A software engineering course that promotes entrepreneurship: Insights from a VUCA perspective

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Abstract. In a context of higher volatility, uncertainty, complexity, and ambiguity (VUCA), engineering education must promote active learning approaches, where the responsibility of learning is focused on students, enhancing their competencies and ability to be competitive in the market. But, such educational strategies encompass many issues, questions and challenges, both for teachers and students. This article presents and discusses the main changes that have been introduced in a course that promotes entrepreneurship in the field of software engineering. The changes were introduced to address two main aims: (1) to provide opportunities for students to experiment new skills, that prepare them to better behave in a VUCA context, and (2) to make the course more efficiently managed. External elements and personal issues complement the intrinsic motivation related to the course on entrepreneurship.
Keywords: VUCA; active learning; problem-based learning; entrepreneurship; software engineering.

1. Introduction

Volatility, uncertainty, complexity, and ambiguity (VUCA) all describe the conditions under which organizations operate in the world today. As there is no predictability for every issue that may arise, it is necessary to react for any issue that may arise. The VUCA world calls for innovative processes that can be used to cope with in any given situation. If treated right, the VUCA world can be an opportunity for teachers and students to develop effective flexible strategies. VUCA is a way of assessing the changeability of general situations and events that are completely unpredictable.

Higher education institutions are not well prepared for the VUCA world due to rigid structures and lack of agility to embrace change [1]. Indeed, universities face many uncertainties, due to VUCA and the chaotic, vibrant, and rapidly changing educational environment of our days [2]. These external factors demand from professors a constant and quick reshaping of the courses they are responsible for, so that they are more attractive to their students. In this context, higher educational institutions are forced to reshape, respond to and adapt to a rapidly changing environment as a result of learning, adaption, and development [3].

Entrepreneurship education is a good context for preparing the students for the VUCA side of the world, where adaptability and flexibility are necessary [4]. Entrepreneurship education is among the fastest growing fields of education. The promotion of entrepreneurship in engineering education is getting significant attention (e.g., [5, 6]). Nevertheless, training for entrepreneurship requires approaches that need to be simultaneously efficient and effective [7]. This implies a permanent evolution of good practices and a continuous reshaping of the courses, where those topics are considered. Otherwise, pedagogical practices quickly become inadequate and obsolete.

This manuscript is focused on describing and discussing the evolution of a project-based course (Project in Software Engineering - PSE) since its inception. We analyse with which rationale the changes were introduced, namely to adapt the course to better achieve its objectives or to better satisfy the expectations of the students. In particular, our analysis of the evolution of the course is grounded in the VUCA principles. Thus, the main goal of the research reported in this manuscript is to contribute to the analysis of the evolution of project-based entrepreneurship/engineering courses that can support those VUCA-oriented educational contexts.

This manuscript is structured as follows. Section 2 presents a brief state of the art on similar projects. In Section 3, we present the research method. The main ingredients of the PSE course are described in Section 4. Section 5 presents the major changes that were introduced in the course to adapt it to different circumstances. Section 6 discusses the impact, limitations, challenges and opportunities of such changes. Section 7 presents the main conclusions and opportunities for further research.

2. State of the art

In this section, both VUCA and entrepreneurship education in active learning contexts are discussed within the body of the literature.

2.1. VUCA

VUCA is a catchphrase, introduced by the U.S. Army War College to describe an uncertain, complex, and ambiguous, multilateral world, which resulted from the end of the Cold War. The world is currently undergoing a serious transformation and presents many signs of what is described by the concept of VUCA [8]. The increasing rate of changes in the modern world places new demands on people, processes, technologies, etc. According to [9], organizations have been pushed to move from the SPOD world (Steady, Predictable, Ordinary, Definite) to this new paradigm.

There are additional factors that have also increased the turbulence in the global higher education world including: the rise of the digital economy, connectivity, trade liberalization policies around the world, increased global competition and innovation [10]. For example, the covid-19 is a new challenge that calls for rapid adaptation.

