Proceedings of the 2019 Winter Simulation Conference
N. Mustafee, K.-H.G. Bae, S. Lazarova-Molnar, M. Rabe, C. Szabo, P. Haas, and Y.-J. Son, eds.

SIMULATION EDUCATION: A SURVEY OF FACULTY AND PRACTITIONERS

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ABSTRACT

This paper aims to raise current simulation teaching practices and identify the challenges and opportunities for improvement in simulation education. A survey was carried out with authors and chairs of Simulation Education tracks of the Winter Simulation Conference editions from 2000 to 2017. The results highlighted the primary practices, difficulties, and opportunities for improvement, raised by professionals that currently teach or used to teach simulation in undergraduate courses in engineering, computer science, and business administration, among others. Two issues highlighted in the survey are the balance between theory and practice, and the role of simulation projects as a tool to consolidate the learning process in simulation education. We found that professors value simulation projects in the discipline and the importance of working with real-world problems. Finally, the present survey identified a concern within the academic community in discussing and improving the process of teaching and learning simulation.

1 INTRODUCTION

Computer simulation has become an essential technology for professionals involved with Operations Management. According to Sargent (2017), simulation ceased to be a “brute force” or “last resort” solution, as it was called in the early days, to become the “first option” in solving complex problems, gaining recognition among academics and practitioners.

This evolution can be attributed to technological development and methodological advances, resulting in a large number of successful simulation projects applied to real-world problems. Through validated computational models, specialists can test different alternatives for the configuration of operating systems, either designing a new system or improving one already in operation.

Jahangirian et al. (2010), Tako and Robinson (2012), Negahban and Smith (2014), and Negahban and Yilmaz (2014) demonstrate the great potential of applying the different simulation paradigms (Discrete Event Simulation - DES, Agent-based Simulation - ABS, Monte Carlo Simulation - MCS, among others) in different areas (manufacturing, logistics, healthcare, defense, marketing research, etc.). Jeon and Kim (2016) present a more specific review of simulation applications in production planning and control.

In order to fulfill the potential of computer simulation, it is necessary to ensure that its learning in undergraduate courses (engineering, computer science, business administration, among others) is effective. Greenwood and Beaverstock (2011) also emphasize the importance of a good education for the advancement of this body of knowledge and point out seven reasons for the change in simulation teaching.

A recurrent issue in simulation education is the balance between theory and practice (Altiok et al. 2001). The theory is predominantly associated with the fundamentals of probability and statistics, both for the understanding of the processes under study and for the analysis of data and outputs of the simulation models.

The practice is often limited to the learning of commercial simulation software, neglecting the most relevant aspects of simulation project management.

To develop the skills required for the simulation professional, undergraduate courses should provide, in addition to theoretical knowledge, the development of modeling, programming, data analysis, problem-solving, teamwork and communication skills (Robinson and Davies 2010). These skills are demanded in professional projects that have multiple steps such as project plan, data collection, conceptual modeling, software implementation, verification and validation, design and analysis of experiments, documentation, and action plan (Banks et al. 2014).

In general, concerning the teaching and learning process in undergraduate courses, we can observe the dissemination of more participatory teaching methods in an approach called "Active Learning" (Zepke and Leach 2010). These methods, which also benefit from the development of Information and Communication Technology (ICT), seek more significant involvement of students, reserving to the professor the role of facilitator of the learning process.

Among the Active Learning techniques, Project-based Learning (PBL) stands out. This method consists in proposing a problem or question for students to seek or develop solutions, preferably in groups, supported by professors and with access to different resources (books, videos, blogs, etc.) (Kolmos and Graaff 2014).

In the specific case of simulation education, some authors emphasize the importance of practical activities as a way to consolidate the concepts and methods learned throughout the course. Although some authors do not use the term PBL, it is observed that many cases reported in the literature are similar to the Active Learning paradigm or, more specifically, Project-based Learning.

In addition to the issue of the balance between theory and practice, other factors impose challenges to the teaching of simulation, such as student motivation and educational background, modeling and systems analysis skills, limited time for teaching, difficulties to update teaching materials and other resources, as well as difficult access to teaching cases.

Most papers on simulation education focus on discrete event simulation (DES). For example, Padilla et al. (2016) propose the use of games for teaching DES as a way to motivate students, Sanders et al. (2016) discuss the application of the PBL methodology in teaching DES and Mesquita et al. (2017) investigate how the use of teaching cases can contribute to the motivation and consolidation of learning of DES.

On the other hand, Macal and North (2013) specifically discuss the teaching of Agent-based Simulation (ABS), sharing experiences in teaching this simulation paradigm that, although less disseminated than DES in undergraduate courses, has been gaining ground in the field of computer simulation. Lastly, other works, such as Saltzman and Roeder (2014) and Jain (2014), deal with the teaching of simulation in business schools, concluding that such courses focus on the practical application of simulation rather than the development of more elaborate computational models.

This work aims to investigate current simulation teaching practices in undergraduate courses, including courses in engineering, computer science, and business administration. Also, we intend to respond to the following research questions:

(RQ1) What are the challenges faced in simulation education?
(RQ2) What are the opportunities for improvement in simulation education?
(RQ3) How can the "practical project" be explored for more meaningful learning?

