Towards an Earned Value Management Didactic Simulator for Engineering Management Teaching*

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Abstract. Agile development (AD) is a methodology that many small businesses have adopted for production convenience, and educators have taken notice of the trend. A need to implement some form of agile development in undergraduate programs at universities is now clear, particularly for undergraduate engineering students who should understand their role in a project focused on AD. This paper presents our preliminary evaluation of user experience (UX) using an Earned Value Management (EVM) simulator, which helps the student understand the team member's role in an agile development process. The simulator uses a Task-board interface to display task status changes, a burn-down chart to depict the remaining work, and EVM metrics to assess the efficiency of the teamwork. Using the Task-board and EVM models, the simulator offers students different agile project management experimental experiences.

Keywords: Agile Development · Earned Value Management · Agent-based modelling and simulation · Undergraduate Engineering Students.

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1 Introduction

Agile development (AD) is a methodology that many small businesses have adopted for production convenience. That is why academics have turned to implementing some form of agile development in undergraduate programs. From a Project Management (PM) perspective, we can approach AD as a particular type of project where the team members have a developer role, and together they attend to the tasks planned in the Work Breakdown Structure (WBS).

Any team member can approach project management from different perspectives: a) Visualize the WBS using a Gantt Chart or a Task-board. Project managers widely use the Task-board in small and agile projects due to its ease of implementation. b) Earned Value Management (EVM) is the standard method to assess the performance of a project. It provides a set of metrics that fundamentally help estimate a project's cost and schedule efficiency.

This paper presents our preliminary evaluation of user experience (UX) using an Earned Value Management (EVM) simulator, helping the student understand the team member's role in an agile development process [4]. The simulator uses a Task-board interface to display task status changes, a burn-down chart to depict the remaining work, and EVM metrics to assess the teamwork efficiency [5]. Using the Task-board and EVM models, the simulator offers students different agile project management experimental experiences.

1.1 Agile development

Agile project management is a lean production approach based on Lean Manufacturing (LM) principles [17], applied to managing projects that require extraordinary speed and flexibility in their processes. In particular, the software industry has adopted agile software development as a viable approach to managing the development of software products, inspired by the "Manifesto for Agile Software Development.[1]"

The Agile approach has gained substantial momentum and has spread to many other areas of implementation, such as in manufacturing processes, education, healthcare, and other industries that are becoming agile [9]. Complementary to the sixth edition of "The Guide to the Fundamentals of Project Management (PMBOK Guide)," published in 2017 [14] by the Project Management Institute, the special edition "The PMBOK Agile Practice Guide" was published as a companion [13]. This publication is intended exclusively for software development project managers who have adopted the agile approach. According to this guide, agile software development is a type of lean production, and it was published not only to address the use of the agile approach in the software development industry but to go beyond its original home, finding applications in environments other than software development. The application of the agile approach in manufacturing, education, healthcare, and other sectors is within the scope of this practical guide [13].

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1.2 Agile practices in education

Education is an excellent fertile ground for extending agile practices beyond software development. Middle school and high school teachers, as well as college professors worldwide, have begun to employ the agile approach to create a learning culture that aligns with state-of-the-art in the business and engineering spheres. Stakeholders have used agile techniques to focus on prioritizing competing priorities. Face-to-face interaction, meaningful learning, self-organizing teams, and incremental and iterative learning that stimulate imagination are agile principles that can change the mindset in the classroom and advance educational goals [3].

In the case of engineering schools, particularly in software engineering programs, the application of agile learning is not only convenient as an educational strategy but is considered almost a necessity. There are experiences in applying agile learning with the aim that software engineering students learn to improve their competence in agile production processes such as Scrum [12]. This requirement is due, in general, to the fact that a large part of the software development industry has adopted some agile production methodology. This situation has motivated university programs oriented to software development to develop skills in future engineers related to these production methods [6].

However, agile learning in engineering schools, particularly software engineering, is still far from standard practice. Oftentimes, the internal processes of educational institutions do not necessarily facilitate agile learning management. In addition, not all have the human capital to implement this practice. Finally, local industry support to implement this practice must be linked appropriately [11]. This situation leads us to seek alternative solutions to the problem of agile development, especially the one that refers to teaching agile software development through an educational strategy based on agile learning.