Volatility signifies here that the speed, volume, magnitude and dynamics of the changes are all high. The problem is not sufficiently stable, which implies that different conditions may apply in different moments.

Uncertainty means that information that is important to solve the problem is not totally available. Uncertainty is present in volatile environments that are complex and that involve unanticipated interactions.

Complexity is a measure of the difficulty in solving a given problem. Complexity in engineering can be measured by a number of dimensions, most notably technical complexity. Essential complexity is inherent in the problem being solved, and cannot be reduced or eliminated. Intuitively, it is a function of the number of features and the number of relations among them that are needed to decompose the problem.

Ambiguity occurs in situations where there is doubt about the nature of cause-and-effect relationships. It is also related to the fact that the information of the problem is subject to various interpretations. This happens in ill-defined problems, where the information is seldom contradictory, inconsistent or originates from different sources.

Volatility can be managed through agility, uncertainty mitigated gathering new data, complexity asks for abstraction and restructuring, and ambiguity can be reduced through experimentation [11].

If the challenges surrounding us are highly complex, often ill-defined and interdisciplinary in nature, universities should prepare students to tackle these challenges by providing them opportunities to hone skills such as the ability to evaluate new inputs and perspectives, and strengthen autonomy.

Experienced workers but particularly students need to learn about and to be competent in several skills to cope with the increasing competitiveness of the companies' world. For example, in [12] the authors identify the dispositions and skills required for the VUCA work environment as following: communications skills, self-management, ability to learn independently and in trans-disciplinary ways, ethics and responsibility, cross-cultural competency, teamwork in real and virtual ways, social intelligence, flexibility, thinking skills and digital skills.In the context of higher education, volatility refers also to the ease and speed in which teaching and learning best practices change. Additionally, many students are looking for educational environments that are better aligned with their needs, so again educational practices should be modified. The typical one-size-fits-all model of education often does not satisfy the expectations of the students. Teaching is very uncertain for the teachers because they have never been sure about what their students understand, whether the misunderstandings come from inadequate content or incomplete understanding of difficult concepts.

There is still little experience on understanding how VUCA can be addressed in universities. Results of a quasi-experiment developed in [13] highlighted that project-based learning, interdisciplinarity, close collaboration between faculty and external partners, and active mentoring that were integrated in a course, contribute to give to students skills to be competitive in a VUCA context.

2.2. Entrepreneurship education in engineering

Entrepreneurship and consequently innovation are crucial topics offered in many engineering degrees. Universities have been introducing new teaching/learning methodologies such as active learning, which is an educational approach that focuses the responsibility of learning on students. This approach is particularly suitable and relevant in a VUCA context and to prepare people for such an environment.

Among several strategies, approaches and tools, project-based learning (PBL) is an active learning educational approach relatively well known in higher education institutions. Through PBL, students gain knowledge and skills by performing a set of tasks within a concrete project typically based on a real or market situation.

In this context, PBL models have been used as a privileged instrument of the new teaching paradigms. This type of learning consists of a methodology that emphasizes teamwork and the resolution of interdisciplinary problems, the active role of students in the learning process, along with the development of not only technical skills, but also of soft skills [14]. The change from traditional approaches to PBL is not free of challenges and issues that should be considered. Five aspects are highlighted in [15]: (1) critical involvement and input of stakeholders external to the course design team; (2) need to adapt PBL for institutional, discipline and cohort fit; (3) importance of preparing the student cohort to cope with the inherent tensions of PBL; (4) managing their potential demands for additional control; (5) clarification of opportunity and resource costs that arise from implementing PBL.

In engineering, the preference for PBL has been growing, based on the argument that the main competence and activity of the engineer is the development of systems, generally complex [16], and that the focus on design, team action, and decision making creates the most appropriate environment for learning these competences.

PBL approaches are, thus, important to help universities to move from more formal traditional teaching and learning and to redefine their institutional mission to include innovation, entrepreneurship, creativity and marketing.

The education and training of entrepreneurs should include the development of skills and the ability to take risks, to develop high creativity, to build strong motivation to get results, high personal achievement and should highlight a strong sense of commitment. Indeed, the literature highlights the relevance of leadership skills, teamwork and communication, and creativity [17].