To answer these questions, this paper presents a survey made with simulation professors and practitioners. To reach this audience, we listed the authors of articles published in the education tracks of the Winter Simulation Conference (WSC), an important forum for the discussion of simulation education (e.g., Jacobson et al. 1994; Altiok et al. 2001; Freimer et al. 2004; Smith et al. 2017).

This article is structured in five sections as follows: the first section presents the motivation and the research questions; the second details the survey methodology; the results and discussions are, respectively, in the third and fourth sections; the last section concludes the paper, pointing out its limitations and directions for future research.

2 METHODOLOGY

This survey aims to identify current simulation teaching practices in undergraduate courses. To reach this goal, research was carried out with the authors and chairs of Simulation Education tracks of the Winter Simulation Conference editions from 2000 to 2017.

We prepared a questionnaire in three different versions. The first version is intended for professionals who currently teach simulation in undergraduate courses (Group 1), the second is for those who used to teach the discipline (Group 2), and the third is for those who have never taught the discipline (Group 3). The three versions are very similar, with small adaptations to the profile of the respondents.

The questionnaire is divided into four parts. The first part identifies the respondent (name, e-mail, institution, department, and country) and his or her current condition (professional that teaches simulation classes, professional that used to teach simulation classes, professional that never taught simulation classes). The second part characterizes the simulation discipline, collecting information such as duration, number of students, syllabus, and prerequisites. The third part raises the practices and resources used, questioning how the students are assessed, the balance between theory and practice, if there are simulation projects in the discipline and, if so, their characteristics. Finally, the questionnaire closes with three open-ended questions; the first two refer directly to the research questions, asking the respondent about the challenges and opportunities for improvement in simulation education, and the third allows the respondent to make comments, critiques, and suggestions regarding the survey.

After finishing the first version, we sent the questionnaire to three professors to evaluate the clarity of the questions and their consistency with the objectives of our research. Their suggestions were considered in the review of the questionnaire, resulting in a final version with 18 questions (see Appendix A). Not all questions are applied to all participants. More precisely, Question 2 does not apply to Group 3 and Questions 4, 5, 12, and 14 do not apply to Groups 2 and 3. The questionnaire was implemented using the Google Forms tool, considering its friendly interface, ease of sending the survey, a good database for the responses, and the fact that it is free.

The authors' e-mail addresses were retrieved from their articles from the Winter Simulation Conference archives. For authors who did not include this information, their e-mails were searched on their institution webpage. If a contact was not found, the author was discarded from the respondent list. In the end, 295 e-mail addresses were listed, from 160 different universities, institutions, and companies.

Of the 295 e-mails sent, 80 (27.1%) were not found and returned error messages. A new search was made looking for alternative e-mails, and 32 new e-mail addresses were found, to which the questionnaire was submitted again. Of these, four returned error messages and were discarded. Thus, in the end, questionnaires were sent to a list of 243 e-mails.

After the first submission, two reminders were sent, the first one ten days after the initial submission and the second one twenty days after the initial submission. Following the answers, an acknowledgment was sent to the respondents by e-mail. In the next sections, we present and discuss the results of the survey.

3 RESULTS

The questionnaire was answered by 51 professionals. Of these, 38 were part of the original mailing list (243 questionnaires sent), 12 were not in the list, and one did not identify himself. Although the responses of all the respondents are consistent, in the analysis that follows, we will consider only the 38 respondents who presented papers on simulation education at the WSC, as defined in the research method.

The survey had validated responses from professionals from 29 different Universities and 2 companies. The majority of respondents were from the United States (39.5%), Brazil (23.7%), and the United Kingdom (10.5%). Table 1 shows the distribution of respondents by continent.

Figures 1 to 18 present the answers to the multiple-choice questions, each containing six questions. From Question 1 (Figure 1), it is seen that the majority of the respondents are professors who teach or used to teach Simulation in undergraduate courses (81.6%). This result was expected since the target audience of the survey were authors from Simulation Education track of the Winter Simulation Conference.

Table 1: Distribution of respondents across the regions.

Region	Frequency	Percentage
North America	17	44.7%
Europe	10	26.3%
South America	9	23.7%
Asia	1	2.6%
Africa	1	2.6%
Total	38	100.0%

The time of experience with simulation teaching varies greatly (Figure 2), ranging from professors with less than five (25.8%) to professors with more than thirty years of experience (22.6%). This experience is mainly related to teaching in Engineering (76.3%), Business Administration (10.5%) and Mathematics and Computer Science (10.5%) undergraduate courses, as shown in Figure 3.

Questions 4 and 5 deal with the number of hours and the number of students per class, respectively. As shown in Figures 4 and 5, the standard for the simulation disciplines is the number of hours between 45 and 60 hours and classes of 20 to 40 students. Question 8 (Figure 8) shows the discipline importance in the curriculum according to the respondents, with 81.6% considering it very or extremely important.

On the syllabus (Figure 6), we verified the predominance of the Discrete-Event Simulation paradigm (100%) when compared to Agent-based Simulation (26.3%) and System Dynamics Simulation (23.7%). Another much-mentioned topic was the Simulation Methodology (97.4%), which concerns the management of simulation projects. Also noteworthy is the simulation-based optimization (55.3%), which can be considered a more advanced topic in simulation.

