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Undergraduate research in software engineering. An experience and evaluation report

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Abstract: The purpose of this paper is to present an undergraduate research experience process model and the evaluation of seven years of its application in an undergraduate research program in software engineering. Undergraduate students who participated in research projects between 2015 and 2022 were surveyed to find out a) their motivations for participating in research projects in software engineering, b) the skills they consider they have acquired or improved by participating in those projects, and c) their perception of benefits and utility for their future work and professional activities. Results reveal that participation in real research projects in software engineering is highly valued by undergraduate students, who perceive benefits in the development of research and soft skills, and for their future professional activity. In addition, these undergraduate research projects and the process followed show that it is feasible to make original contributions to the body of knowledge of software engineering.

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Categories: D.2, L.0.0, L.3.4
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1 Introduction

The Council on Undergraduate Research defines Undergraduate Research (UR) as "a mentored investigation or creative inquiry conducted by undergraduates that seeks to make a scholarly or artistic contribution to knowledge" (CUR, 21).

Since 2015, at the School of Engineering of Universidad ORT Uruguay we have been developing an undergraduate research program with undergraduate students of the Systems engineering and Information systems degrees, focusing on doing research in the field of software engineering.

Software engineering is defined as the application of a systematic, disciplined, quantifiable approach to the development, operation, and maintenance of software, that is, the application of engineering to software (IEEE, 1990).

Software engineering is fundamentally an empirical discipline, where knowledge is gained by applying direct and indirect observation or experience. Approaches to software development, operation, and maintenance must be investigated by empirical means to be better understood, evaluated, and deployed in proper contexts (Felderer, 20).

As previously demonstrated in other engineering fields, research in software engineering represents an essential instrument to support the understanding of the software-related phenomena and the mitigation of issues in the software processes (Staron, 20).

As noted by Malhotra (Malhotra, 16), empirical studies are important in software engineering as they allow software professionals to evaluate and assess the new concepts, technologies, tools, and techniques in a scientific and proved manner. They also allow improving, managing, and controlling the existing processes and techniques by using evidence obtained from the empirical analysis.

Considering that most undergraduate students will work in the software and information technology industry after graduation, acquiring not only theoretical knowledge but practical, hands-on research skills (by actively participating in a research experience) will allow them to plan, execute, and evaluate empirical studies to meet the needs of the software industry.

However, a recent study (Ahmad, 22) on learning models for undergraduate research experience proposed in the literature between 2011 and 2021 did not identify any related study or proposal for the discipline of software engineering.

The purpose of this article is to present the process model for undergraduate research in software engineering at the School of Engineering of Universidad ORT Uruguay, the vision of the students themselves in relation to their experience of participating in these research activities, and the results obtained in terms of scientific publications derived from the research reports and completed degree thesis.

We consider that the undergraduate research process model presented in this work can be particularly useful for higher education institutions with limited resources to do research, for example, with few senior researchers and postgraduate students.

The rest of this article is organized as follows. In section 2 some background on desired characteristics of undergraduate research is given, and a model for undergraduate research is presented. Section 3 presents the undergraduate research program in software engineering at Universidad ORT Uruguay and describes the process that is followed for students who decide to do their capstone project in research mode. Section 4 describes the methodological design for evaluating the program from the point of view of students who have participated in research projects: research questions, participants, and procedure for collecting data by means of a survey. Section 5 presents the most relevant results of the survey, while section 6 is devoted to discussing the results and answering the research questions. Section 7 is devoted to presenting some learnings and good practices obtained throughout the seven years of execution of the undergraduate research program described in section 3. In section 8, the conclusions of the study are presented, and in section 9 some proposals for future work are depicted.

2 Background on undergraduate research

According to Blessinger and Hensel (Blessinger, 20), undergraduate research is identified as a high-impact learning practice and, as such, it is linked to improved student achievement and institutional advancement. To these authors, the ultimate objective of undergraduate research is for the students to make, to one degree or another, an original contribution to the discipline.

2.1 Desired characteristics for undergraduate research projects

To be meaningful to students, the research project must be “real”; that is, an investigation with the following characteristics: the research questions are well defined so that they can be systematically investigated, but their answers are unknown, research results may not be quickly forthcoming, but when they emerge, they constitute a genuine contribution to the field, and the research methods are the ones used in the discipline and seen as valid by disciplinary experts (Laursen, 10).