Entrepreneurship is particularly important in this context of VUCA that can be promoted using active learning particularly, PBL approaches. It is closely linked to the concept of change, i.e. entrepreneurs are agents of change and entrepreneurship is the phenomenon associated with the change process.

The promotion of entrepreneurship in engineering education, more specifically in software engineering is getting significant attention. In particular, it is evident that entrepreneurship requires active educational approaches, so that students learn new skills and reflect on what they have learnt and how they can benefit from and apply those skills. There are some examples.

The multidisciplinary, active, and collaborative approaches used in teaching requirements engineering is described in [18]. The use of game-inspired exercises to address all the relevant topics of software engineering is presented in [19]. In [20], the authors discuss the insights on how providing students the opportunity to explore their entrepreneurial skills has an impact on students towards entrepreneurship.

Indeed, the success or failure of software-based products is highly dependent on a good alignment of technology, market needs and business model in very volatile, uncertain, complex and ambiguous (new) markets and industries. Students must understand that software development processes should meet the needs of all stakeholders (i.e. clients, customers and users) and result in profitable products and services in the actual very competitive globalized and digital-oriented world.

Additionally, learning-by-doing programs, which emphasize practical work in real contexts, require a high degree of student involvement and also significant resources, and, at the end, they can result in a range of different outcomes from case study analysis and business case preparation to the development of startups [21]. Research on the VUCA perspective in the context of entrepreneurship education is still in its infancy and the scarce work on VUCA in engineering education (e.g., [22]) must be complemented with contributions from the study of VUCA in companies (e.g., [23]).

3. Research method

The research strategy used in this article was essentially qualitative and with descriptive and exploratory nature. The information and data presented were obtained by the researchers as teachers participating in the studied processes, essentially through direct observation, interaction with the students and other interveners in the process (e.g., guests and mentors) and documentary analysis. The research was based on an eminently ethnographic approach, which allows us to understand the behaviour of a group or of a given system based on observable patterns.

The ethnographic approach is particularly appropriate to support the study and understanding of the phenomenon of entrepreneurship within universities and, in particular, the processes and strategies for entrepreneurship training. In a typical case study approach, the action of the researcher is limited to observing and interpreting the phenomenon under study, without influencing it. In this case, researchers assume a participating role by actively intervening in the phenomenon.

The data was collected since 2015 during five consecutive editions of the PSE course. The researchers have been participating actively in the changes made and were able to follow its implementation and routinization over the years. The personal perceptions were complemented with important artefacts of the course, namely the several versions of the course guide provided to all students every year which is updated after each edition, the final reports submitted by students, pitches presentations, feedback provided by mentors and guests, the analysis of marks, peer evaluation, project management information submitted through the project platform (Redmine), final interviews made with all teams on opportunities and expectations for further developments of the project towards possible commercial products or startup creation. Such unstructured data collection approach and subsequent inductive analysis creates conditions for the identification of relevant categories and the development of new perspectives of the phenomenon, new findings and explanations particularly when the context is not well known. The different sources of data, which was collected in different academic years and particularly the combined analysis of the two researchers allowed a relevant triangulation of the data collected and analysis made.

4. Entrepreneurship education in the software business

The "Project in Software Engineering" (PSE) course, offered since 2009/2010 to final-year students of the Master Degree in Computer Engineering at University of Minho (Portugal), is a project-based course to teach entrepreneurship in the field of software engineering [5, 24]. This course intends to follow a worldwide trend, linked to the promotion of initiatives, such as prizes and competitions, which promote an entrepreneurial attitude among the population in general and university students in particular. Software is particularly attractive to be exploited from an entrepreneurial point of view, due to its intangible nature that facilitates the development of products or services oriented to the market.

In this course, students combine a technical vision with a business perspective. This combination is still unusual in the training of software engineers. The main aim of PSE is to enable students to acquire a set of skills related to (1) the development (analysis, design, implementation, testing and management) of a software product as a team and (2) the analysis of the business potential of that product. Students are organized in relatively large teams (from 6 to 10 elements) to carry out the project during an academic semester.