1.3 Task-Board and Earned Value Management

The Earned Value Management (EVM) [15] is considered a fundamental part of the Project Management Body of Knowledge (PMBOK) [16] to establish practical measures. Over the last four decades, project management professionals have used this method to measure performance and assess the status of a project [8]. This notwithstanding, managing an Agile project can be a challenging endeavor, forcing managers to use a task board to visually represent the work on a project and the path to completion. The route includes pending, in-progress and completed tasks performed by teams. For example, the "Kanban" methodology uses a task board to distribute assignments and activities as a fundamental part of a production process [11].

2 Methodology

We designed a small experiment to evaluate students' experiences in using the Web Earned Value Management simulation didactic tool to learn the concepts of project management, which we summarize in the three actions below:

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– Earned Value Management model adaptation.
– Class experiment design and implementation.
– Assessment questionnaire application.

2.1 The Earned Value Management model adaptation

The tool that we evaluated is a Web-based version of the NetLogo Earned Value Management Model 1.0. A complete model description is available in [5], with a downloadable original NetLogo model in [4].

2.2 The class experiment design and implementation

20 students in the "Software development tools" class of the Software Engineering undergraduate program at the Universidad Autónoma de Baja California in Mexico [10] participated in a learning experiment as described below:

1. First, they received a lesson about Project Management, WSB, Task-board, EVS metrics, and other basic concepts.
2. Second, they answered a short quiz to evaluate what they had learned.
3. Third, they conducted a laboratory practice using the Web Earned Value Management simulation didactic tool.
4. Fourth, they retook the same quiz to re-evaluate their learning.
5. Finally, they answered a questionnaire to evaluate their user experience when interacting with the Web tool.

2.3 The assessment questionnaire application

We applied a short User Experience Questionnaire (UEQ) to evaluate the User Experience (UX) of the 20 students after interacting with the tool [19]. The questionnaire evaluates the pragmatic quality (Efficiency, perspicuity, and dependability) and the hedonic quality (Stimulation and novelty) of the tool. We can find complete information about this questionnaire in [22]. Additionally, the students gave feedback on their experience in short comments to complement the assessment.

3 Assessment results

We have three outcomes as a result of this first approach:

– Web Earned Value Management simulation didactic tool.
– Student's UX assessment results.
– Student's quiz results and feedback.

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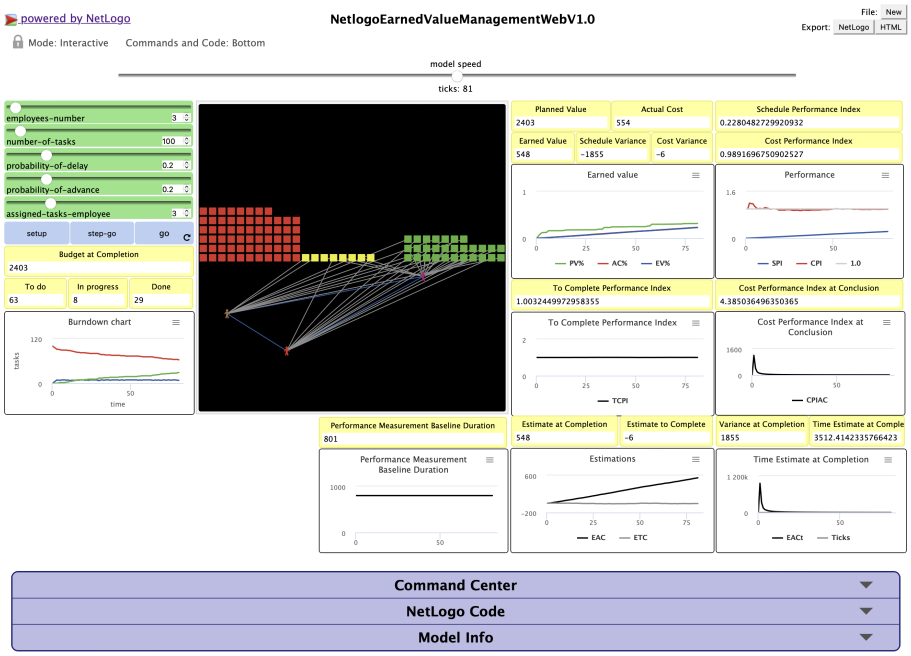

Fig. 1. Web Earned Value Management simulation didactic tool screenshot.