Murray, Obare and Hageman (Murray, 16) call for undergraduate research to be “authentic”; that is, hands-on research in which students actively engage with original questions or problems, usually with the guidance of a research mentor, and attempt to find unknown answers or solutions where the emphasis is on generation of new knowledge and/or problem-solving as done by practicing scientists and engineers.

According to Ellison and Patel (Ellison, 22), there are two key features of an undergraduate research experience that distinguish it from lab exercises and active classroom learning methods that simulate the research process. First, in an undergraduate research experience the student will learn to set research objectives, develop hypotheses, and research questions that build on previous work but for which no one knows the outcome or answer. Second, in addition to learning new technical skills, the student will also learn to use them and, in case of need, to adapt them for the tasks at hand.

2.2 Undergraduate research model

According to Healey and Jenkins (Healey, 09), there are four main ways of engaging undergraduates with research and inquiry, as shown in Figure 1:

- research-led: learning about current research in the discipline.
- research-oriented: developing research skills and techniques.
- research-based: undertaking research and inquiry.
- research-tutored: engaging in research discussions.

To these authors, even though all those four ways of engaging students with research and inquiry are valid and valuable, in much of higher education relatively too much teaching and learning is in the bottom half of the model, while most students would benefit from spending more time in the top half.

As we will explain in next section, the research activities developed under the undergraduate research program are focused the most on the upper side of Healey and Jenkins model.

3 Undergraduate research at the School of Engineering

The School of Engineering of Universidad ORT Uruguay offers a five-years degree in Systems Engineering and a four-years degree in Information Systems, both with a strong emphasis on software engineering.

Both careers have a common core of courses in their curricula, named Software engineering fundamentals, Software design (two courses), Agile software engineering, and Human-computer interaction. The Systems engineering career also has a set of more advanced courses on Software architecture, Testing and software quality, and a second course on Agile software engineering and DevOps. These advanced courses, in turn, can be taken as optional/complementary courses by the students of the Information systems career.

For students to complete one or the other degree, they must undertake a final capstone project that can be of one of the following "modes": a) software development project proposed by the software engineering lab, b) software development project proposed by industry, c) entrepreneur project proposed by the students, and d) undergraduate research project.

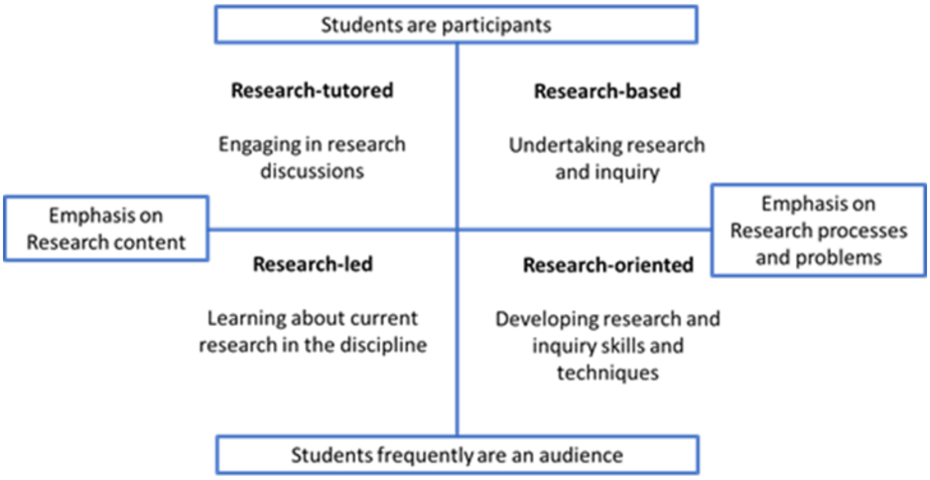

Figure 1: The nature of undergraduate research and inquiry (Healey, 09)

The undergraduate research project mode introduces students to practical research activities, and at the same time supports the research lines of the different laboratories and senior researchers, having as its main objective the creation and dissemination of knowledge.

3.1 Undergraduate research in software engineering

Research in software engineering is performed at the Centro de Investigación e Innovación en Ingeniería de Software – CI3S (Software Engineering Research and Innovation Center) of the School of Engineering.

The undergraduate research program in software engineering started in March 2015 and, as of March 2022, 20 projects were developed and completed, and 34 students participated in them. These undergraduate research activities are being led by the author, who acts as a mentor of research teams and proposes research topics within the main research lines of the CI3S.

Table 1 shows the software engineering topics researched, the number of projects completed up to date, and the number of students that have participated in them.