Students are evaluated based on three main aspects: (1) the software product that they develop, (2) the respective business model, and (3) the pitch of the product.

In this course, students acquire several skills, which in most cases are not properly explored in their previous academic path, but that are clearly valued by the market. These skills include: leadership, team management, requirements management, interaction with customers/users, product design, software testing, communication and presentation, technical documentation, marketing, business, entrepreneurship [24].

PSE follows the philosophy advocated in [25], which argues that any topic can be achieved more effectively if students were confronted with the whole issue of this topic, instead of isolated parts. Perkins also describes the benefit that results for students when they learn skills and concepts in the context of creating a real-world artefact, using tools and best practices from the professional world. At the same time, students learn the academic subjects required for this level of software engineering.

The analysis made is based on the last five editions, in which 68 teams and 559 students developed a significant range of software products. In the last two editions, ten teams have worked on projects proposed by companies (e.g., Accenture, Bosch, Freeletics, OutSystems), but mostly develop their own product ideas (58 projects). During the period under analysis, the annual teaching staff ranged between four and six teachers and around 80 guests were invited to give feedback to them about the projects. The final presentation has been made outside the university in different places (companies and incubators).

5. The need of change, adaptation and evolution

A course with these characteristics needs itself to be continuously adapted and changed, according to the surrounding conditions. In the actual world qualified as VUCA, the modern professor needs to rapidly adapt his/her courses according to the reality and the expectations of the society, particularly organizations and students. We analyse the main factors that have induced changes that we, as professors, have introduced in the last five years in the PSE course, basically with two main aims in mind:

- **PSS** (promoting the students skills): to make it more appealing to the students, by providing them opportunities to experiment important skills.
- **ECM** (easing the course management): to facilitate how the course is managed.

The eight main factors that have induced change in the PSE, as verified throughout its editions, are presented in Table 1. Each one is more associated with a specific set of VUCA dimensions. For example, factor #4, related to the contact with external elements, creates opportunities for students to acquire skills that are useful to deal with volatility, uncertainty and ambiguity. Factor #1 (number of students per team) is related to complexity, as complex projects can only be addressed by a relatively large number of students. The skills are divided in the following major classes: Create (CR), Interact (IN), Plan (PL) Work in a Team (WT), Design and Develop (DD), Communicate (CO), Validate (VA) [5]. These seven classes of skills are to be seen as indicative, as a way to better group the skills, as some overlaps exist among them. For example, when designing and developing (DD) complex software, some form of team work (WT) and planing must be considered.

5.1. Number of students per team

Every year, the number of students that attend PSE varies. Since the course is oriented towards team-based projects, the task of the professors is to act as mentors/coaches of the teams, in order to guarantee that the projects progress as smoothly as possible. This variable number of students implies that either the number of teams also varies accordingly, or we have to change the number of students per team, if we want to fix a given number of teams. In both cases, the associated challenges are appreciable.

A high number of elements per team implies a bigger effort in management and typically, when a given threshold is reached, it reduces the capacity of the team to deliver good results. At some point, more elements mean more conflicts and less productivity per element, as indicated by the Law of Diminishing Marginal Returns. According to our experience, the ideal number is between 6 and 9 students.

There are also some challenges for the professors whenever the number of students in each team is high. One of them is the risk that some team members have a reduced (or even null) contribution to the project. Another issue is that all projects are different, so, based again on our experience, it is problematic for a professor to support more than three projects. In this case, if more students are enrolled in the course and the number of professors remains relatively stable, there should be some compromise between the number of teams and the number of students per team. In some cases, this is a difficult equation to solve and there are obviously no definite general answers.

The changes in the number of elements by team is the major one from the perspective of the teachers. The other two are the relevance of own projects and the visits of guests and specialists from the industry.

Table 1. Major factors that have induced changes in the PSE course (in the last five years).

