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Towards a Simulation-Based Project Monitoring and Control Learning Approach

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Abstract. Software project management is a core competency for today's software engineering. However, most undergraduate software project management courses are not prepared for the new generation of software engineers. One reason is that instructors are not giving the students the tools that would enable the development of competencies to apply all knowledge areas covered by a PMBOK-based course. In particular, we are concerned with competencies related to project monitoring and control which are difficult to be put in practice in a classroom scenario. This paper presents our experiences and results in designing a software project management course including project execution simulation. This simulation gives students the opportunity to apply project monitoring and control competencies based on data provided by the project execution simulation. We have piloted the approach and observed positive perceptions towards it by a cohort of 19 students.

Keywords: Software engineering, Software project management, Software project management education. Software project simulation

1 Introduction

Software development projects are complex endeavours, and arguably, software project management competencies are necessary for Software Engineering (SE). Software project management is present in both SWEBOK [1] and ACM Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering [2]. On the other hand, students' expectation has changed in the past years. Millennials are now the majority of the undergraduate population, and they expect and demand new approaches for the university classroom [3].

At Universidad ORT Uruguay (ORT) and Universidade Federal de Santa Catarina (UFSC) a module on Software Project Management has been part of undergraduate Software Engineering, computer science and information systems curricula for over a decade. Reflecting upon our teaching practice and reviewing the available literature, we came to the realization that a key missing element in project management education was the possibility to give students opportunities to apply Project Monitoring and Control - PMC (a process required to track, review and regulate project progress and performance and identify and manage changes when needed [4]). We have observed that applying project planning – and related process areas – can be achieved through application-oriented exercises. In contrast, to give the students the opportunity to apply PMC within an undergraduate course could require the introduction of a project execution simulation approach.

As a result, we embarked on a joint effort with the objective of develop and apply a suitable strategy to enable project management students to practice PMC in both universities taking into consideration the available resources.

This paper describes how we have introduced application-oriented exercises and simulation that fulfils the requirement. We have adapted and aligned the curricula of the project management module in both universities and implemented a software tool capable of simulating the execution of the students' project plans. This approach gives students the opportunity to apply PMC in a controlled environment. A differentiating factor of this approach is that we have re-designed a PMBOK[4]-based course, with a view to adopting our simulation approach. As a result, the practical exercises can span multiple weeks throughout the semester – as opposed to one shot interventions which are currently the norm when serious games or simulations have been introduced in the literature. In order to evaluate the applicability and the perception of learning of our approach, it was applied to 19 students at UFSC. Overall, our results demonstrate positive perceptions about the proposed approach.

This paper is organized as follows. Section 2 presents the results of our literature review. Section 3 presents the methodology. Section 4, describes the development of the simulation approach, including how it is grounded in the module descriptor (section 4.1) and the technical aspects of the simulation software (section 4.2). Section 5 presents the results of our pilot implementation. Finally, section 6 presents our conclusions and future work plans.

2 Background - Simulation in Software Engineering Education

This section presents a summary of our research on the application of simulation to SE education. Dörner et al. define a "serious game" as a digital game created with the intention to entertain and to achieve at least one additional goal (e.g., learning or health). These additional goals are named characterizing goals [5]. These authors also define the concept of "educational games" to denote a subgroup of serious games, tackling the formal educational sector from elementary schools to higher education, vocational training, and collaborative workplace training. Educational games focus on formal learning in dedicated educational institutions.

Educational games and simulations have been observed in literature as excellent tools to improve the teaching-learning process because they stimulate and inspire the students, providing a more attractive and ludic way of learning, as multiple experiences have reported [6] [7] [8] [9]. On the other hand, a “simulation game” is one that attempts to copy various activities from real life in the form of a game for various purposes such as training, analysis, or prediction [10]. Well-known examples of simulation games are war games, business games, and role-play simulation.

Claufield et al. present a systematic review of the literature [11] aimed at games or simulations used for educational or training purposes in SE across any of the SWEBOK knowledge areas. The results showed that games were mainly used in the knowledge areas of SE management and development processes. The results also showed that most games in the field have learning objectives aimed at the first level of Bloom’s taxonomy (knowledge) [12].