Year ended	Projects	Students	Research topic (number of projects)
2015	1	2	Soft skills in software engineering
2017	1	2	Soft skills in software engineering
2018	2	2	Human aspects of agile methodologies (2)
2019	6	10	Soft skills in software engineering (1) Human aspects of agile methodologies (2) Software startups (3)
2020	2	4	Software startups (2)
2021	4	6	Software startups (4)
2022	4	8	Software startups (4)

Table 1: Undergraduate research projects completed between 2015 and 2022

3.2 The undergraduate research process

With some minor variations along the last years, the whole process for undergraduate research projects is organized in three phases and 14 steps, as shown in Table 2.

The pre-project phase has the objectives to let students know what research in software engineering is about, the kind of work to perform during the project, the required level of engagement, and the expected outcomes. Students are also informed about current research topics and given introductory reading material so that they can choose one topic that is interesting to them. After they choose a topic, students participate in the development of a research proposal.

During the in-project phase, students prepare a project plan that includes usual activities and expected deliverables in a research project: reviewing the literature according to the research problem posed for the project, specifying its purpose, objectives, and research questions, and defining the research design for collecting and analysing data suitable to the type of research to carry on. Project team regularly meet with the senior researcher acting as a mentor to keep track of project progress, discussing decisions and actions taken by the students, and obtain advice on how to proceed with the next steps. The plan also includes activities related to writing and reviewing the research report or thesis, and to participate in a "work-in-progress" seminar to report on their project work up to date and receive feedback and suggestions, especially from their fellow students. At the end of the project, students submit their thesis for evaluation.

In the post-project phase, the project team prepares the presentation of its thesis, while (hopefully) planning with the senior researcher a research paper as a final activity for the dissemination of results.

Because projects last 6 or 12 months, it is usually not possible to write a research paper within the project execution phase. However, half of the students have carried out this post-project activity (which does not grant them extra credits) together with the senior researcher (mentor); some of them in more than one article, as shown in Table 7.

Phases	Steps and activities
Pre-project	1. Students come to the CI3S with intention to do a research project. 2. Senior researcher explains the characteristics of a research project and expected level of engagement. 3. Senior researcher shows the students the list of current research topics and explains main objective of each one. 4. Students select preferred research topic and, jointly with senior researcher, develop the research proposal. 5. Project scope and objective are defined according to expected duration of project (6 or 12 months) and size of project team (1, 2, or 3 students). 6. Project team members participate in a brief, one week pre-project workshop on research methodology.
In-project	7. Based on the research proposal, team members and senior researcher prepare the research project plan. 8. With the project plan approved, students start the project execution. 9. Weekly or biweekly meetings are held by team members and senior researcher to evaluate and discuss project status and receive guidance on the next steps. 10. As the research progresses, the students write their research report (thesis) and receive comments and advice from the senior researcher. 11. Students participate in at least one seminar with other students and researchers to receive feedback and engage in discussion about the progress of their project. 12. When the project ends, students submit their final report to the evaluation committee and are assigned a date to present and defend their thesis.
Post-project	13. Students prepare their dissertation with feedback from the senior researcher. 14. Students and senior researcher plan for writing a research paper based on the main outcomes of the project.

Table 2: Undergraduate research process model: phases and activities

Regarding the Healey and Jenkins model explained above, the described process is mainly in the upper right corner of the model, with students doing real, hands-on research (steps 4, 7, 8, 10) but also taking into consideration the upper left corner of the model with students engaging in research discussions (steps 9 and 11).

4 Undergraduate research program evaluation

To evaluate the 7 years period (March 2015 – March 2022) of running undergraduate research projects, a study was carried out to find opinions of the students regarding their participation in those research projects.

4.1 Research questions

Initially, three research questions were posed for this study aimed at knowing why students choose the research project mode for their capstone project and their opinion about their experience.

The research questions are as follows:

- RQ1: What motivates students to participate in an undergraduate research project in software engineering?
- RQ2: What skills do students consider they have acquired or improved by participating in the undergraduate research project?
- RQ3: What perception do students have in relation to the usefulness of participating in an undergraduate research project for their future work and professional activity?

In addition, we also wanted to evaluate the undergraduate research program in terms of outcomes in the form of research papers published in journals or conference proceedings. So, a fourth research question was added:

- RQ4: What have been the main results of the undergraduate research program in terms of contributions to the body of knowledge of software engineering?

4.2 Data collection method and instrument

For research questions RQ1 to RQ3, the data collection method was a survey to the 34 students who participated in undergraduate research projects between 2015 and 2022.