Among those surveyed, 78.9% cited Statistics and 60.5% Probability as disciplines that are or should be prerequisites for the Simulation discipline. A little less cited are the Computer Programming and Operational Research disciplines (Figure 7). Regardless of whether or not these disciplines are required, the deficiency of student knowledge and skills in these topics is pointed out in the open questions as a complicating factor for simulation teaching.

Questions 9 and 10 deal with resources for simulation teaching. Figure 9 shows some consensus about the use of publications, computers, and software. A little lower in the ranking comes the teaching assistant. Figure 10 shows a variety of options for choosing simulation software. In the software issue, the choice of some respondents for the use of free software is highlighted, as well as the recurrent presence of the spreadsheet, which, although not properly a simulation software, is a valuable tool both for teaching and for professional use in simulation projects.

We asked the professionals that currently teach simulation if the discipline provides a practical simulation project. Of the respondents, only one responded that his discipline did not offer practical projects, but that it should (Figure 12). The importance of the practical simulation projects for the teaching-learning process is also evident in Question 11 (Figure 11), where only one respondent indicated it as only somewhat important.

Question 12, which also deals with simulation projects, was broken down into four questions (Figures 13-16). The first one (Figure 13) shows that the dominant practice is the teamwork, with only 7.9% of respondents pointing out that the project should be exclusively an individual activity. The second (Figure 14) evaluated the nature of the projects, that is, whether they are based on teaching cases (44.7%) or real problems (52.6%). The third one (Figure 15) reveals how the projects are assessed, the standard practice being the assessment based on report and presentation (73.7%). The fourth question (Figure 16), addressed only to the active professors of the discipline, attempts to evaluate the importance of the practical projects for the learning of project management, more specifically, of the phases of simulation projects as defined by (Banks et al. 2010). The phases received close average scores ranging from 3.4 (Model implementation) to 2.6 (Design and Analysis of Experiments).

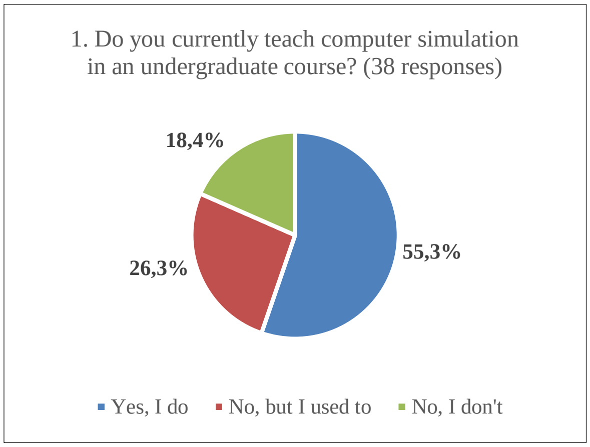

Figure 1: Answers to Question 1.

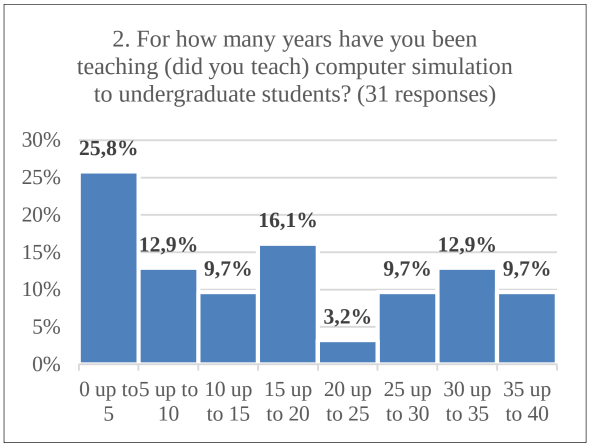

Figure 2: Answers to Question 2.

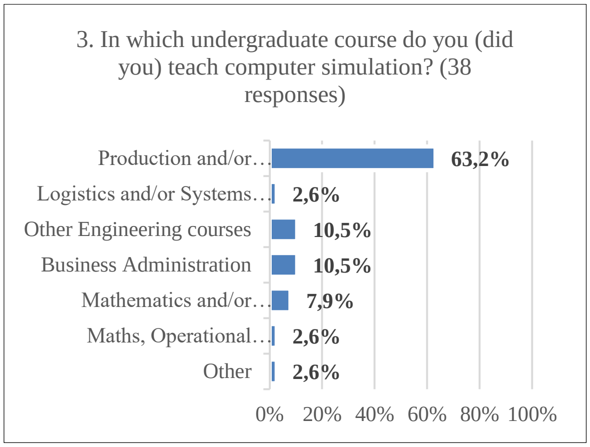

Figure 3: Answers to Question 3.

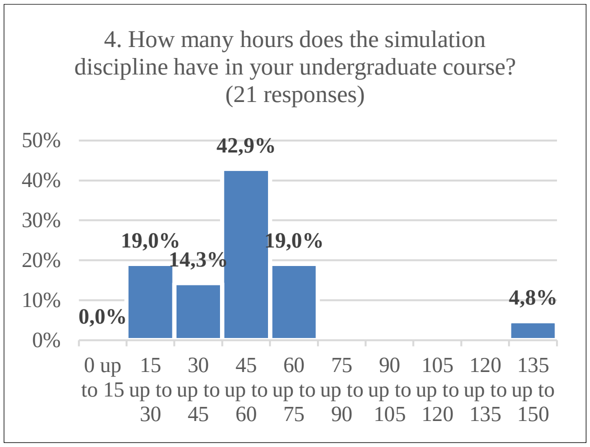

Figure 4: Answers to Question 4.