Calderon et al. [13] introduce experiences of integrating a simulation-based serious game for software project management training (ProDeck). ProDeck aims to place the learners in a virtual organization where they can manage software projects and apply their knowledge to real-life scenarios. The achieved outcomes show positive evidence about the learners’ motivation, experience and learning acquisition with the use of ProDec.

To contribute to the student´s formation process in Software Project Management, de Souza et al. [8], presents the development and validation of an electronic board serious game named SCRUMI, whose goal is to introduce concepts of the SCRUM framework. They observed positive results and found that games in the classroom are worth exploring.

Simsoft [11] is a serious game at the center of a research project designed to see if and how games can contribute to better SE management education by helping software engineers and project managers explore some of the complexities of the field in a controlled environment.

Go for it! [14] is an educational game for contributing to teaching the ISO/IEC 29110 standard. It is designed for use in conjunction with project management education modules, and helps reinforce concepts presented in up-front teaching environments.

PMG-2D [6] is an educational serious-game that aims to assist in the training of inexperienced software project managers. The game simulates a real software development environment where the player, acting as a project manager, goes through all phases of a software project lifecycle.

DELIVER! [7] is a board game to teach the Earned Value Management (EVM) technique used for monitoring and controlling the execution of a software project. The game is intended to be used as part of a project management course, and its purpose is to reinforce EVM concepts and to exercise its application. The authors argue that the game does not substitute, but complements other instructional strategies such as, expository lessons, to be adopted beforehand to present the basic concepts of EVM.

Schoeffel proposed a simulation game named PizzaMia in a way that he called an experiential dynamics to support teaching and learning in a project management course based on the PMBOK [14]. The activity is based on planning and execution of a real meal.

As it was identified by Claufield et al. [11], we found just few references that included systematic evaluations of the results. A review [15] on the use of games-based learning within SE to identify what empirical evidence exists within this literature to support this approach. Authors found that the evaluation of the impact of the simulation-based learning approach is severely limited and in many cases non-existent. They suggest that more research needs to be carried out to evaluate the use of this approach and longitudinal studies are required in simulation-based learning within higher education. In order to evaluate the software engineering educational approaches, [16], present an example of a multi-angled evaluation that showcases the difference between the amount of insight gained through a small pilot study versus that from a more comprehensive evaluation.

Regarding evaluation of serious games, Calderon et al. [15], performed a systematic literature review to summarize the existing evidence on evaluation procedures and methods to assess serious games in different application domains. They found that the educational domain, especially the higher education, is the domain where more studies evidenced assessment experiences, followed by health and wellness, and professional training and learning. They noticed that “computer games” is the type of game that attracts more interest towards assessment. Most of the studies analyzed selected the questionnaire as the main assessment method. Petri and von Wangenheim also present a systematic literature review [9]. Their results show that most evaluations use a simple research design in which, typically, the game is used, and afterwards subjective feedback is collected via questionnaires from the learners. Most of the evaluations are run with small samples, without replication, using mostly qualitative methods for data analysis. We also observed that most studies do not use a well-defined evaluation model or method. The authors conclude that there is a need for more rigorous evaluations as well as methodological support to assist game creators and instructors to improve such games as well as to support decisions on when or how to include them within instructional units. Furthermore, in Petri et al. [14], authors present an analysis of 43 case studies that use MEEGA, a model for educational games evaluation. The analysis provides evidence that digital and non-digital games can yield a positive effect on the learning of SE, providing a pleasant and engaging experience to the students and motivate them.

3 Methodology

This proposed simulation-based project monitoring and control learning approach is been developed and applied to overcome the limitations we had identified in the previous sections, and, in particular, to give students the opportunity to apply project monitoring and control body of knowledge.

Both at ORT and UFSC, we had identified that students were not being given the opportunity to apply PMC competences. While in both universities modules of the body of knowledge for PMC was included in the syllabus, it was only being delivered at the *remember* and *understand* levels of Bloom’s taxonomy [12]. In contrast, areas associated with project planning were given at *remember*, *understand* and *apply* levels through the implementation of assigned classroom projects.

