# SimStructure: 3D simulation tool to evaluate the learning aspects of students in an engineering course

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*Abstract:* - Software tools are used in all levels of education in order to improve learning outcomes. There are several simulation tools based on active learning concepts and game based learning strategy used in STEM courses with a multitude of features designed to help students in the learning process. One difficulty of students in engineering courses are the abstraction of structures and their behaviour when forces are applied. The SimStructure software is based to active learning concepts and use a game engine to create a virtual learning environment to provide tools to build 3D structures, apply axial forces and evaluate the effects of such forces in the structure. In this work, it is discussed the learning outcomes of the application of SimStructure in an engineering class and it is also compared the use of SimStructure with other software and the traditional method. Results indicates that SimStructure produced a positive impact in the students learning, since SimStructure could provide mechanisms to students understand the physical effects of axial forces and node displacement. The results also indicate that students try to apply a set of concepts in any exercise when they try to solve it in traditional method regardless the kind of evaluation that it is required in the exercise. Using the software students changed this behaviour and try to think about the exercise before start to solve it.

*Key-Words:* - Active learning, open educational resources, virtual learning environment, game engine, simulation games.

## 1 Introduction

Active Learning concepts were applied to develop an educational software named SimStructure, which aims to create a simulation tool to students develop a more complex reasoning about structures, such as trusses, motivating and engaging them in various activities [1]. The software was developed in eMundus European project (http://www.emundus-project.eu/) as an Open Educational Resource, allowing anyone to modify and improve it [2].

This work proposes a set of learning strategies and application of SimStructure and other tools to evaluate the learning outcomes from students of an engineering course. The main features of SimStructure and mechanisms of structure simulation is described in [3]. In order to evaluate students' performance and critical thinking through structure simulation, the Bloom`s Revised Taxonomy was applied as a way to evaluate the impact of SimStructure in students learning. The Bloom's Taxonomy classifies 6 complexity levels of reasoning triggered when students work in an activity [4]. In this way, it is possible to propose a multitude of activities (e.g. discussions, case studies, etc.) in order to stimulate some cognitive reasoning areas [5] and evaluate them.

## 2 Active Learning and Games

The learning process and the role of teachers are under discussion in several forums because education is determinant for the economic and social progress. The UNESCO report developed by Delors et al. (1998) is still an important reference about the challenges that must be faced to make the education an "indispensable asset" of the society. It considers the education in the 21th century should be supported by four pillars to support the learning society, in which most activities should be "founded on the acquisition, renewal and use of knowledge" [6].

The education should be based on the complex thinking where uncertainty and error must be discussed and reflected upon. In this context, experimentation has a relevant role. Therefore, Active Learning can be employed as a way to meet these objectives [7]. Both procedures and experimentation are fundamentals to structure the reasoning and abstracting concepts and learning process be effectively constructed [8]. This is coherent with active learning concept, which is defined by Grabinger and Dunlap [9] as: "learning activities that engage students in a continuous collaborative process of building and reshaping understanding as a natural consequence of their experiences […]".

Active Learning has been applied in all levels of education, and it also has relevant outcomes in Science, Technology, Engineering and Mathematics (STEM) courses and their subjects. Freeman et al. (2014) report significant improvements in the outcomes obtained by students in these areas [10]. Simulations through software can be used for students to experience the concepts, as proposed in the active learning concept, and so they can reflect on the experience's results from their homes (online) without attending classes in the university's laboratories, or even in traditional lectures.

Simulation games are also another learning strategy that carry two fundamental characteristics to hone the teaching-learning process: they allow students to analyze different solutions, which are not feasible in practice, and they grab the student's attention. In the educational context, games can be a motivational factor, which is needed for a new teaching approach [11], [12].

Despite digital games having a critical function to motivate the students and to engage them in the scientific learning, there is a lack of further studies to verify if this impacts the learning cognitive aspects [13].