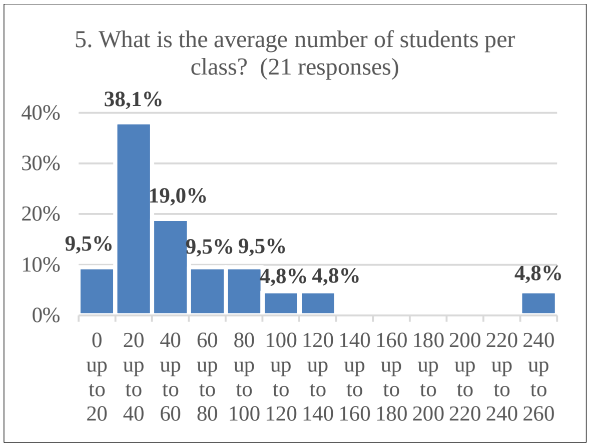

Figure 5: Answers to Question 5.

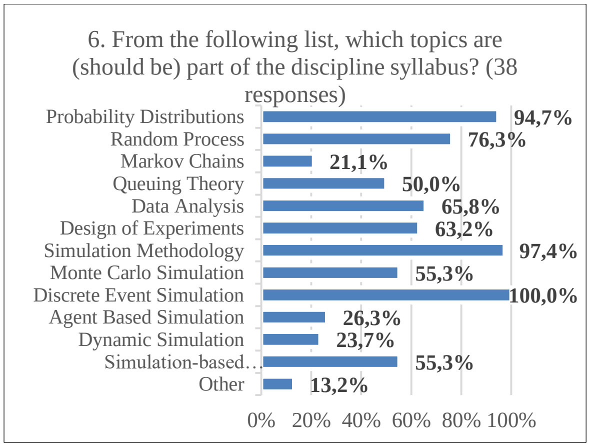

Figure 6: Answers to Question 6.

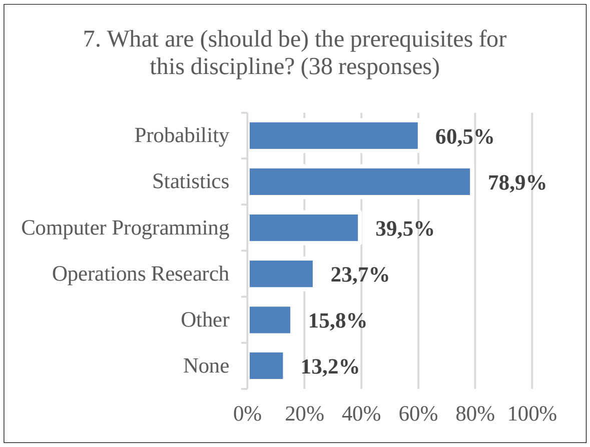

Figure 7: Answers to Question 7.

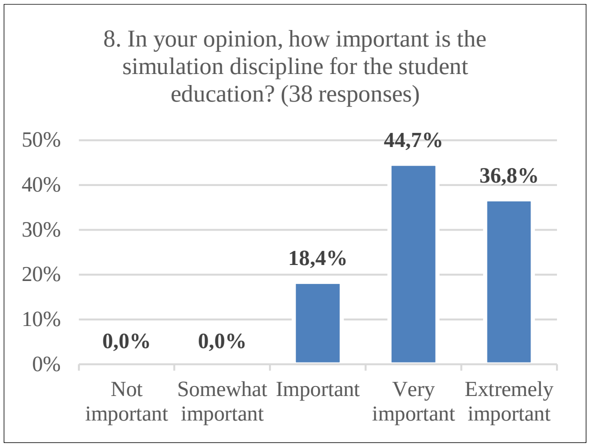

Figure 8: Answers to Question 8.

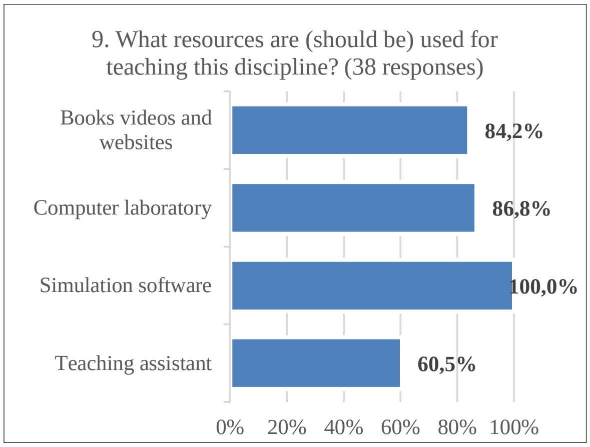

Figure 9: Answers to Question 9.