Thus, the following activities were undertaken to develop the proposed approach:

- Syllabus alignment: to align ORT and UFSC project management modules, we mapped the topics and learning outcomes for the courses. Even though both courses were based on the Project Management Body of Knowledge, they drifted in the amount of effort devoted to each knowledge area. The result of this work is presented in **Table** 1;
- Learning module piloting: we piloted the module at ORT giving more importance to the PMC knowledge areas. To achieve this, the application exercise involved the planning and management of a simple project. Students were lead to an incremental lifecycle, with three deliveries. First a plan (which should include chapters for all knowledge areas associated with PMBOK initiation and planning). Secondly, they were requested to hand in two progress reports;
- Development of the simulation software: following an incremental Use-Case centered software development approach, we have developed the first version of the project execution simulation software. This is described in section 4;
- Simulation software piloting and evaluation: we piloted the simulation software with a small cohort of students at UFSC. This is described in section 5.

Fig. 1 shows a high-level overview of the activities that we performed during 2016-2017 as a joint effort to define and apply the approach.

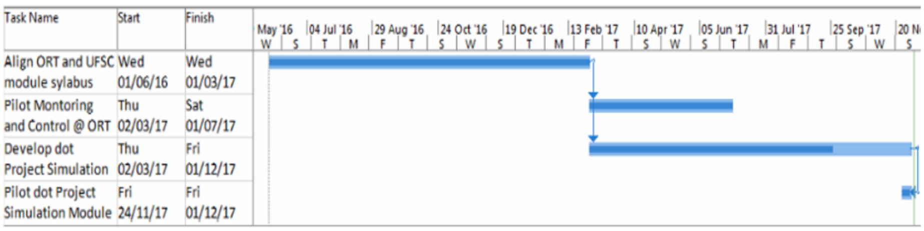


Fig. 1**.** Overview of the project plan

Thus, the two major results of the development of the approach: the teaching module and the software tool for simulation are presented in the following sections.

4 A project simulation-based approach to educate students in software project management.

The simulation-based project monitoring and control learning approach was developed to address the students' need to apply monitoring and control. In particular, the intention of this approach is to give students opportunity to apply the PMC body of knowledge.

Starting the approach development, our appraisal of the initial situation at both universities was:

- Both courses were based on the PMBOK
- Both covered most of the knowledge areas
- Both were evaluated with an application-oriented exercise and final exams.
- The application-oriented exercise involved extensive planning but required no applied execution nor monitoring and control real practices.

Thus, having this initial scenario, we decided that, to give students the opportunity to apply the processes of the monitoring and control knowledge area, one way was to change the application-oriented practical activities.

These activities include decision-making on significant deviations that may lead to corrective actions, even in the context of the time constraints of an undergraduate project management class course in which it is not possible to develop a real project, and more than half the time of the course is dedicated to the project planning. As the result, the learning plan presented in **Table** 1 was developed to achieve the pedagogical objectives defined for a one-semester 72 hours course.

Thus, we also envisioned a simulated software platform, were students would write-in their project plans, while instructors would control the execution, introducing simulated deviations from each student plan. Thereby, allowing students to apply the monitoring and control knowledge they had received during the modules.

4.1 Module delivery strategy

This section presents how we envision the module delivery. **Fig.** 2 presents an overview of the proposed approach.

Each week, a theoretical overview of project management is presented. These presentations cover the project management knowledge areas of Scope, Time, Costs, Quality, Human Resources, Communications, Risks, Acquisitions and Stakeholders, as defined in the teaching plan (see **Table** 1).

For the practical activities, the students are asked to form into groups that will make up their project teams for the duration of the module. The practical activities are presented and defined by the instructor. Then, the introduction of the software simulation enables the instructor to present case studies of real software requirements specification documents. Thereby, the breadth and scope of the practical activities are not compromised by the introduction of the monitoring and control activities (as it was the case in the pilot activity carried out at ORT described in section 3). For the practical activity, students are required to document each area of their planning in a project management tool.