The questionnaire used for the survey has 21 questions and is organized into the following thematic sections:

- Demographic information of the respondents and the projects in which they participated: study program completed, year of project completion, number of members of their project team, topic and research problem addressed.
- Previous knowledge or experience in academic research activities.
- Motivation to participate in an undergraduate research project.
- Perception of improvement in the performance of a set of skills.
- Perception of usefulness of participating in a research project for their working and professional activities.
- An open space to leave criticisms and proposals for future improvements.

To prepare this questionnaire, two pre-existing data collection instruments were taken as a reference. One of them was version III of the "Survey of Undergraduate Research Experiences" (SURE) (Grinnel, 18) which, as presented by Lopatto, is a survey designed to evaluate the benefits of undergraduate research experiences (Lopatto, 04), (Lopatto, 08). The other was the "Undergraduate Scientists. Measuring Outcomes of Research Experiences Student Survey" (USMORE-SS), proposed by Maltese, Harsh and Jung (Maltese, 17) as a tool to measure student achievement as a result of their participation in these research experiences.

The questionnaire was developed using Google Forms functionalities and was open for responses between April 1 and April 30, 2022. The distribution of the survey to the target population was carried out by sending a personalized email that included the link to the online version of the questionnaire.

For research question RQ4, bibliographic data were collected directly from the conference proceedings and the journal where the research papers were published.

4.3 Data analysis

The data collected with the survey were extracted from each completed questionnaire and tabulated in different Excel spreadsheets to facilitate their analysis and organized for presenting results.

Responses to closed questions were tabulated to count the number of answers for each option. With respect to the open questions, prior to their analysis, an "open coding" process was carried out, which involved comparing text units (responses of the survey respondents) to discover relevant categories for the research problem (Grbich, 13). In this process, codes arise that represent categories of responses to the open questions, as shown in Table 3.

5 Results

This section presents the results obtained from the responses to the survey, and the answers to the research questions.

Twenty-nine students completed the survey, out of the 34 that were invited, giving a response rate of 85%. Self-identification of respondents was optional in the survey, so we anonymized all the answers.

None of the 29 respondents had prior experience in research activities, and only nine had taken an optional undergraduate course on research methodology.

5.1 Motivations to undertake a capstone research project

Regarding the research question RQ1, referring to the reasons students have for choosing the research mode for their capstone project, two questions were asked in the survey. The first one was an open question: What was the main reason for choosing to do your final degree project in "research" mode?

Table 3 shows the codes assigned to the textual responses and the corresponding response quantities.

Some illustrative answers of the different motivations expressed by the participants are the following: "*I work as a programmer, and I wanted to do something different. I didn't feel like scheduling an additional 4 hours a day and having to work for another client*", "*...because I was interested in something different from development, since I develop software in my work as well...*", "*...because I was more interested in learning by researching than doing software development ...*", "*...when deciding, I was inclined to know and apply research methodologies, a topic that I hadn't learn during the program...*".

Also regarding research question RQ1, in the survey participants were asked to indicate their degree of agreement with the following statement: "*The topic and research problem posed for the project was very motivating to decide to do my capstone project in research mode.*". Possible answers were given by the following options: "Strongly disagree, Disagree, Neutral, Agree, Strongly agree". Table 4 shows the results obtained: fourteen of the sixteen respondents agreed or strongly agreed with that statement.

Main reason	Quantity	Percentage
To learn on how to research	12	41.4%
Don't do another software development project	8	27.6%
To delve into a topic of interest	6	20.7%
The mode is compatible with my current working activity	2	6.9%
I did not have another choice	1	3.4%
	29	100%

Table 3: Motivations to undertake a research project

Answer	Quantity	Percentage
Strongly disagree	1	3,45%
Disagree	0	0,00%
Neutral	3	10,34%
Agree	9	31,03%
Strongly agree	16	55,17%
	29	100,00%

Table 4: Research topic/problem posed as a deciding factor

As explained above, the proposed research topics are related to the research lines of the software engineering research group of the Software Engineering Research and Innovation Center. Examples of proposed research topics are, among others, the following: Soft skills in software engineering: study on their valuation in Uruguayan companies (Fontán, 15), A knowledge management-based solution to the problem of newcomers to running software projects (Barrella, 17), Difficulties and strategies for adopting DevOps practices: a case study in a government agency (Maidana, 19), Difficulties and insertion strategies of an external Product Owner in outsourced software projects (Píriz, 19), The process of creation and evolution of a Minimum Viable Product in software startups (González, 19), Team building, decision making and conflict resolution in software startups (Suárez, 21).