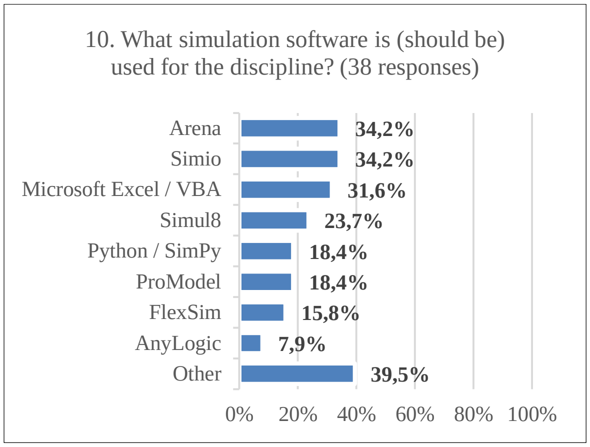

Figure 10: Answers to Question 10.

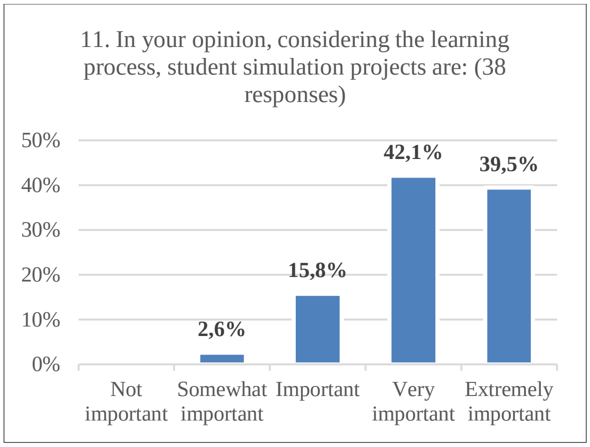

Figure 11: Answers to Question 11.

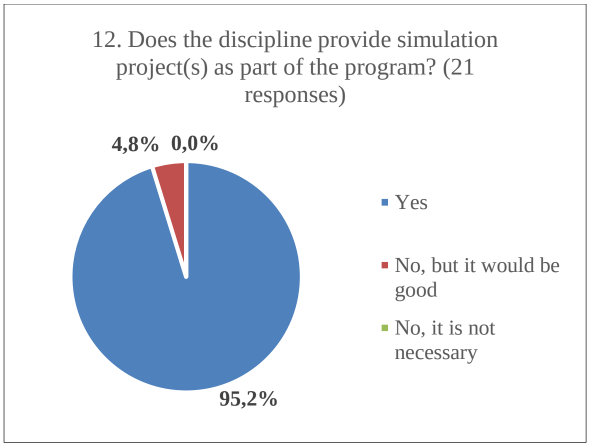

Figure 12: Answers to Question 12.

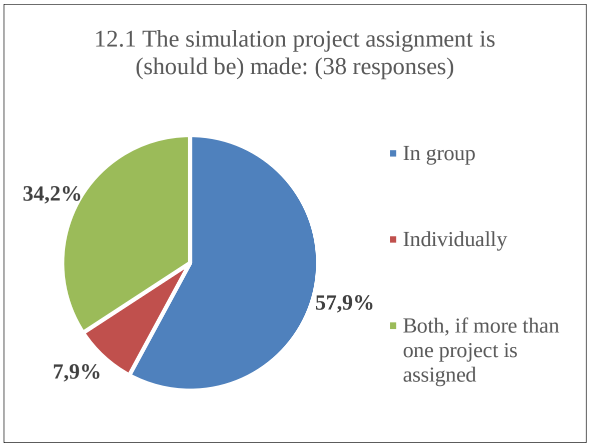

Figure 13: Answers to Question 12.1.

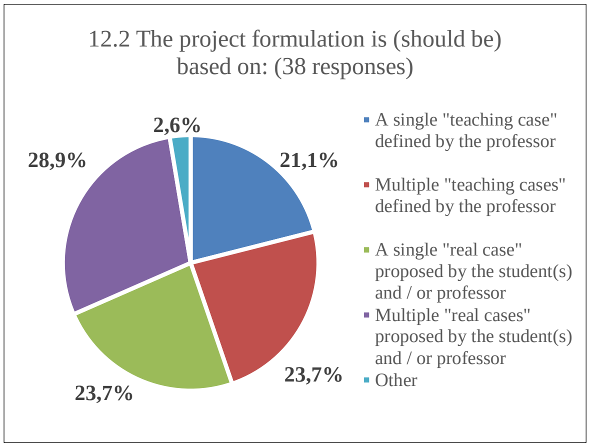

Figure 14: Answers to Question 12.2.

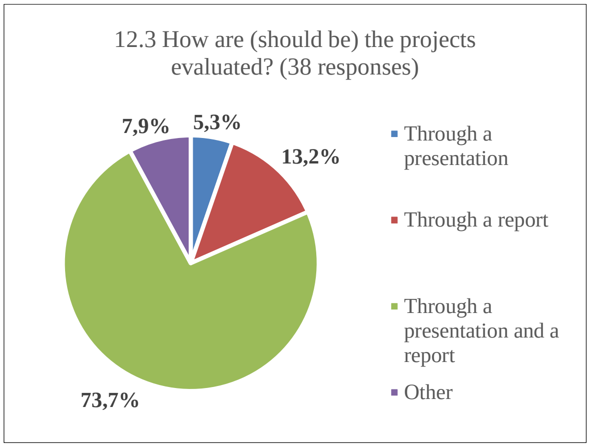

Figure 15: Answers to Question 12.3.