We use dotProject+ [17] as the project management tool to support the approach and as the basis for the development of the project execution simulation. dotProject+ is a free project management tool that has been developed and evolved through improvements in its main features and also by the development of several plugins to support project management education [17]. These improvements in dotProject+ have expanded its functionality by supporting all processes of the PMBOK knowledge areas.

As it has been mentioned, the practical activity results in three deliveries. The first one with the project plan, and two subsequent deliveries with progress reports.

Upon the first deadline, all teams are requested to present their plan to the class and to the instructor, who evaluates the project plans for their technical quality.

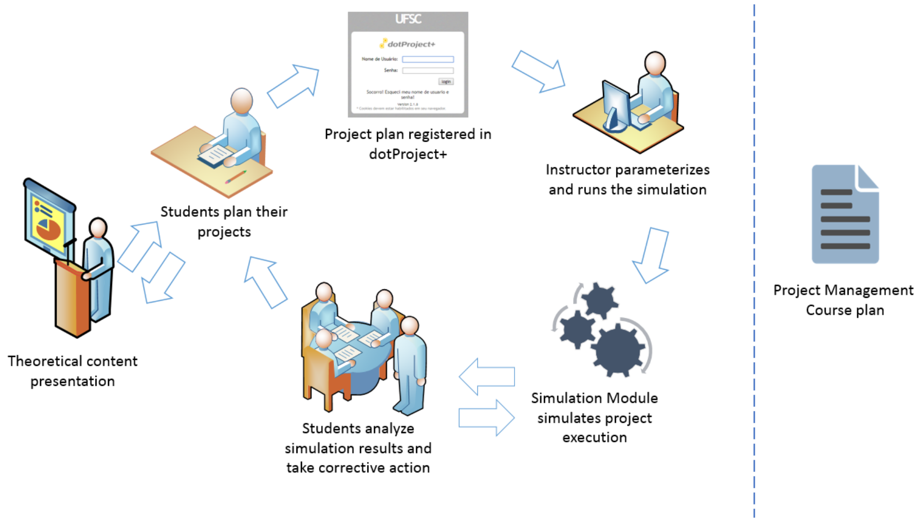


Fig. 2. Simulation-Based Project Monitoring and Control Learning Approach

The deadline for the delivery of the project plan, coincides with the presentation of the PMC concepts. Thus, the instructor parameterizes dotProject+ to allow students to start simulating the execution of their projects.

The simulation generates progress records and possible risks occurrences with its impacts in terms of effort, costs, deadlines and resource allocation. Following, the students then analyze the project status, based on the management indicators provided by the tool, such as the earned value analysis indicators. Students then decide on possible necessary corrective actions, perform them, and present it to the whole group.

For each of the next three weeks, this cycle of simulation of execution, analysis, taking of corrective actions and presentation, are repeated by the students, using the tool. Next section presents a technical overview of the dotProject+ simulation tool.

Table 1. Unified Project Management Course Plan

Subject	Learning Objectives	Module milestone
Introduction and Basic concepts	Understand project management basic concepts	
Project Initiation and Planning	Understand project initiation	Application-exercise presented to students.
Project Charter	Develop Project Charter	
Scope, WBS, and Activities	Plan scope and activities	
Resources Estimation	Estimate project resources	
Schedule	Develop project schedule	
Quality, Human Resources and Communications	Plan quality and human resources and communication	
Risk Management	Plan project risk management	
Acquisitions, Costs and budget	Plan project acquisitions, costs and budget	Deadline for project plan delivery
Project monitoring and control	Understand software project monitoring and control concepts	
Simulated project execution	Execute monitoring and control activities	Deadline progress report 1
Monitoring and control practice	Analyze project execution data and take corrective actions	
Project closure	Understand project closure concepts	Deadline final report

4.2 The dotProject+ Project Simulation: technical overview

dotProject+ has been successfully used to support the learning of project management knowledge areas [17]–[19]. One of the most important functionalities for this support is the instructional feedback to the students, which is carried out during the student's project planning (**Fig.** 3). The platform provides immediate feedback about necessary planning steps, incomplete artefacts and tips on how to better carry out each step of the planning. On the instructor's side, the tool provides support to the management of student classes, groups and teams/projects, as well as the artefacts they produce and also performing a semi-automated evaluation of the various artefacts produced, especially in relation to its completeness.