5.2 Skills gains

In relation to RQ2 about student's perception of improvement in certain skills, the participants were asked to evaluate, using a Likert scale, to what extent they considered that they improved the following specific skills:

- Plan and control a research project.
- Read and interpret technical and scientific literature.
- Clearly define a research problem.
- Collect and analyse data and other information.
- Present results effectively.
- Write a technical or research report.

The Likert scale used for all the statements had the following options: "I did not improve this skill at all, I slightly improved this skill, I improved this skill, I strongly improved this skill, I learned something that I did not know before". Table 5 shows distribution of answers for the six skills surveyed. From those answers, students perceive the greatest gains in the abilities to plan and control a research project, to read and interpret technical and scientific literature, and to write a technical or research report.

Skill	Quantity	Percentage
Ability to plan and control a research project		
I did not improve this skill at all	1	3,45%
I slightly improved this skill	1	3,45%
I improved this skill	10	34,48%
I strongly improved this skill	3	10,34%
I learned something that I did not know before	14	48,28%
Ability to read and interpret technical and scientific literature		
I did not improve this skill at all	1	3,45%
I slightly improved this skill	0	0,00%
I improved this skill	8	27,59%
I strongly improved this skill	13	44,83%
I learned something that I did not know before	7	24,14%
Ability to clearly define a research problem		
I did not improve this skill at all	0	0,00%
I slightly improved this skill	2	6,90%
I improved this skill	5	17,24%
I strongly improved this skill	11	37,93%
I learned something that I did not know before	11	37,93%
Ability to collect and analyze data and other information		
I did not improve this skill at all	1	3,45%
I slightly improved this skill	2	6,90%
I improved this skill	8	27,59%
I strongly improved this skill	12	41,38%
I learned something that I did not know before	6	20,69%
Ability to present results effectively		
I did not improve this skill at all	0	0,00%
I slightly improved this skill	3	10,34%
I improved this skill	9	31,03%
I strongly improved this skill	11	37,93%
I learned something that I did not know before	6	20,69%
Ability to write a technical or research report		
I did not improve this skill at all	0	0,00%
I slightly improved this skill	3	10,34%
I improved this skill	4	13,79%
I strongly improved this skill	10	34,48%
I learned something that I did not know before	12	41,38%

Table 5: Skills acquired or improved

5.3 Usefulness of research participation for professional activities

Regarding the research question RQ3, referring to the students' perception of the usefulness of participating in a research project for their work and professional activity, the participants were asked to indicate their degree of agreement with the following statements:

- My experience of participating in the undergraduate research project has been useful to my performance in my work and professional activities.
- The general experience of participating in an undergraduate research project better prepares the participants for their work and professional activities.

For these two statements, the possible answers were given by the following options: "Strongly disagree, Disagree, Neutral, Agree, Strongly agree". Table 6 presents the answers received to those two questions.

Answers	Quantity	Percentage
My experience of participating in the undergraduate research project has been useful to my performance in my work and professional activities.		
Strongly disagree	0	0,00%
Disagree	1	3,45%
Neutral	9	31,03%
Agree	9	31,03%
Strongly agree	10	34,48%
The general experience of participating in an undergraduate research project better prepares the participants for their work and professional activities		
Strongly disagree	0	0,00%
Disagree	1	3,45%
Neutral	0	0,00%
Agree	12	41,38%
Strongly agree	16	55,17%

Table 6: Perception of usefulness of participating in a research project

Even though only two-thirds of the respondents consider that having participated in an undergraduate research project had a positive impact on their present work and professional activity, all except one consider that this type of undergraduate project is beneficial for the professional future of the participants.

5.4 Program evaluation in terms of publications

Dissemination of research results is an essential scholarly activity because it is the way to inform academics and practitioners of a discipline about the results of a research project and to contribute to its body of knowledge.

Writing and publishing a research paper in a journal or conference proceedings is not mandatory but it is a highly desired activity for undergraduate students, because it is an additional learning opportunity and a way to have 'third party' validation of the originality and quality of their research outcomes.

Half of the students that participated in undergraduate research projects since year 2015 have taken part of this post-project activity. To answer RQ4, bibliographic data of research papers published in a journal and several conference proceedings are shown in Table 7.