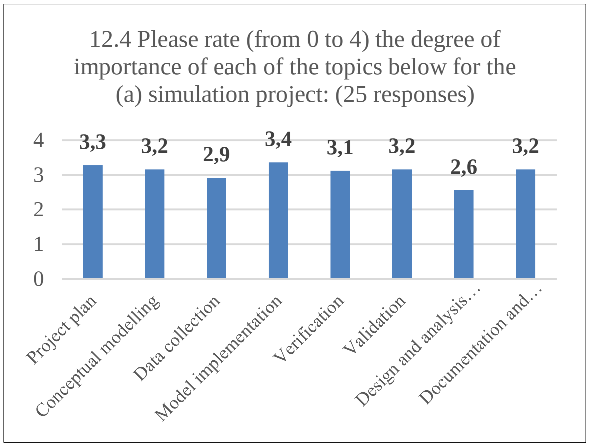

Figure 16: Answers to Question 12.4.

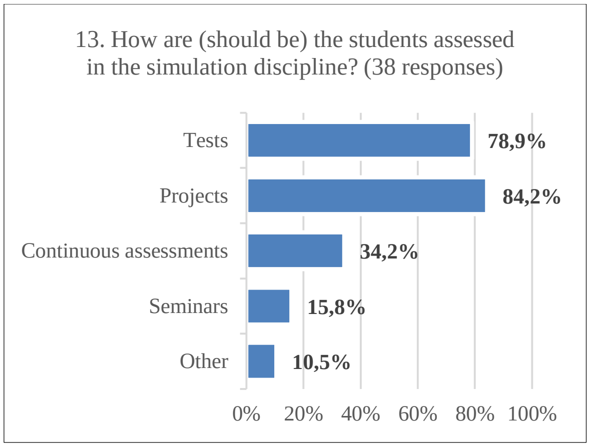

Figure 17: Answers to Question 13.

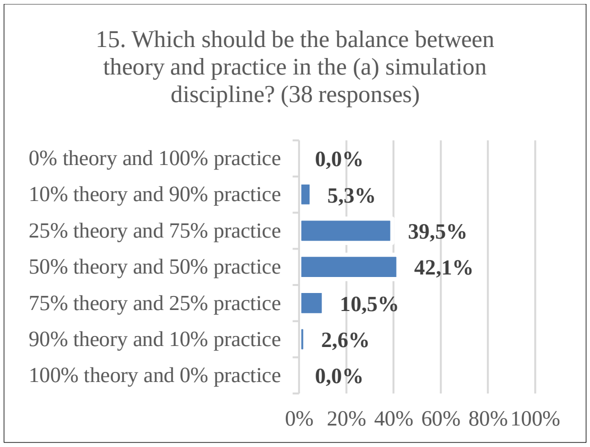

Figure 18: Answers to Question 15.

Question 13 asked the participants about how students are or should be assessed in the discipline. Figure 17 shows a combination of projects (84.2% of the respondents) and tests (78.9%) as the standard mode of evaluation, with some citations to continuous assessments and seminars.

Lastly, in Questions 14 and 15 regarding the balance between theory and practice, there was an alignment between what is practiced by active professors (Question 14) and what all respondents consider the ideal balance (Question 15). Due to space limitations, we present only the answers to Question 15 (Figure 18), that deals with the expectation of all about this question. For most respondents, the distribution should be of "50% theory and 50% practice" (42.1%) or "25% theory and 75% practice" (39.5%).

The results from the multiple choice questions above give the reader a good insight of the practices of professionals that currently teach or used to teach simulation in undergraduate courses in engineering, computer science, and business administration. In the following section, we return to the research questions, which will be analyzed in light of the answers to the open questions of the questionnaire and based on the revised literature.

4 DISCUSSION

Among the three open-ended questions at the end of the questionnaire, the first two deal directly with the first two research questions of the present study, i.e., what are the difficulties and opportunities for improvement in simulation teaching. The third one is a free space for criticism and suggestions of the respondents.

(RQ1) What are the challenges faced in simulation education?

All respondents answered this question. The responses were analyzed and classified to identify similarities (Figure 19). The percentages do not add up to 100%, as some respondents pointed out more than one difficulty.

The category "teaching topics" refers to the inherent difficulties of teaching topics such as modeling, simulation methodology, statistical analysis, and simulation software. Reports in the literature reinforce these results, as Hoad and Kunc (2018), in the context of teaching the System Dynamics Simulation and Discrete Event Simulation paradigms; Macal and North (2013), in the context of ABS paradigm teaching; and, Saltzman and Roeder (2013), in the context of simulation teaching in business schools.

The second class ("student background") refers to the limitations of students' background knowledge and skills, especially in statistics and computer programming (typically prerequisite subjects), and was pointed out as a challenge by 21.1% of the respondents. However, in investigating the background effect on student performance, Robinson and Davies (2010) conclude that, depending on the degree of complexity of the activities proposed in the course, this effect may not be noticeable.

