usage of new programming languages in the projects does not seem to match to the programming languages learned during their career (mainly C++ and Java). Through the last semesters it has been observed, not without some surprise, how Node.js (JavaScript) has been gaining share until it has become the most widely used language, both in the client and the server side. In addition to other possible reasons, the authors believe that the increase in complexity of the client side code, which forces developers to use JavaScript intensely, makes JavaScript a natural choice for the server side as well, avoiding the overhead of using two languages.

Server-side technologies

Figure 6 shows the evolution of the server-side technologies used in the projects. During the first reported period, students

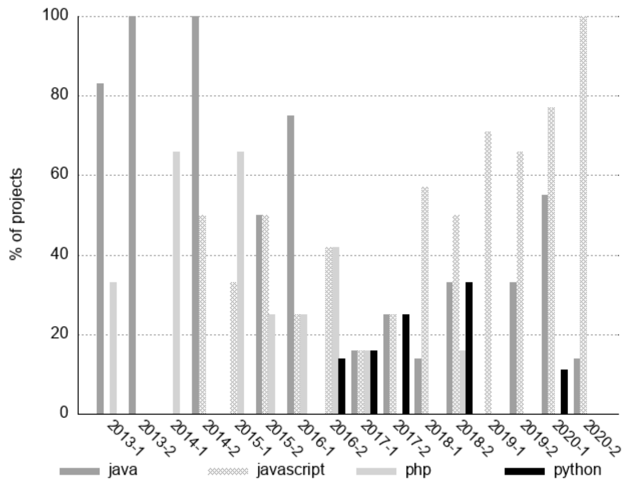

Figure 4. Bar chart showing the relative frequencies of the students choice of programming languages over time.

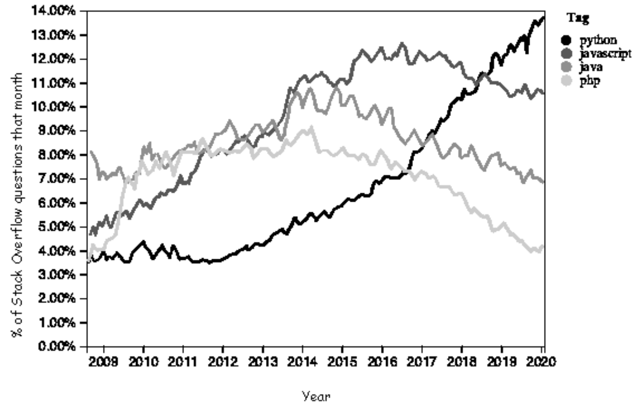

Figure 5. Popularity of programming languages according to the % of Stack Overflow questions that month[21].

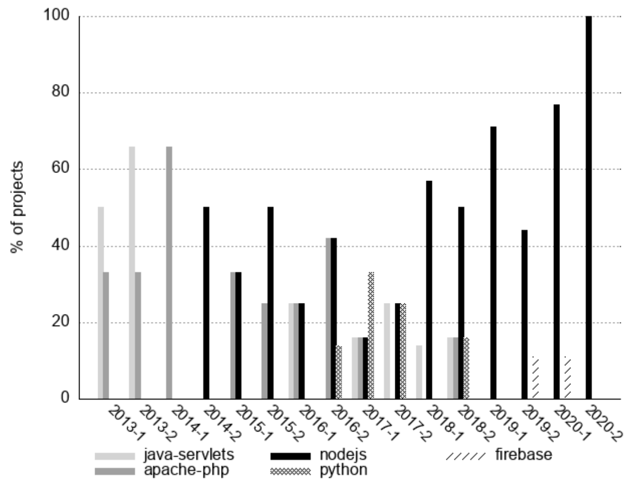

Figure 6. Bar chart showing the relative frequencies of the students choice of server-side technologies over time.