Factor	Description	Skills	Aim	VUCA
1. Number of students per team	Variation in the number of members of each team (in general, between 6 and 9)	WT	ECM	- - C -
2. Project management and leadership	The use of a centralised project management tool is mandatory and each team has a leader	WT PL	ECM, PSS	- - C A
3. Different types of projects	Students can develop their own projects or projects proposed by partner companies of the course	CR DD	PSS	- - - -
4. Contact with external elements	Interaction between students and external elements to receive feedback and suggestions about the business potential of the product idea	IN	PSS	V U - A
5. Going out of the building	Searching for mentorship, getting feedback from the market	IN	PSS	V U - A
6. Accountability of students in the evaluation process	Empowering students in the evaluation process through the implementation of a peer review mechanism.	WT	ECM, PSS	- U - A
7. Creation of a business plan	Developing a proper business plan.	CR VA	PSS	- - C A
8. Communication with the public	Developing persuasive pitches/presentations.	CO VA	PSS	- - C A

5.2. Project management and leadership

In a team-based work, free-riding strategies are common, independently of the dimension of the team. Thus, in order to mitigate this problem, the use of a project management tool is mandatory. With this mechanism, the contribution of each student for the project can be controlled.

The use of software applications for project management is mandatory, and for uniformity purposes all teams must use the Redmine platform, which is made available by the teaching team. Online platforms used within PBL courses are powerful tools to improve the attitude of students with respect to continuous work and individual participation in the activities of the team. This is of paramount importance whenever the number of students and the number teams are high.

Leadership is also important in this context because, as other relational skills, it is very important in the VUCA environment as stated in [13]. In this course, the leader must manage the team in a calm but determined way. Furthermore, a balanced team well managed, with people with the proper skills, is a factor that has a very high impact on the success of the projects. Both aspects are highlighted at the beginning of the course and *ad-hoc* seminars on these issues are promoted but it is a process deliberately non-guided by the teaching team, as the grouping of the students in teams. Students must be very pro-active and autonomous in such decisions. Advantages and disadvantages, and also opportunities for improvements, may be explored in further developments to be made in the course.

The composition of the teams is discussed with the professors. It is suggested to choose students with different backgrounds, for the team to include members with different skills. It is also a good approach to not include people on the same team who have conflicts with each other or whose personalities foster some sort of antagonism. In the last edition of the course (2019/20), two students quit their teams as they were not able to cooperate. This was a very extreme situation, which unfortunately implied that those students failed to conclude with success the course. It clearly shows that the composition of the teams is an issue that deserves great attention.

5.3. Different types of projects

There has been an increasing number of products developed by the teams and remarkable progress in technical complexity and in the level of sophistication of the solutions, as presented in [5]. The quality of the value propositions underlying the products developed has also improved considerably.

Nevertheless, with big classes (with 100+ students), the expectations of the students are diverse. Thus, since the 2018/19 edition of the course, students are allowed to choose between projects proposed by themselves or by partner companies. The projects proposed by companies are monitored on a weekly basis by their proponents, which provides alignment between what is expected and what is achieved.

These two types of projects allow students to better match the course to their expectations. Many similar skills are required for both types of projects (like, technical development, presentations, team management), but each one also promotes different skills. The projects proposed by the students are more likely to promote creativity and innovation, while the ones proposed by the companies are more oriented towards the correct understanding of the needs of the stakeholders. Students projects require students to put attention in the business model, while company projects are more focused on user experience. Most students prefer to develop their own projects, which represented more than two thirds of the projects in the last editions.

Most teams are quite consistent in developing the project from the beginning, because making considerable changes requires a considerable additional effort. However, some teams hesitate a little in the first weeks about the direction the project can take. Around a quarter of the teams make some changes to their products. The number of radical pivots is very small (at most one per edition, typically), because students have to balance the realism of a business context with the need to approve the course.

5.4. Contact with external elements

In many universities, the students within their academic activities have very limited or no interaction with people from industry. In engineering, this contact is fundamental, so that students can experience during their academic path the challenges associated with having a more business-oriented approach.