## 2.1 Revised Bloom's Taxonomy

The Bloom's taxonomy [14], revised by [15] and presented by [16], is proposed to assess the learning processes in this research. This taxonomy presents three domains that reflect the development of a human being as follows: psychomotor domain (focused on physical skills), the affective domain (his attitudes and emotions) and the cognitive domain (based on knowledge). Although there are various discussions about the importance of the noncognitive skills, which can be understand as behaviour, attitudes and strategies crucial to academic performance [18], only the cognitive domain is under consideration in this research.

The cognitive domain of Bloom is divided into six levels, which do not represent a cumulative hierarchy, i.e. each one is not a prerequisite for the next one [17]. The levels are: (i) Remember, reflecting the skill of identify and remembering concepts; (ii) Understand, linked to the skill to interpret data, exemplifying, classifying and comparing them; (iii) Apply, which consists into execute or to implement an algorithm or a to follow a set of steps to solve a problem ; (iv) Analyze, which consists into differentiate elements, organize data coherently, logically structure the object under study; (vi) Create, encompassing the creation of hypotheses, planning and activity production [15]. Segmenting the students' reasoning structure allows a more effective analysis of the effects of a proposed learning strategy.

# 3 Software SimStructure

SimStructure was developed using a set of API of the game engine Unity3D. One of the main reasons to use such game engine is the advanced physical simulator named *PhysX NVIDIA® 3D Physics*, which allows the user to apply forces in objects, thus facilitating the simulation of structures' reactions and physical properties.

The features were developed to present the models as a honed model of the classroom's subjects. Figure 1 exemplifies a structure with rigid nodes, in which is a torque and an axial force is applied in the trusses. During the simulation of structure behaviour, it is possible to see the structure deforming, allowing the student to visualize the displacements of all parts of the structure, leading to a new situation, represented in Figure 2.

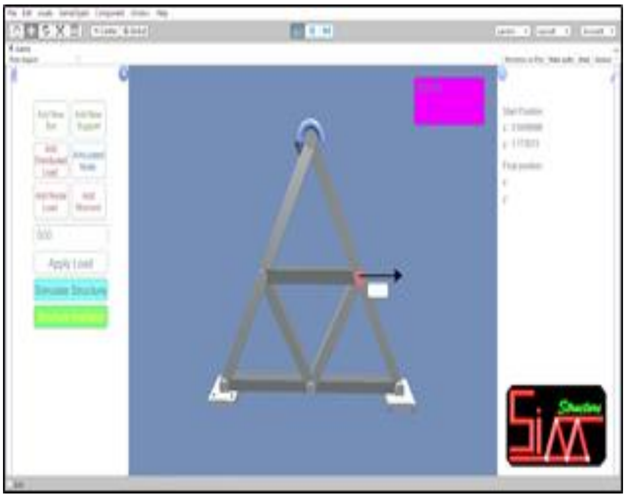

Fig. 1 - Simulation environment with a steel lattice structure.

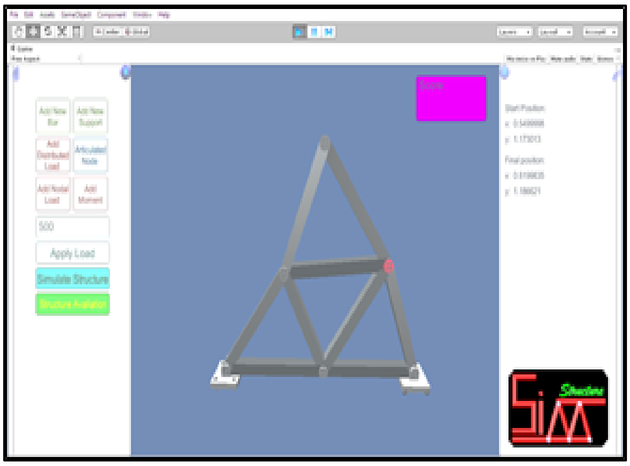

Fig. 2 - Deformed lattice structure due to the forces' action.