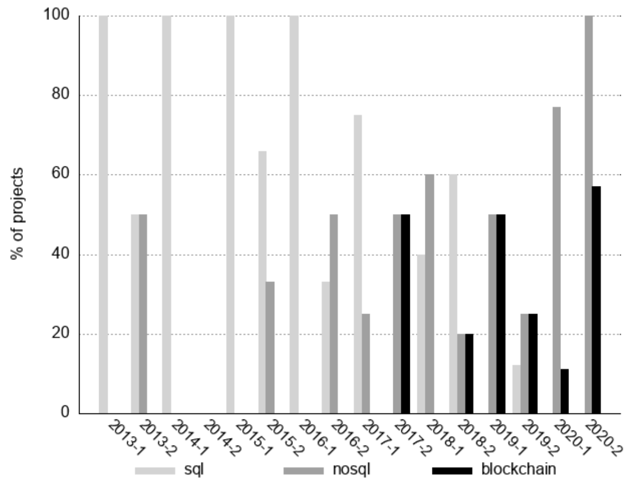

Figure 7. Bar chart showing the relative frequencies of the students choice of database technologies over time.

usually chose Java Servlet (e.g. the Apache Tomcat open-source Java Servlet Container) for the backend of their client-server applications. This choice was probably conditioned by the fact that this technology is used during the introductory labs of the course. An usual alternative, during the first reported period, was the Apache HTTP server with PHP CGIs, usually proposed by students with some professional experience (circumstance not very common at the beginning of the decade, but very common now). While the usage of CGIs has almost disappeared, the usage of an HTTP server remains in many projects, though lately Apache is usually being replaced by NGINX. In line with the success of Node.js, the Express web application framework has been gaining popularity. Analogously, students that prefer Python, usually choose the Flask micro web framework for their backends.

Another notable change observed regarding the server side is Docker, a tool for operating-system-level virtualization. Since the spring semester of 2015/2016, the number of projects that serve their applications within Docker containers has been growing. Within the most recent projects, even Kubernetes, an emerging orchestration tool for container deployments, was integrated in a few projects.

Database technologies

Figure 7 shows the evolution of the database technologies used in the projects. Beyond the student choices among specific products, it is interesting to highlight the transition from object-relational database management systems (typically MySQL Community Edition but also PostgreSQL, MariaDB and others), to NoSQL database management systems (typically MongoDB but also Cassandra, CouchDB and others). The resistance of MySQL is remarkable, as it accounts for almost all the object-relational cases in front of the myriad of alternatives and the traction of NoSQL systems. The success of MongoDB is also worth mentioning: it accounts for the 90% of the NoSQL cases, probably because of its strong linkage with Node.js.

A recent observed trend is the usage of external cloud services, such as Google's Firebase, that provide direct and secure data access to applications.

Hardware

Figure 8 shows the evolution of the hardware components used in the projects. During a first period, the usage of smartphones (labelled as "android" in the chart) was the main

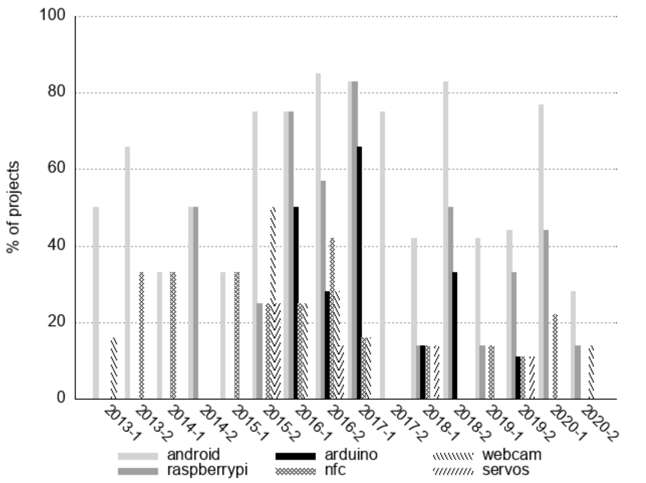

Figure 8. Bar chart showing the relative frequencies of different hardware components found in the projects over time (Note: "android" refers to any kind of smartphone).