Year	Publication
2015 Conference	Raschetti, F., Fontán, C., Matturro, G.: *Soft Skills in Software Development Teams. A Survey of the Points of View of Team Leaders and Team Members*, 8th International Workshop on Cooperative and Human Aspects of Software Engineering (CHASE 2015), 2015.
2015 Conference	Raschetti, F., Fontán, C., Matturro, G.: *Soft Skills in Scrum Teams. A survey of the most valued to have by Product Owners and Scrum Masters*, International Conference on Software Engineering and Knowledge Engineering (SEKE 2015), 2015.
2017 Conference	Barrella, K., Benitez, P., Matturro, G.: *Difficulties of newcomers joining software projects already in execution*, 4th Annual Conference on Computational Science & Computational Intelligence (CSCI 2017), 2017.
2017 Conference	Barrella, K., Benitez, P., Matturro, G.: *Dificultades de los "recién llegados" a proyectos software en ejecución*, 23 Congreso Argentino de Ciencias de la Computación (CACIC 2017), 2017.
2018 Conference	Cordovés, F., Solari, M., Matturro, G.: *The role of Product Owner from the practitioner's perspective. An exploratory study*, International Conference on Software Engineering Research and Practice (SERP 2018), 2018.
2018 Conference	Cordovés, F., Solari, M., Matturro, G.: *An exploratory study of the role of Product Owner in industrial practice*, 13 Jornadas Iberoamericanas de Ingeniería de Software e Ingeniería del Conocimiento (JIISIC 2018), 2018.
2019 Conference	Píriz, V., Matturro, G.: *The "external" Product Owner in Scrum outsourced projects: business knowledge, product vision, and decision-making*, 14 Jornadas Iberoamericanas de Ingeniería de Software e Ingeniería del Conocimiento (JIISIC 2019), 2019
2019 Journal	Raschetti, F., Fontán, C., Matturro, G.: *A Systematic Mapping Study on Soft Skills in Software Engineering*, Journal of Universal Computer Science, 25(1), 2019.
2020 Conference	Buffa, A., Febbles, D., Solari, M., Matturro, G.: *Technical knowledge and soft skills in the founding teams of software startups*, 24 Congreso Iberoamericano de Ingeniería de Software, 2020.
2021 Conference	Nieto, G. Gonzáles, A., Solari, M. Matturro, G.: *Minimum Viable Product Creation and Validation in Software Startups*, XLVII Conferencia Latinoamericana de Informática (CLEI 2021), 2021.
2022 Conference	Lanata, K., Benítez, P. Matturro, G.: *Pivoting in software startups. Motivations, process, and evaluation*, 26 Congreso Iberoamericano de Ingeniería de Software (CIbSE 2022), 2022.

Table 7: Papers published in journal and conference proceedings

6 Discussion

The undergraduate research program in software engineering presented in this paper allows undergraduate students to carry out their capstone project in one of the modalities of software development projects, entrepreneurial projects, or research projects.

Since the Systems Engineering and Information Systems undergraduate programs offered by the School of Engineering have a strong emphasis on software engineering and software development, during their studies students carry out several projects that involve the design, development, and maintenance of software. On the other hand, most students of those careers are also working in the software and IT industry at the same time they are pursuing their degree.

This is the reason why a significant number of students choose the 'research' mode for their final project, expressing 'Not to do another development project' or 'The mode is compatible with my current working activity' as the main reasons (34.5% of respondents to the survey, Table 3), but they also mention a desire to learn how to research or delve into a topic of personal interest (62% of respondents).

However, the topic and the research problem posed for their research projects also play a relevant role when deciding on this type of capstone project, as indicated by 86.2% of the survey respondents (Table 4). Steps 2, 3, and 4 of the undergraduate research process presented in Table 2 have an important bearing on this decision factor.

Thus, the two main reasons for choosing the research mode are: (i) being able to do something different from "another" software development project and (ii) having a challenging and interesting problem to research. This is the answer to RQ1.

Regarding RQ2 (student's perception of improvement in certain skills), the undergraduate research program allows students to do "real" research on relevant topics of software engineering and to apply methodological designs and research methods used in the discipline, such as case study, survey, observation, and research interviews. Steps 7 to 11 of the undergraduate research process let students to have some control on the research planning and execution, with the senior researcher acting as an advisor and giving orientation and feedback.

In terms of the Healey and Jenkins model explained in section I, the "students as participants" mode of engaging students in research allow them to learn or develop skills other than hard research skills, such as the ones shown in Table 5. Even though these skills are acquired in research projects, in fact they are examples of what are considered soft skills. In a recent study aimed to identify the most relevant soft skills for the practice of software engineering (Matturro, 19), communication skills (present results effectively, write a technical report), analytical skills (read and interpret technical literature, collect, and analyse data), and organization/planning skills (plan and control a research project) are among the top five most relevant soft skills.