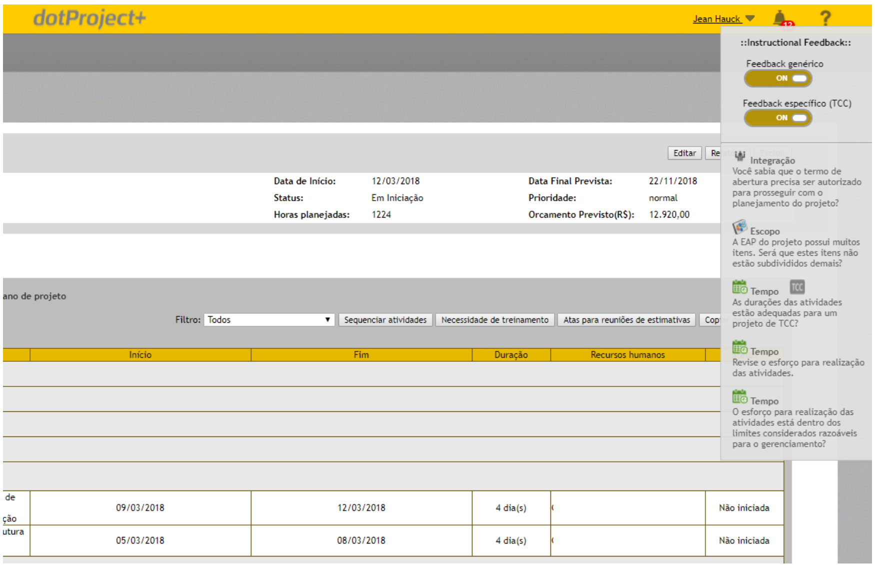


Fig. 3. dotProject+ with instructional feedback supporting Project Management learning

Thus, we decided to use dotProject+ for supporting the software Project Management course, and enhance it by developing a project simulation plugin to fulfil our learning objectives.

Based on our needs, a requirements engineering was performed following an Use-Case based analysis approach. Through this approach, two main actors were identified: Instructor and Student. As can be seen in **Fig.** 4, the Instructor can configure the simulation parameters, generate the execution of the simulation and analyze the results of the simulation. The Student can visualize the results of the project execution simulation and manage the possible corrective actions.

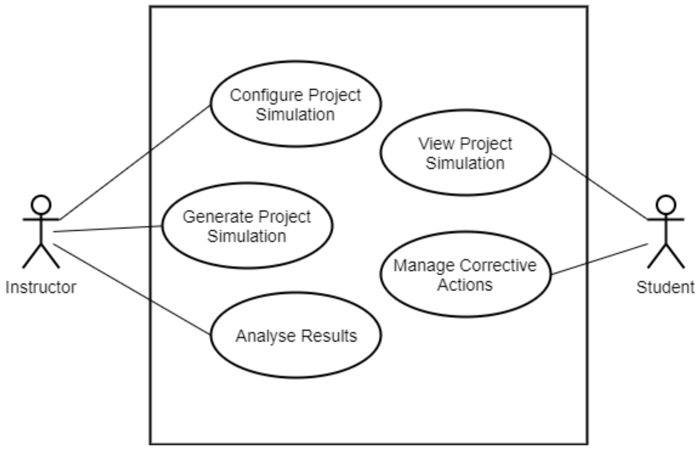
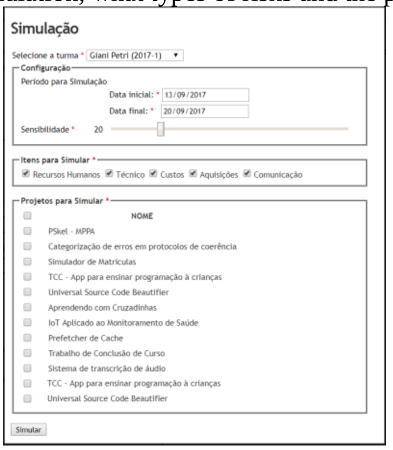
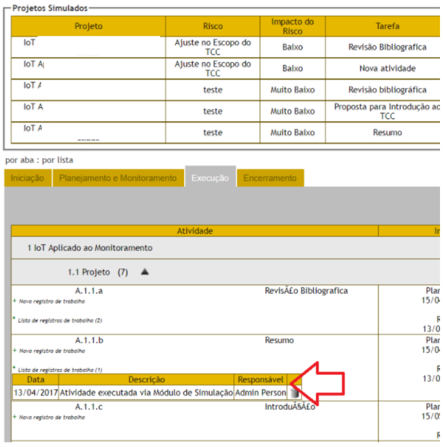