3.1 The Web Earned Value Management simulation didactic tool

We produced a Web version from the original model [5] for better student access to the tool during the evaluation. Figure 1 shows the Web tool interface with which the participants interacted.

The tool interface has three parts to interact with: a) components where the initial conditions of the scenario are configured and the simulation is run (step-by-step or continuous execution), b) an interface that visually draws a dashboard of tasks and employees, c) components that show the Earned Value calculation at run-time.

3.2 The student's UX assessment results

In this section, we present the results of applying a short questionnaire to measure the students' experience after interacting with the simulation Web tool.

Pragmatic and hedonic quality We used the "Short UEQ Data Analysis Tool" [21] to analyze the questionnaire responses according to [19]. In table 1, we show the results by questionnaire item [20]. We can observe that the means results are relatively high in all assessment cases.

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Table 1. Results

Item	Mean	Variance	Std. Dev.	No.	Negative	Positive	Scale
1	(High) 2.0	1.5	1.2	20	obstructive	supportive	Pragmatic Quality
2	(High) 1.4	1.2	1.1	20	complicated	easy	Pragmatic Quality
3	(High) 2.3	0.4	0.6	20	inefficient	efficient	Pragmatic Quality
4	(High) 1.4	1.3	1.1	20	confusing	clear	Pragmatic Quality
5	(High) 1.9	0.5	0.7	20	boring	exciting	Hedonic Quality
6	(High) 2.5	0.3	0.5	20	not interesting	interesting	Hedonic Quality
7	(High) 1.7	2.1	1.5	20	conventional	inventive	Hedonic Quality
8	(High) 1.3	1.8	1.3	20	usual	leading edge	Hedonic Quality

The table 2 shows the results by quality area. We can observe that the pragmatic and hedonic qualities resulted in high assessment.

Table 2. Short User Experience Questionnaire Scales.

Short UEQ Scales.	
Pragmatic Quality	(High) 1.738
Hedonic Quality	(High) 1.825
Overall	(High) 1.781

Figure 2 depicts the mean value per questionnaire item. We can note that in all cases, the mean value results are positive, and figure 3 depicts the mean value per questionnaire scale. We can note that in all cases, the scale and overall value results are positive.

The "Short UEQ Data Analysis Tool" [21] provides details on how we can interpret the means of the scales as pragmatic quality and hedonic quality according to [19]. Table 3 shows the 5% confidence intervals for the means of the single items, and table 4 shows the 5% confidence intervals for the scale means.

In table 5, we show the pragmatic and hedonic quality correlations of the items per scale and Cronbach Alpha-Coefficient [7].

Benchmark comparison According to [18], the benchmark data set contains data from 21175 persons from 468 studies concerning different products (business software, web pages, web shops, social networks). Currently, these benchmark data sets are based on the full UEQ, but the scale values of the short version are a reasonably good approximation of the corresponding values of the full version; thus, it is a rough approximation possible to use the data from the complete UEQ benchmark as a target for the short UEQ [19]. However, these are still different

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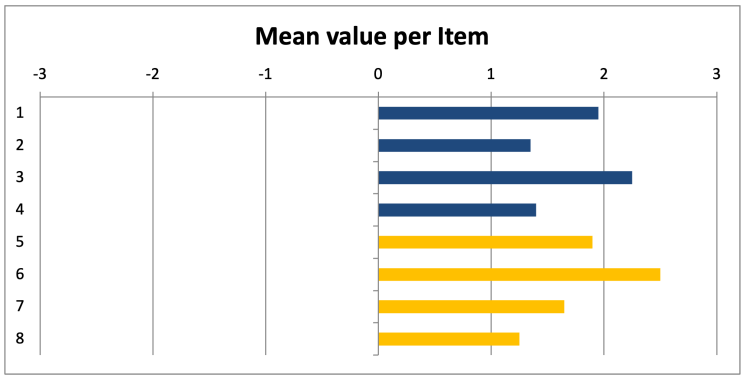

Fig. 2. Mean value per Item.