We followed a strategy that promotes the participation of external experts, either from other departments of the university or from companies. The contribution of these elements was reinforced since 2014, by increasing the number of companies that regularly collaborate with the course.

As of the 2014/15 edition, the teams began to be visited, for eight weeks, by several specialists in the software business area (entrepreneurs, engineers, product managers, business angels), who discussed the respective value proposals. On average, 16 guests and business specialists visit the teams in every edition of the course.

The feedback and suggestions provided by these external elements are quite useful in general and expose students to the scrutiny of business experts and specialists, which is a new experience for them. However, sometimes students follow immediately all the suggestions that are provided by the experts, without carefully analyzing the impacts of those suggestions in the project and without the necessary critical spirit and self confidence in the potential of the project whatever others' opinions. This is not a reasonable approach, since often those suggestions, even if relevant, imply significant or even drastic changes, which may put in risk the success of the project. Every year, there are one or two teams that are not able to deal with the different comments and suggestions made by the visitors and change the business idea repeatedly. These teams begin the development of the software product very late and typically cannot reach a very sophisticated product at the end of the semester.

5.5. Go out of the building

The students that develop their own product ideas have to align their products with the market. As already indicated in section 4.4, the contact with experts allows the products to be improved in that dimension. This is promoted essentially by suggesting each team to search a mentor for the project. Again, students must be autonomous in this task but the teaching team can act also as facilitators of contacts or, eventually, as a mentor if their area of expertise and knowledge of the market fits well the project; but that is not expected neither desirable. The mentor can be a potential first client, a business partner, an investor, someone with a good knowledge of the market or the domain. This contact is important to validate the value proposition, to help in developing the proof of concept, and to test the minimum viable product that should be designed and evaluated with feedback from the market throughout the semester. The role of the mentor is to give some advice and feedback and not to coach the project.

In the last edition of the course (2019/20), a team of students developed an app to suggest outfits based on clothes from different clothing retailers. During the semester, they were able to establish agreements with four well-known retailers, allowing their app to interact with their catalogues (i.e., their databases). This was a very successful example of what students are able to achieve by attracting external persons and companies to their projects. In the 2019/20 edition, almost all teams were able to contact and get the support of a mentor of the project, who helped to get data about the market, to give feedback during the development process, and to validate the value proposition.

5.6. Accountability of students in the evaluation process

Whenever there are many students in a team working together, it is always a challenge for the professors to decide how to differentiate the members of each team, according to the individual contributions. In many cases, the easiest solution is to evaluate the collective performance of the team and assign that evaluation to all its members. However, this may be quite unfair in many cases, as students contributed very differently to the final outcome. Thus, we suggest students within the same team to be allowed to decide how to differentiate their individual marks, if they find it appropriate. In fact, providing this power to the students is adequate, since they are the ones best entitled to make a fair evaluation of the performance of each team member.

Transferring this responsibility for the students makes sense, since they should be able to collectively arrive at a consensual decision. In the various editions of the course, for almost 100 teams, only once a team was not able to arrive to a unanimous decision. This evaluation process is accomplished through the implementation of a peer evaluation mechanism [26].

Students provide regular feedback to the teachers regarding the peer assessment. At the end, they indicate for each student the delta that should be summed to the collective mark in order to obtain his/her individual mark. This indication should result from a consensual decision. The total of the deltas should sum up to zero. The indication of the deltas should be given before the collective mark is announced, otherwise students are invited to artificially assign the deltas to maximize the total of the marks.

The peer assessment normally functions as a good indication of the team spirit. A team that is well organised and that promotes the collaboration of its members tends to give a “0” as the delta for all. Teams where there are frictions or problems usually have difficulties to collectively define the deltas. In 2017/18, a team was not able to agree on the peer deltas. At the end, the teachers decided to use “0” as the delta for its members. A final advantage of the peer assessment is to detect students with very low contribution to the project. In the 2019/20, a team suggests one of its members to have -4 as his delta. This high value (in the scale 0-20) prompted the teachers to analyse more carefully the situation. After some meetings with the students, it was concluded that that student interrupted the participation in the project in the middle of the semester. We eventually decided that he failed to conclude successfully the course.