In the category "resources", there are difficulties regarding the availability of computers, software, and teaching cases. The respondents also pointed out the motivation of the students and large classes as challenges. The "theory and practice" class refers to the problem of balancing theory and practice within the discipline. Finally, with a single quotation each, they mentioned the establishment of "partnerships" with companies, the difficulty of supervising projects in large classes and the need for the practical experience of the professor in simulation.

(*RQ2) What are the opportunities for improvement in simulation education?*

This question was answered by 37 out of 38 respondents. Figure 20 presents a classification of the responses. Once again, the percentages do not add up to 100%, as some respondents pointed out more than one difficulty.

In the first category ("teaching topics"), respondents pointed to the need for a greater emphasis on teaching conceptual modeling, to accelerate the learning of the simulation software, and to address less explored topics such as systems theory and simulation and optimization. Two other related points are the recommendation to work with real problems and to spend more time with practical content ("real world problems" and "more practice"). Aligned to these points is again the recommendation to seek partnerships with companies to bring real problems to the classroom ("partnership"). Freimer et al. (2004) point out that the opportunity for future student recruitment would be an additional motivation for these partnerships.

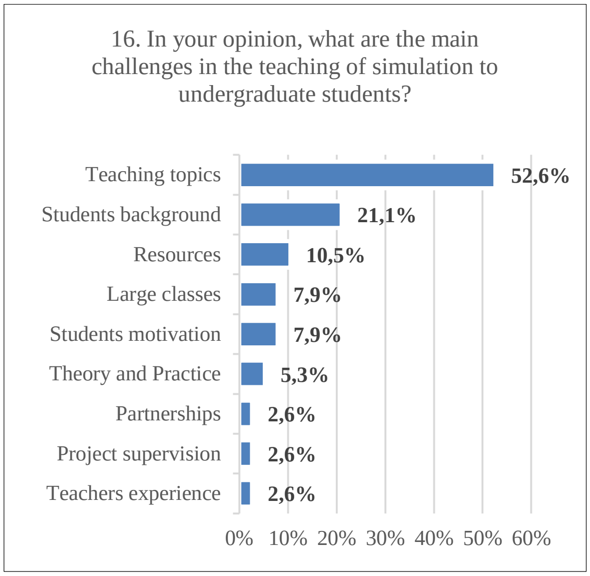

Figure 19: Answers to Question 16.

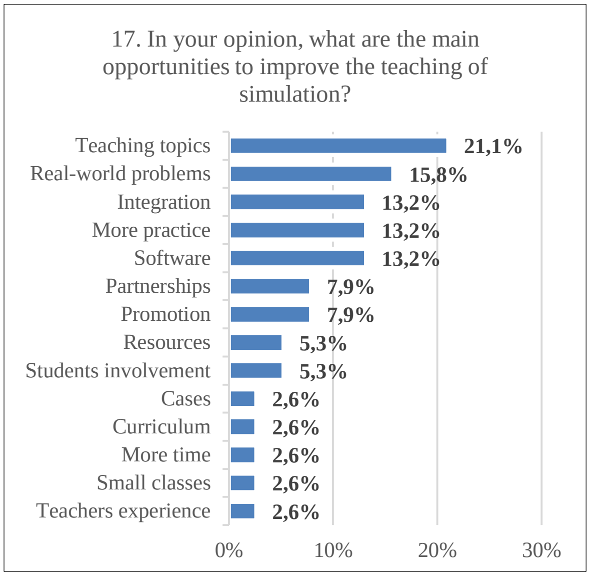

Figure 20: Answers to Question 17.

On the pedagogical side, there are opportunities for integration of the discipline with others of the curriculum ("integration"), of increasing the hours of the discipline ("more time") and of seeking greater involvement of students in the learning process ("involvement"). As for software, some respondents indicate the use of free software, which, in addition to the lower cost, provides a better understanding of the logic of simulation models (in the sense pointed out by Schriber et al. 2015) and the possibility of students continuing to use it after graduation (Altiok et al. 2001). Finally, other points cited include updated resources, good teaching cases, smaller classes, and teachers training as opportunities for improvement.

(RQ3) How can the "practical project" be explored for more meaningful learning?

A particular concern among simulation teachers in undergraduate courses is that the discipline, in addition to theoretical knowledge, should provide the development of the skills for the practical application, that is, that graduates can conduct projects for the design or improvement of operating systems based on computational modeling and simulation. Standridge (2000) shows positive results with the application of Active Learning and Case Studies in introductory courses of DES for industrial engineering students.

As seen before, Questions 11 and 12 (13 to 16) deal with the students' practical project. From the answers, one can conclude that this activity, preferably performed in a group, should be mandatory in undergraduate courses. The nature of the project can be based on actual cases or didactic cases idealized by the professor, and the project should, as far as possible, cover all stages of the simulation project methodology. As emphasized in Freimer et al. (2004), teamwork favors learning by allowing students to collaborate.

In the open questions, besides the strong recommendation to bring "real world problems" to the discipline, some comments were made about the importance of the practical project both for consolidation of the learning process and for the development of problem-solving skills and teamwork. Robinson and Davies (2010), Macal and North (2013), and Hoad and Kunc (2018) explore the simulation project as an opportunity to assess the knowledge and skills acquired by students throughout the course.