The software interface is organized in such way that software presents the information necessary to a student solves the task and could evaluate the structure; not just presenting a set of equations and the equivalent linear systems that represents the structure and the distribution of forces on it. The software also provides support to student calculates such equations and linear systems whether such feature would be activated. It is possible to create any structures and visualize forces and reactions of experiments in the simulation environment. Therefore, the teachers can turn the SimStructure software into an environment of active learning, as long as the students interact with the software, allowing them to have more autonomy and engagement in the learning process. The elements of the learning environment help students to assimilate the structure behaviour, honing the students' abstraction ability, since it is difficult and complex to visualize the structure displacement only with the traditional diagrams using paper and a scientific calculator (traditional method). The node displacements is another important feature to the students think about the effects that would hardly be identified in a traditional diagram. In addition, the disciplines of structure calculation demonstrate gaps in the learning process, since it is possible to check in the assignments non-meaningful solutions given by students. Taking this into consideration SimStructure presents the physical effects in perceptible manner applying a scale factor to amplify the visualization of the structure displacements and other relevant properties to study the structure. It is important to stimulate the students to have numerously experiences in this environment in order to make them able to apply the concepts in the real world. Students are warned about the scale factor.

Besides, when students carry out the mathematical process, they are able to develop the ability to understand and assess their outcomes when they repeat experiences in the software. They will be encouraged to better understand the calculus process since they learned how to interpret the physical process, enriching the teaching-learning process.

## 4 Use of SimStructure in the classroom: initial results

For a better understanding of the cognitive enhance expressed by the students in front of a new teaching methodology, a set of learning strategies was proposed and applied in two steps. The first step was a questionnaire applied to evaluate students' knowledge and the results evaluated according to Bloom's taxonomy. The second step the students were organized in three groups and the set of learning strategies were applied, including the SimStructure.

### 4.1 Evaluation based on Bloom's taxonomy

The first step a group of 44 students should answers a set of questions, which would similar to questions that they usually did in the classroom. However, the questions did not ask to do a set of calculations only, but in most cases students should evaluate the structure, answer what kind of concepts were involved to answer the question, how to apply some technique to calculate some reactions. The objective was to identify the cognitive capacities of this students according to revised Bloom's Taxonomy [15], [16]. Each question had a set of aggregated concepts, as follows: support reactions, shear and bending moment efforts, traction and compression in the bars, nodal displacement and then, restriction degrees of freedom of the structure.

The questions were organized in an incremental level of complexity, from understanding until evaluation level. To check whether students perceived such incremental level, it was required that students indicate the level of difficulty of each question. Each one of them was elaborated based on three aspects: (i) level of question according to the revised Bloom's Taxonomy, (ii) level of difficulty indicated by the students and (iii) number of concepts related in each question. The Figure 3 presents the results of these three factors that contributed for the first evaluation.

The results present a high positive correlation between the average of wrong and null answers which the degree of difficulty (r = 0,797) and also a high positive correlation between the level of difficulty and the number of concepts of each question (r = 0,787), indicating an interdependence of these variables.

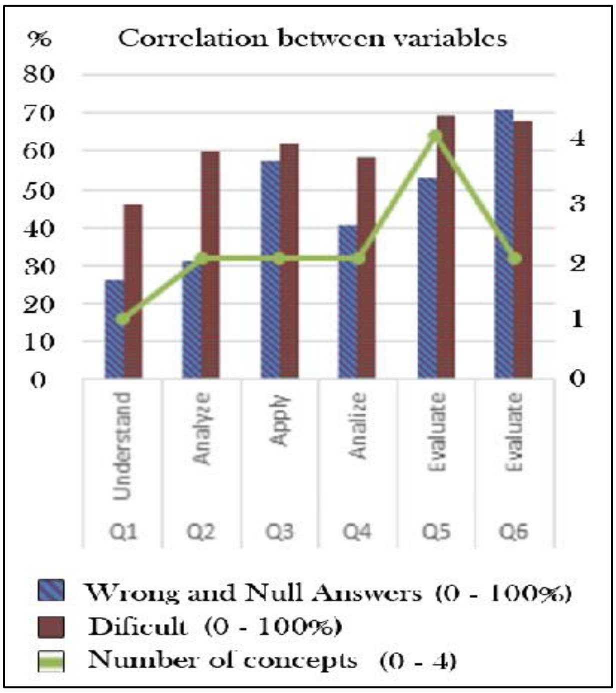


Fig. 3 - Results of the first test with students.