Thus, skills gain in these research projects are useful not only for doing research in academic or industrial settings, but also for the professional practice of software engineering; that is, for the development, operation, and maintenance of software systems.

RQ3 was about the student's perception, after completing the project, of the expected usefulness of their participation in undergraduate research projects for their present and future professional and working life.

From the answers received for the first of the two questions in the survey regarding this research question, only half of the respondents actually perceived some personal usefulness of that participation.

Research in software engineering is more common in academia than in industry. The possibility that graduates and working undergraduate students can apply hard research skills (conducting experiments, case studies, surveys, etc.) in their companies depends on the research and development policies of the organizations themselves, and on the role that the graduate performs in those organizations.

However, all except one of the respondents consider that participating in a research project better prepared them for their future professional and working life; maybe not because they expect to do research in an industrial setting in the near future, but for the certainty of using the skills learned or developed during the projects that, as previously discussed, are also useful for the general practice of software engineering.

7 Learnings and good practices

Based on the seven-year experience of the software engineering undergraduate research program described in Section 3, what follows are some brief learnings and good practices associated with each step of the process model presented in Table 3.

7.1 Pre-project phase

1. Since undergraduates are often unaware of the possibility of participating in research as part of their capstone project, informing soon-to-graduate students about past and ongoing projects helps pique their interest and curiosity. This encourages students with an interest in research to approach a research group to explore this option for their capstone project.

2. To participate in a research project requires a different mindset than just "attending another course" to complete the curriculum. In this sense, clearly explaining what a research project is, what it implies regarding the work ahead, and the required level of commitment and engagement to do a good job is essential for students to better decide on this mode of capstone project.

3. Students need to feel that they will be "part of" the serious research efforts taking place in the department, laboratory, or academic unit, and understand where their work fits in as a continuation of research projects that have already been completed, but in a predefined line of investigation. It is desirable that the research topics are related to professional practice, at least in the discipline of software engineering (as is in our case).

4. Co-writing the research proposal helps students develop a sense of ownership of the project while helping them to "begin with the topic," understand the stated goals, and the work to be done to achieve those goals.

5. The experience the senior researcher has in conducting research is relevant in setting the project scope in terms of expected results within the time frame students

must complete the project and the number of students that will work together in a team. This is a very sensitive step because a too limited or a too big scope in terms of work to do and expected results can have undesired consequences on the student's dissertation. Some characteristics to take into account are: a) being well structured, b) being achievable in the time frame, c) using techniques common to the discipline (software engineering, in this case), and d) in the best case, using a single technique or two (case study or survey and interviews, for example).

6. Although students will learn to research throughout the project, an overview of the whole research process will let them understand the main tasks to do and what to expect from them. A brief workshop to introduce students to the primary theoretical, conceptual, and methodological ideas, and to teach the technical skills and methods of conducting research in the discipline.

7.2 In-project phase

7. The step 6 above also prepares students to actively participate in planning the project. When developing a research schedule, consider students time commitments outside of the research project. Many students may have work or family obligations that make scheduling research difficult.

8. At the beginning of project execution, it is a good thing to reinforce the roles the students and the senior researcher will perform during the project, the frequency of meetings to discuss progress and difficulties, and to define communication channels.

9. Establishing a schedule for regular meetings helps students to set timelines and deadlines. During those meetings, encourage students to ask questions and give them constructive feedback. Clear expectations of work to be done between meetings also help facilitate productivity and commitment to the work to be done.

10. Make it clear to students that writing the research report is part of the research project, and that it is something that can (should) be done during the execution of the project and not at the end. Writing the thesis document following the "academic style" is a difficult and new task for students, so giving advice on how to do it and periodically reviewing the writing helps them "learn to write" and progress in this task.

11. Encourage students to share their progress and findings and provide guidance on how to do so effectively in oral or poster presentations. Attending seminars with other senior researchers and with students from other projects "forces" them to reflect on their work and to accept criticism and suggestions, as well as to argue in favour of their work.

12. Before thesis submission for evaluation, a joint review of its structure and contents helps students to find ways to improve their writing and to better present their main contributions, and to make clear to what extent they have achieved the project objectives.