Fig. 4. Simulation plugin Use Cases

Following the process presented in **Fig.** 2, as part of managing students' progress in the dotProject+ tool, the Instructor accesses the tool and views the student groups and their projects from each of the classes in which he or she teaches. In the project simulation screen (**Fig.** 5**a**), after selecting the class, the instructor can parameterize the project simulation, indicating the period of execution to be simulated, the sensibility of the simulation, what types of risks and the projects to be simulated.



(a) Simulation configuration



(b) Simulation results

Fig. 5. Simulation Module

After clicking on "simulate", the system performs the simulation of the project execution and generates execution records of the project, as shown in **Fig.** 5**b**. Then, the Simulation plugin scrolls through the list of planned activities for the simulated period of all selected projects, including tasks not yet finalized from previous periods. Based on this list of tasks, the simulation plugin draws from the planned risks those that may occur in the period, based on a Poisson distribution simulation [19].

Based on the planned risks, classified according to a field-based classification [20], previously prioritized by students based on the calculated exposure factor, the Simulation Plugin then simulates the occurrence of risks, generating the possible impacts, according to each type of risk. **Fig.** 6 shows a high-level description in pseudo-code of the plugin simulation algorithm.

```
function do_simulation($configuration){
        global $projectRisks, $projectTasks, $projectChangedTasks;
        foreach($configuration->selectedProject as $project){
                $projectRisks = selectProjectRisks($project, $configuration);
                $projectTasks = selectProjectTasks($project, $configuration);
                executeSimulation($projectTasks, $projectRisks);
                updateRisks($projectRisks);
                saveTaskLogs($projectChangedTasks);
        }
}
```

Fig. 6. Project Execution Simulation plugin high-level algorithm

Within the `executeSimulation` procedure (**Fig.** 6), the Poisson distribution (**Fig.** 7) was chosen for the possibility of simulating the probability of occurrence of a risk in a possibly large number of tasks executed within a certain range of dates of the projects' planned schedule. Furthermore, the historical probability of occurrence of each type of risk is obtained from a survey conducted by the Brazilian PMI Chapter [21].

$$f(k;\lambda) = \frac{e^{-\lambda}\lambda^k}{k!}$$

Fig. 7**.** Poisson risk-type probability

The probability of occurrence of each type of risk is calculated, as follows:

- *e* is the basis of the natural logarithm,
- *k!* is the factorial of the number of discrete occurrences of a given type of risk in the planned time interval,
- λ is the expected number of occurrences, taken from the PMI survey [21] , with the sensibility parameter, defined by the instructor on starting the execution simulation.

Currently, the first initial version of the simulation module is implemented and has already been used in the context of a project management course, as presented in the next section.

5 Initial Evaluation

To evaluate the applicability and the perception of learning of our approach, the unified Project Management Course including project execution simulation to support PMC learning was applied in the Project Management class of the Bachelor of Information Systems course at UFSC during the second semester of 2017.

The use of the project execution simulation was evaluated under two perspectives: (i) whether the use of the simulation in the course contributed to the learning of Project Monitoring and Control and (ii) if the simulation module is adequate to be used as support for Project Monitoring and Control learning.

This initial evaluation was conducted using a single group posttest-only design [22]. Nineteen students participated in this initial evaluation. Students participated in the simulation module and after asked to answer a questionnaire. This questionnaire included questions related to the two aspects of learning perception and applicability of the simulation module. **Fig.** 8 presents initial evaluation results, broken down by the applicability of the module in terms of five categories: easiness to use, usefulness, functional completeness, functional correctness and satisfaction.