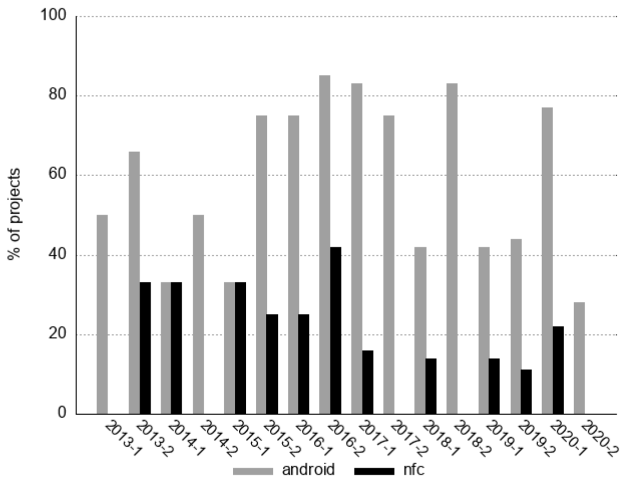

Figure 9. Bar chart showing the share of projects involving smartphones ("android") and near-field communication ("nfc").

novelty in terms of hardware, considering that before that time almost all the projects were limited to PCs for both the client and the server side. Despite the fact that the number of projects focusing on mobile applications has decreased over time, the presence of smartphones has remained, or even increased, as almost all the projects include some client-side functionality (for the students the smartphone always takes priority as a client device).

A typically smartphone-related technology (its usage with other hardware has been marginal), near-field communication (NFC), has had a relevant role in several projects (see Figure 9), mainly as a proximity sensor used in applications related to public transportation, restaurants/bars and music clubs.

Powerful servers with which the administration of cloud management platforms, such as OpenStack, OpenNebula or Proxmox could be experienced, have not yet been part of the student projects. From the perspective of a customer, however, the cloud services of major providers were used (IaaS and PaaS) to deploy applications and integrate services. The lack of projects that focus on cloud service provision may be explained by the fact that the hardware resources the instructors can make available for the course do not include this type of infrastructure, and the students would need to find ways to provide them by their own means.

During the spring semester of 2013/2014, the first projects using Raspberry Pi were proposed. The Raspberry Pi was typically used in IoT related projects (e.g. for the domotics application domain) but some students also used it as a low-cost server for other kind of projects. With one-year lag, the Arduino open-source microcontroller boards appeared (plus a variety of sensors and actuators), and from that moment the tandem Arduino plus Raspberry Pi became common in IoT related projects (typically for the smart home and meteorology application domains).

Conclusions

The study assessed whether an open-statement and open-solution methodology in an IT-related project-based learning (PBL) course led to the adaptation of skills learned by students to the trends in the main IT technological domains. The empirical data from more than 90 projects were analysed in order to answer the question of to what extent letting students in a project-based learning course participate in the definition of the projects' goals and in the selection of the technologies resulted in a spontaneous adaptation of the learned skills to technological change.

The analysis focused on six different aspects: the global technological focus, the application scope, the programming languages, the server-side technologies, the database management systems and the hardware. The results of our analysis showed that the six aspects, as applied in the projects, have undergone important changes throughout the semesters of the course and in a relatively short period of time, while closely following technological trends. Furthermore, our result revealed that the duration of technological trends have become shorter and the number of technological alternatives for each problem grows rapidly.

Since the course is taken in the last year before graduation, the technology knowledge acquired by the student from the project can be expected to address the needs of the industry (for instance blockchain technology, container orchestration with Kubernetes). Therefore, a project focusing on current technologies might be the prioritized choice for students planning to enter professional life after their graduation. However, given as an open statement PBL, a project orientated towards more fundamental work is also principally possible. From our experience, such projects are rarely chosen. One reason could be that the students already acquire the knowledge on fundamental techniques and methods from many other courses during their academic career. Indeed, the combination of courses, such as the open statement PBL-based course allowing to explore current technologies, with other courses for acquiring the knowledge on fundamental methods and techniques, seems to be beneficial: the students will gain the skills to work with current technologies for immediate industrial applicability, while the knowledge on the fundamentals will help them to adapt to the fast changes of the technologies.

This highly dynamic scenario of technological changes, which is certainly a challenge for IT education professionals, seems not to be a problem for students, who have shown to be able to adapt the learning content of their projects to the technological trends, as the open project statement allowed them to do so.

Declaration of conflicting interests

No potential conflict of interest was reported by the authors.

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