Table 2 shows that 63% of the teams proposed to change the final marks of some students. On average, the absolute values of the negative deltas tend to be higher than the positive deltas, which imply that a higher number of students are positively affected in their marks by the peer assessment than the ones that are negatively affected. Considering the maximum and minimum changes on average the delta is almost 3 points, ranging between 2 and 4 points. Thus, this instrument is important and it was more used in some editions (i.e., 2018/19) and less in other ones (e.g., 2017/18).

Table 2. Indicators related to the peer assessment process.

academic year	max (average)	min (average)	Teams with changes/total (%)
2015/16	+1,55	-1,67	5/8 (63%)
2016/17	+1,28	-2,19	4/9 (44%)
2017/18	+2,54	-1,45	4/12 (33%)
2018/19	+0,92	-1,36	17/20 (85%)
2019/20	+1,01	-1,71	13/19 (68%)
Total	**+1,20**	**-1,59**	**43/68 (63%)**

5.7. Focus on business and communication

Developing a complex project in a team entails producing a significant volume of documentation in different moments. In the initial editions of PSE, students were asked to produce many deliverables, like requirements documents, user's manuals, installation guides, and business plans.

It is now clear that requesting such amount of documentation is counterproductive, because it deviates the students from the primary aims of the course. Currently, the focus is on developing a proper product/system and its business plan, since it forces engineering students to be able to combine their "natural" technical perspective with a business-oriented one. Students are, thus, asked to justify how their technical product is aligned with the business plan they proposed.

Reduction in the number of deliverables allows students to put more effort on communication issues. In fact, the quantity of deliverables was reduced considerably in 2017/18. Initially, students had to submit various elements and technical documents that were replaced by a small report (max. 20 pages). This change intends to put the focus on product development and the design of the business model. Anyway, it should be highlighted that each team is supposed to develop, within its project, other artefacts (like requirements documents, business plan), but that their contents is not fully evaluated (only the related parts that are included in the report).

Pitching is a crucial element of the project, highlighting the idea that communicating efficiently is a crucial skill for a modern engineer. Thus, students are requested to put great care on it. Three pitches are formally performed throughout the semester. The first pitch takes place at an early stage of the project (after three weeks). The second pitch occurs when the project is near the end (two weeks before the end). The final pitch takes place when the project is finished and aims to present the product and its business model to a panel composed of specialists external to the university.

6. Discussion

This section discusses the pedagogical issues related to the ingredients of the PSE course and how its design/application reflect the concerns with the context of VUCA.

The effort to regularly change the PSE course follows the principle that professors must understand their audience (way of reasoning, culture, dreams, and typical reactions). PSE evolved in order to enhance students' motivation. This is a relevant challenge for educators, because a conquered students audience participates in a more enthusiastic way. Universities must prepare people to deal with the future, where unskilled people, obsolete knowledge and ineffective tools have no room.

6.1. External elements

Interaction between students and external elements raises the chances that the projects have potential to develop products with a better fit to the market. In general, this interaction is positive, because students can improve their products. Additionally, this interaction allows students to test their communication skills, since they need to align their messages to the different persons with whom they speak.

An additional feature of PSE is the focus on pitching. The final pitch usually takes place outside the university (e.g., in a company) and the session is open to the general public. The presence of the media (e.g., journalist of local newspapers in the final pitches session) has already happened in some editions and puts more pressure on students to have the greatest impact with their pitches, not only for professors but also for external elements.

The contact with external elements means the absence of the typical academic guidelines, which are substituted by VUCA. Students must learn to deal with such experience and to learn from it. It is not an easy task and some of our students do not like it. But students adapt themselves very quickly. During the years of the financial crisis the availability to continue with the project after the course was higher than now. VUCA and entrepreneurial skills appear to be linked.