The questionnaire also had a final open question for comments and suggestions. Answers can be divided roughly into three equal parts. One-third made positive comments on the survey and its relevance, another third made comments reinforcing views expressed in Questions 16 and 17, and the remaining third did not add new comments.

5 CONCLUSIONS

This work is an exploratory research that had the objective of mapping the current practices of simulation teaching, identifying difficulties and opportunities for improvement in the context of undergraduate courses. Because the survey is a non-random sampling, the results obtained cannot be generalized. However, since the respondents were a select group of teacher-authors, with works published in the simulation education field, it is fair to assume that the practices pointed out in this survey are close to the current best practices in simulation teaching.

The paper pointed out the main difficulties (RQ1) faced by professors, whether new or experienced, in teaching undergraduate simulation courses. It also showed a concern within the academic community, aligned with the literature reviewed, to discuss and improve the teaching and learning process of the discipline, part of the field of Operational Research. Many of the difficulties pointed bring forth opportunities for improvement (RQ2), which were also explored in the previous section.

In relation to RQ3, the survey method showed that the professors effectively value the "practical project" (the simulation project of the students in the discipline) and use this practice in their disciplines. However, to answer more precisely the question of "how" to explore the potential of this activity, i.e., to identify and understand best practices, would require a study focused on successful experiences in undergraduate courses. This would be the next step of the present research, which could be conducted as a case study or even action research.

We believe that this survey, even with the inherent limitations of the research method, contributes to the discussion about simulation teaching in undergraduate courses that, as pointed out in this research, is responsible for the professional qualification and future development of this important area in the field of Operations Management.

ACKNOWLEDGMENTS

We thank the colleagues who participated in the questionnaire pre-test and all survey respondents.

A SURVEY QUESTIONS

1. Do you currently teach simulation in an undergraduate course?				
a. Yes, I do	b. No, but I used to	c. No, I don't		
2. For how many years have you been teaching computer simulation to undergraduate students?				
3. In which undergraduate course do you teach computer simulation?				
a. Production and/or Industrial Engineering	b. Logistics and/or Systems Engineering			
c. Other Engineering courses	d. Business Administration			
e. Mathematics and/or Computer Science	f. Other:			
4. How many hours does the simulation discipline have in your undergraduate course?				
5. What is the average number of students per class?				
6. From the following list, which topics are part of the discipline syllabus?				
a. Probability Distributions	b. Random Process	c. Markov Chains		
d. Queuing Theory	e. Data Analysis	f. Design of Experiments		
g. Simulation Methodology	h. Monte Carlo Simulation	i. Discrete Event Simulation		
j. Agent Based Simulation	k. Dynamic Simulation	l. Simulation-based Optimization		
m. Other:				
7. What are the prerequisites for this discipline in your undergraduate course?				
a. Probability	b. Statistics	c. Computer Programming	d. Operations Research	e. None f. Other:
8. In your opinion, how important is the simulation discipline for the student education in your program?				
a. Not important	b. Somewhat important	c. Important	d. Very important	e. Extremely important
9. What are the resources used for teaching this discipline?				
a. Books, videos and websites	b. Computer laboratory	c. Simulation software		
d. Teaching assistant	e. Other:			
10. What simulation software is used?				
a. Arena	b. ProModel	c. Simul8	d. FlexSim	e. Simio
f. AnyLogic	g. Python / SimPy	h. MS Excel / VBA	i. None	j. Other:

11. In your opinion, considering the learning process, student simulation projects are: a. Not important b. Somewhat important c. Important d. Very important e. Extremely important
12. Does the discipline provide simulation project(s) as part of the program? a. Yes b. No, but it would be good c. No, it is not necessary
12.1. The simulation project assignment is made: a. In group b. Individually c. Both, if more than one project is assigned
12.2. The project formulation is based on: a. A single "teaching case" defined by the professor b. Multiple "teaching cases" defined by the professor c. A single "real case" proposed by the student(s) and / or professor d. Multiple "real cases" proposed by the student(s) and / or professor e. Other:
12.3. How are the projects evaluated? a. Through a presentation b. Through a report c. Through a presentation and a report d. Other:
12.4. Please rate (from 0 to 4) the degree of importance of each of the topics below for the simulation project: a. Project plan (problem, objectives and scope) b. Conceptual modelling c. Data collection d. Model implementation e. Verification f. Validation g. Design and analysis of experiments h. Documentation and reporting
13. How are the students assessed in the simulation discipline? a. Tests b. Projects c. Continuous assessments d. Seminars e. Other:
14. In your simulation discipline, which do you estimate to be the actual balance between theory and practice? a. 0% theory and 100% practice b. 10% theory and 90% practice c. 25% theory and 75% practice d. 50% theory and 50% practice e. 75% theory and 25% practice f. 90% theory and 10% practice g. 100% theory and 0% practice
15. In the previous question, what would be the ideal balance between theory and practice? a. 0% theory and 100% practice b. 10% theory and 90% practice c. 25% theory and 75% practice d. 50% theory and 50% practice e. 75% theory and 25% practice f. 90% theory and 10% practice g. 100% theory and 0% practice
16. In your opinion, what are the main challenges in the teaching of simulation to undergraduate students?
17. In your opinion, what are the main opportunities to improve the teaching of simulation?
18. Feel free to make any comments, critiques and suggestions regarding this survey and the subject of simulation education.

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