The data from questionnaire indicate that the question 6 had the highest rate of wrong and null answers, in accordance with the level of difficulty pointed by the students. The level evaluate was the most complex between all of the levels included in this test, which demonstrates the difficulty presented by the students when it is demanded more than just apply skills or techniques to solve a question.

The question that presents the second highest number of wrong answer was the question 3, revealing a fragility in the process of application of some learned concepts or a technique to solve a question. In this question it was observed that students knew the involved concepts (understanding) in the question and they should be able to do the exercise, but they were not able to apply the concepts correctly. The consequence was the failure to get the correct answer.

There is no evidence of correlation between the number of concepts and the number of students mistakes and misunderstanding (represented by wrong and null answers), but it is possible to afirm that when is required a more sophisticated level of cognitive process, such as in question number 3, when the student should associate more than one concept to apply the right technique to solve the question, the number of wrong and null answers increases.

However, the perception of difficulty doesn't indicate the same variations regarding to the errors and the cognitive level required in the question. It's mean, by hypothesis , that the students study to know how to solve a set of exercises, and if the assignment doesn't correspond to previous solutions studied, the exercise is classified as a hard thing to do. All of the exercises of this propose evaluation was based in lists of exercises that students receive to study and check the knowledge; the difference resides in the fact that it is not necessary to do any complex calculation to achieve the solution, most of them could be reach just analyzing the structure and the applied forces (intuitive resolution). It was expected that the students could identify the content learned and be able to respond properly the questions. However, when the student cannot solve the exercise using the same method that the professor used in an example in the classroom, he could not able to do the steps further in the learning process, and may be not able to reach the learning outcomes.

## 4.2 Evaluation based on learning tools and learning strategies

The second evaluation process were organized in three sessions and 48 students were involved (the same of the first evaluation plus four new students). They were organized in three groups and every session each group had an assignment composed by a set of exercises with a particular learning strategy.

In every session, each group of students worked using one learning strategy, and in the end of three sessions all groups worked with all learning strategies, and all exercises and results were evaluated, as the same way students evaluated the sessions as well.

The students solve exercises using the SimStructure in the first learning strategy. In the beginning of the session students work with several examples in order to learn how to use the software, and after that the objective of this learning strategy was to evaluate the behaviour of some structures not using calculation, but only concepts and the software to check whether they understood the structure behaviour. The focus of the second learning strategy was the same of first one, but using an open source software called in this paper as Comparative Software used to teach structures. The Comparative Software use traditional diagrams to present 2D structures and it shows the structures in the original state and final state after calculation. SimStructure presents structure in 3D and shows the structure displacement. The third learning strategy was the traditional way to solve an exercise using paper, pencil, scientific calculator and drawing diagrams, as the same way it is done in traditional lecture.

The first concept for all learning strategies was the study of axial forces in the structure, when students should indicate the axial efforts in each part of the structure. They should also indicate whether each part of the structure was supporting compression or traction forces. It was not necessary to do calculations, but think about what would happen with the structure when some axial forces were applied in the structure. Figure 4 indicates the results for each learning strategy.

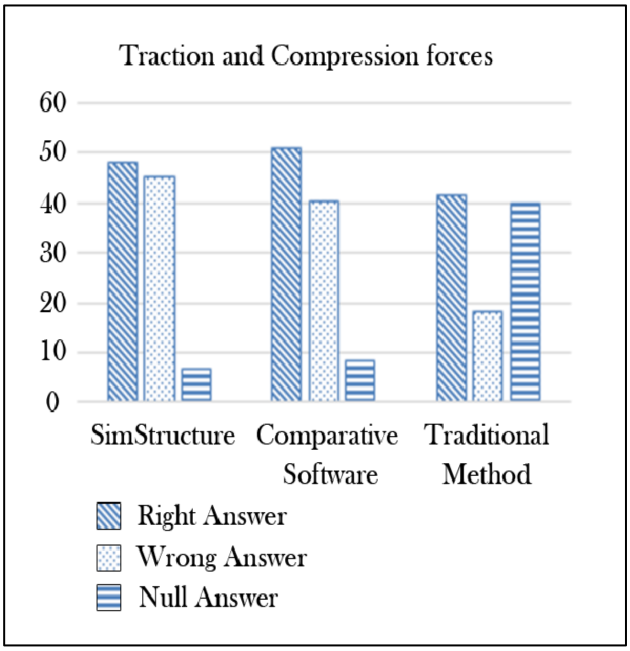


Fig. 4 - Test results of the concept “Traction and compression forces”.