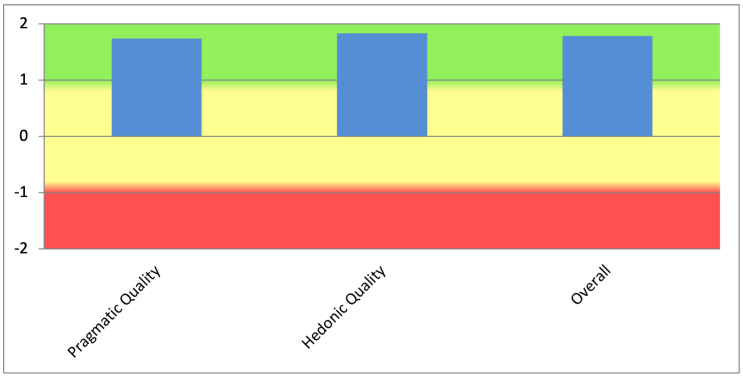

Fig. 3. Results.

questionnaires, forcing us to treat the data carefully. Benchmark authors intend to replace this proposed measure with a special benchmark for the short version when enough data with the short UEQ become available. Table 6 compares to benchmark interpretation. The measured scale means are set in relation to existing values from a benchmark data set [18].

The comparison of the results for the evaluated product with the data in the benchmark allows conclusions about the relative quality of the evaluated product compared to other products. Two versions of the benchmark chart are shown. Figure 4 shows only the scale scores in relation to the benchmark categories, whereas figure 5 reflects the confidence intervals of the scale scores.

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Table 3. Confidence interval per item.

Confidence interval (p=0.05) per item					
Item	Mean	Std. Dev.	N	Confidence	Confidence interval
1	1.950	1.234	20	0.541	1.409 2.491
2	1.350	1.089	20	0.477	0.873 1.827
3	2.250	0.639	20	0.280	1.970 2.530
4	1.400	1.142	20	0.501	0.899 1.901
5	1.900	0.718	20	0.315	1.585 2.215
6	2.500	0.513	20	0.225	2.275 2.725
7	1.650	1.461	20	0.640	1.010 2.290
8	1.250	1.333	20	0.584	0.666 1.834

Table 4. Confidence intervals per scale.

Confidence intervals (p=0.05) per scale					
Scale	Mean	Std. Dev.	N	Confidence	Confidence interval
Pragmatic Quality	1.738	0.719	20	0.315	1.423 2.052
Hedonic Quality	1.825	0.783	20	0.343	1.482 2.168
Overall	1.781	0.588	20	0.257	1.524 2.039

Table 5. Correlations of the items per scale and Cronbach Alpha-Coefficient. Pragmatic and hedonic quality.

Pragmatic Quality.		Hedonic Quality.	
Items	Correlation	Items	Correlation
1.2	0.25	5.6	0.43
1.3	0.08	5.7	0.32
1.4	0.16	5.8	0.30
2.3	0.25	6.7	0.04
2.4	0.69	6.8	0.12
3.4	0.36	7.8	0.86
Average	0.30	Average	0.34
Alpha	0.63	Alpha	0.68

3.3 The student's quiz results and feedback

When applying the earned value management quiz before and after experimenting with the tool, 45% of the students increased their scores. However, 40% of the students kept their scores unchanged, and 15% of the students decreased their scores. Unfortunately, 5% did not answer the quiz. Table 7 shows the distribution of the percentages of the results obtained, and figure 6 depicts these proportions.

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Table 6. Comparison to benchmark interpretation.

Scale	Mean	Comparison to benchmark	Interpretation
Pragmatic Quality	1.7375	Good	10% of results better, 75% of results worse
Hedonic Quality	1.825	Excellent	In the range of the 10% best results
Overall	1.78	Excellent	In the range of the 10% best results

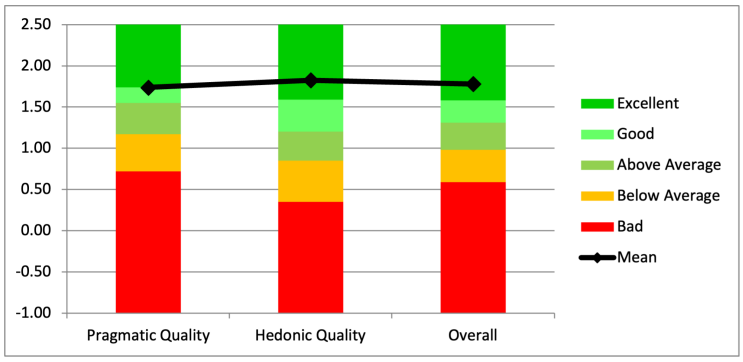

Fig. 4. Comparison to benchmark. The scale scores in relation to the benchmark categories