7.3 Post-project

13. Presenting and defending the dissertation before an evaluation committee is somewhat intimidating for undergraduate students. It is important to accompany the students in the preparation of their defence, giving guidelines on how to organize the presentation, decide what to include and in what order, and consider the time established for the presentation and for the questions that the members of the committee may ask. Practicing the presentation and asking "hard" questions while pretending to be a committee member helps students gain confidence in defending their work.

14. Although writing a research paper is not usually within the scope a of project, dissemination of results completes the research cycle, increases awareness of the work, and ensures the findings are shared outside the research group, laboratory, or department.

8 Conclusions

The undergraduate research program in software engineering at the School of Engineering of Universidad ORT Uruguay began in 2015 and to date, 20 projects have been executed and 34 students have participated in them. The program takes the "students as participants" approach and allows students, with the guidance of a senior researcher mentor, to a) complete a capstone project in 'research' mode, learning by doing how to do research on topics of interest in software engineering, and b) acquire or develop certain skills that they will find useful in their future professional and working life in the software industry.

In this sense, and according to Camacho (2018), mentoring as a learning alliance offers students specific contributions that are tangible as benefits, such as: greater clarity on the topics covered, greater preparation to strengthen their skills or carry out specific activities, and having received guidance on specific projects.

The 14 steps of the undergraduate research process lead students through the entire research process on the topic and problem raised by the tutor. In all cases, these are authentic research projects that generate new knowledge in the discipline, and half of the completed projects have achieved the publication of results in a peer-reviewed journal and in several refereed conferences.

9 Study limitations and future directions of the program

As explained in section 4, the evaluation was carried out by using a data collection instrument built based on two well-known and validated instruments such as SURE and USMORE-SS. Both are examples of self-administered survey instruments to collect data regarding the experience of undergraduate students in participating in research projects; in particular, their perceptions of skills gains.

Like the aforementioned instruments, we applied our survey as a post-test only, this being a limitation in terms of knowing in depth the gains in skills mentioned by the students. Applying a post-test-only self-administered survey has two limitations. First, answering a self-administered survey can conduct in response bias; for example, answering questions in the direction the respondent perceives to be desired by the investigator (e.g., faking good). Second, applying the survey as a post-test only does not allow to determine the magnitude of the skills gains or if they were influenced by other variables. For example, while participating in research projects, some students also attend other courses in which they could have to read scientific literature or present results. In these cases, the gains reported in those skills could have been influenced by these activities external to the research project itself.

Since the undergraduate research program is now well established, with a continuous flow of students willing to participate in it and with several and interesting software engineering topics that deserve investigation, we are now in position to implement changes on how to evaluate it, both in terms of results and of its internal workings.

In the first place, and starting on March 2023, we are going to add a pre-test instrument, as suggested by McDevitt et al. (McDevitt, 16). This will require changes to the current data collection instrument, and perhaps the adoption and adaptation of some other instrument such as URSAA (Weston, 15).

Second, more insights are needed to understand and evaluate the internal dynamics of each research project in terms of students' activities and participation, and also in their relation to the other research projects and the research community.

To achieve this, it is necessary to place the research projects and the program as a whole in a more comprehensive theoretical framework that allows, for example, knowing the ins and outs of participating in an undergraduate research project, the collective construction of knowledge by the project team (students and mentor or senior researcher), and the coordination and division of tasks among team members (search and read scientific literature, collect data, prepare data for analysis, write research report and, in some cases, write a research paper), among other aspects of interest. One such framework is known as Cultural-Historical Activity Theory (Cong-Lem, 22).

As described by Qureshi (Qureshi, 21), Cultural-Historical Activity Theory (CHAT) is a social theory which is useful as a methodological framework for the task of studying practice-based learning in complex learning environments. A complex learning environment can be defined as situations in natural settings where multiple individuals are involved in shared activities within a single or multi-organizational context (Yamagata-Lynch, 10).

To apply CHAT to better assess different dimensions of an undergraduate research experience, McDevitt et al. (McDevitt, 20) have proposed a series of useful guidelines in the form of questions for characterizing the CHAT components (subject, object, rules, tools, community, division of labour, and outcome) and practical recommendations for rating the quality of collected data. As noted by these authors, properly applying CHAT requires knowledge and familiarity with theory and literature, as well as clear definition of objectives that translate into meaningful research questions. However, it is well worth the effort to identify opportunities to enhance the undergraduate experience and to make the program grow and last.

Finally, other short-term and tactical changes include a) preparation of posters for better dissemination of projects results, b) develop further academic writing capabilities to increase publications in high-quality journals, and c) carry out research projects in conjunction with companies in the software industry.

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