6.2. Personal issues and motivations

Preferably, product ideas should be proposed by students, who will thus be more motivated to develop them. The choice of the idea is a difficult moment for almost all teams, for two major reasons. Firstly, in general, students are not used to conceive a software product from scratch. They have experience in technologically developing a piece of software for a specific client. Developing products for a potential set of users entails a set of different challenges, namely the market fit and the comparison with the competitors. Secondly, the choice of the product idea is easily understood as a critical moment of the project. Students rapidly realize that a bad initial choice has tremendous impact in the rest of the activities. So, they want to make a safe decision.

A good product idea (i.e., with business potential) allows the team to work with a realism similar to that experienced in a business context. It is also a motivating factor, as it allows exploring viable development alternatives and promotes the personal satisfaction of the team members. Contrarily, a weak product idea causes frustration and does not allow the technological development to advance, as it is not stimulating to develop something that has no commercial interest. In some editions, some teams have changed their ideas, after five or six weeks, exactly because they feel frustration (or little interest) in developing a project in which they did not see any potential.

Students learn to deal with VUCA whenever they decide about the type of project and inherent trade-offs, particularly, in terms of technological and business characteristics. A project with little technological risk and a classic business model implies that the team has to explore other aspects much more deeply, like for example an excellent user experience, a solid market validation, or a detailed financial analysis. In contrast, a project with a high technological risk or involving a disruptive business model requires a greater focus in these aspects, which justifies a lower investment in others.

During project development, the effort between planning and building needs to be well balanced. Starting to develop too early, but based on a poorly supported product idea, is not recommended. However, thinking too much and for too long about the idea and then not having time to develop a professional product does not work either. Knowing how to manage this balance sheet is fundamental. In this sense, using an iterative/incremental approach, with regular interaction with users, usually proves to be the and adequate decision.

It is recommended for the students to frame their effort according to the 'Lean Startup' development cycle. The goal is to run short development cycles, adopting a combination of experimenting with the product's value assumptions, using minimal versions of the product for that purpose. Thus, many validation cycles are performed until a valid value proposal is reached. Again, contacting potential customers/users of the product should be carried out to accomplish this validation.

Finally, it must be mentioned that one established software company originated directly from the projects developed within PSE: Nutrium (nutrium.io/en). Other startups could also be considered here, but in those cases what was transposed was only the team (not the products). This is a positive side-effect of the course and shows that students do appreciate the possibility to develop commercially their own ideas.

7. Conclusions

This manuscript presents and discusses the main changes that have been introduced to the PSE course, whose aim is to promote entrepreneurship in the field of software engineering. The changes were introduced to address two main aims: (1) to allow students to experiment with new skills, so that they get better prepared to behave in a VUCA context, and (2) to ease the management of the course. The discussion is focused on the main factors that have induced change in the course: number of students per team, project management and leadership, types of projects, contact with external elements, go out of the building, accountability of students in the evaluation process, and focus on business and communication.

Some of the ideas, guidelines and lessons learned can be used or adapted in similar courses that try to promote engineering and entrepreneurship in a VUCA context. Entrepreneurship education can help students to cope with the characteristics of a VUCA world. The development of market-driven software products in the context of a course may fit particularly well such purpose. Firstly, software engineering education tends to be focused on the technological issues, but this is always not enough.

Indeed, students must understand that when in companies they must build products that are valuable for users. A common mistake is to develop products that were not sufficiently validated by the market. This sensitiveness is important in the competitive markets that face a globalized competition. This validation needs to be repeated regularly, to address VUCA characteristics.

Furthermore, companies exist to make money. Product and services are sustainable if they are profitable. Profitability is a function of the characteristics of the product in terms of price, quality and functionality, but also of the revenue models and these should be consistent with the firm's business model. Software-based products must be designed in accordance with the firm's characteristics and stakeholders' strategies.

The methodology followed in the engineering course presented here instigates students to develop their creativity, agility (fast reaction to changes), communication skills, and capacity to work in teams, which are important competencies for the VUCA world. The participation of business experts that have knowledge in the market domain is also crucial for the correct development of software products and connects students with the reality of the companies.

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