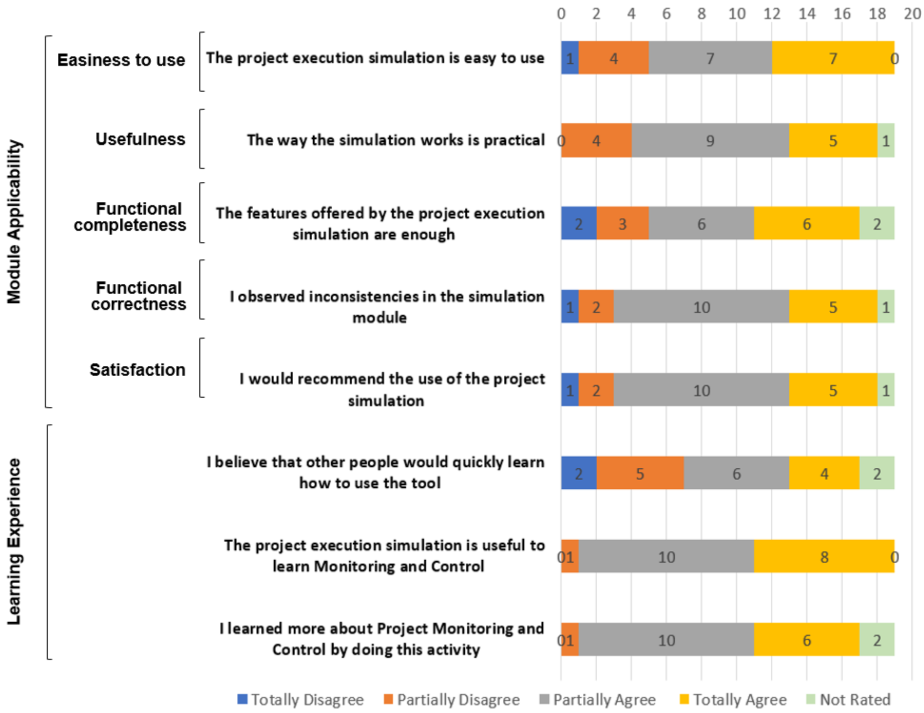


Fig. 8. Initial evaluation results

In terms of the evaluation of the simulation module applicability, it is possible to observe (**Fig.** 8), that most of the participating students agree that the module is easy to use (74%), its use is practical (74%) and that the functionalities offered by the simulation module are enough to support the learning of Project Monitoring and Control process area (70%). As opportunities for improvement, 83% of the students identified inconsistencies in the simulation. A causal analysis of this result revealed a defect in the programming that generated incomplete execution data in some cases.

Regarding the learning perception, the majority of the students (95%) agree that project execution is useful as a support for Project Monitoring and Control learning and most agree (89%) that they had learned more about Project Monitoring and Control using project execution simulation.

Some threats to the validity of this initial evaluation can be observed, such as the small sample of students, which limits the possibilities of generalization of the conclusions. Likewise, the use of single group posttest-only design is naturally subject to maturation and testing threats. Despite these threats to validity, this application is an initial evaluation of the project execution simulation, using a simulation module that is still in development, and the results can raise insights that contribute to the continuity of its development and the possibility of experimentation with larger experimental groups in the future.

6 Conclusions

This paper presented our current approach to teaching software Project Management. This approach focuses on giving the students the opportunity to work at the first three levels of the Bloom’s taxonomy. In particular, the motivation with this approach is to provide students with the capacity to apply project monitoring and control knowledge. A key differentiating aspect of our approach is that we have re-designed a PMBOK-based course from the ground up so that technological elements could be seamless integrated into the students´ experience in the module.
As such, the enabler for giving the students the capacity to apply this knowledge is a project execution simulation plugin. This paper presented the development process and main design decisions of this plugin.
Furthermore, we have presented our initial evaluation of the project execution simulation approach. In general, positive responses have been received from the students who have come into contact with the approach.
Our future line of work will include the full deployment of the redesigned module at ORT and UFSC software project management modules.

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