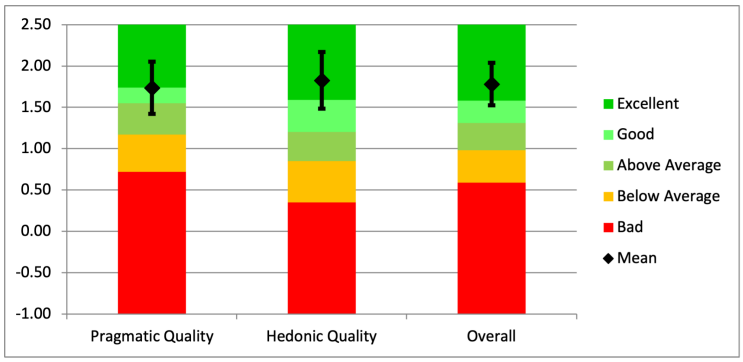

Fig. 5. Comparison to benchmark. The confidence intervals of the scale scores

Although we would have liked to have had a more substantial recorded impact on learning, the written statements of students described their experience with very positive comments. After doing a sentiment analysis of the students' feedback [2], we obtained that 86% sentiments were positive, 7% neutral, and 7% negative. Many of them found the exercise interesting and enjoyed the interac-

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Table 7. Percentage distribution of 'Score impact'

Score impact	Percentage distribution
Increase	45.00%
No change	35.00%
Decrease	15.00%
No answer	5.00%
Grand Total	100.00%

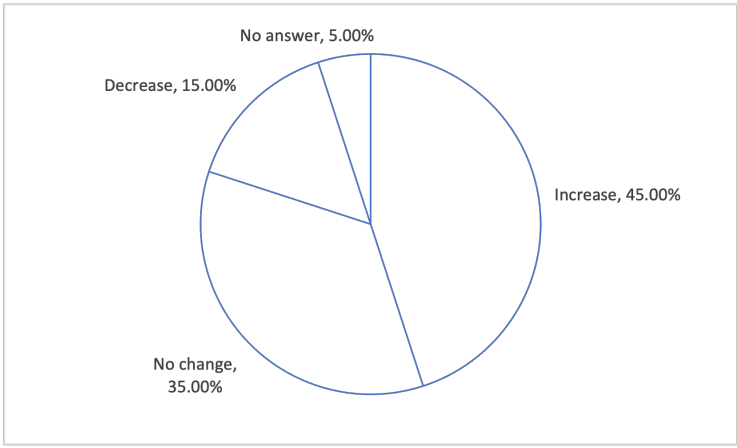

Fig. 6. Percentage distribution of 'Score impact.'

tion. Moreover, the exercise was considered intuitive for a significant portion of the students, who, after some interaction, understood the mechanism and found it rewarding. Figure 7 shows a word-cloud representative of students' comments.

4 Conclusion and future work

In this paper, we have presented a preliminary study with undergraduate students in engineering and their experience using a web-based task-board simulation tool in NetLogo. The students used the tool to learn the earned value management approach. In classroom practice, they experimented with various scenarios to observe an agile project's behavior and performance. We proceeded to evaluate their experience by applying a short questionnaire and assessed their learning using a quiz before and after the interaction. The preliminary result shows an excellent practical and hedonic experience and a trim learning outcome. This result bids us to continue with the evaluation of the user experience in a full way but will be necessary to re-design the experiment to improve the learning evaluation method.

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Fig. 7. The student's feedback word-cloud.

In future work, we will first continue to evaluate the tool with a more extensive and diverse sample of students. Our interest is to include different courses where we consider it essential to teach students the project management process. Secondly, we will apply the comprehensive questionnaire to evaluate the user experience and identify the most significant characteristics of the student's interaction with the tool. Finally, we will improve the learning evaluation method to more accurately measure the contribution of the instrument in comparison to other digital learning media. We will also analyze student feedback through their comments to discover new interactive qualities.

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