The number of right answers in both software is higher compared to the traditional method, but the number of mistakes is similar to the number of right answers, which indicates the students did not reach the learning outcome proposed in the classroom. However, the number of null answers, which means the students could not even propose any kind of answer, was quite low in the both software compared to traditional method. This is relevant because clearly identify an inconsistency in students learning, which could not be seem in the traditional method because the reason of a null answer is unknown (without any further investigation). Using the software students felt they could try to get an answer, and using paper students tried to do calculations to understand what was happening with the structure and as the exercise was not the same that they usually did, several students did not give any answer.

The second concept for all learning strategies was the structure nodal displacement when axial forces were applied in the structure. In the SimStructure students should indicate when each node would be (in space) after the simulation. In the "Comparative Software" students could also estimate when nodes would be in the end of simulation, but it could not see the node displacement happening, just its final position. Figure 5 indicates the results of this learning strategy. Once again students could see examples and after that solve the exercises (in both software and examples in paper as well). As such exercises is not the exercise that students usually do in the classroom, about 50% of the students did not do any answer in the traditional method. In this case the software could help students to better understand the nodal displacement and most of them could give an answer to the exercise.

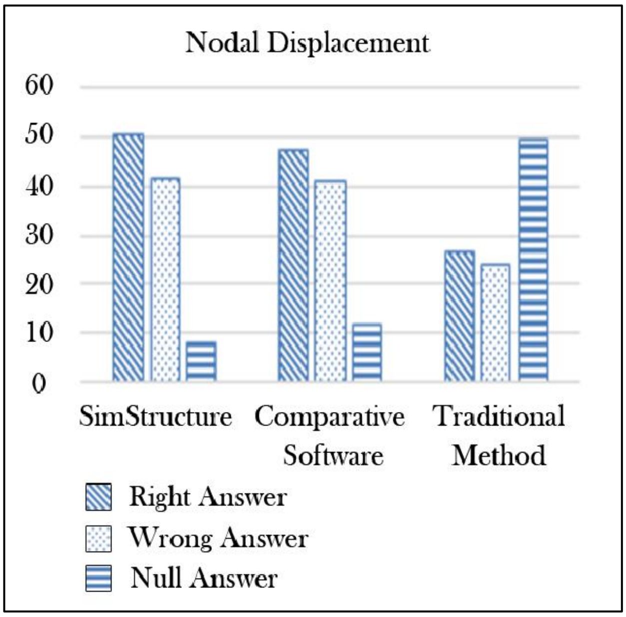


Fig. 5 - Test results of the concept “nodal displacement”.

## 5 Concluding Remarks

The SimStructure software and its features presented a good performance compared to an important software tool used to teach structures (the

Comparative Software) and it means that the proposed game engine and the physical engine, as well as the whole software produced a positive impact in the students learning, since SimStructure could provide a way to students understand the physical effects of axial forces and node displacement. SimStructure promotes active learning, since students can examine and evaluate each exercise at is own pace and receive an instant feedback. Although it could not directly be measured, it could be observed the students engagement in the learning activities during the sessions, particularly when they use a software tools, because they produced an answer for the questions, what not happened in the traditional method.

The results of both evaluation by Bloom taxonomy and the software tools and learning strategies indicate that SimStructure can support learning and could give to students a better way to apply concepts and evaluate structures in a better way compared to traditional method to answer the exercises. In the first learning strategy, using only paper and calculator, it was observed that student tried to solve exercises as the same way they did in the classroom. It means that they did not try to analyze and evaluate a strategy to solve the exercise, but also did all calculations that they learnt and after that they try to analyze the question. Around 50% of students on the first week just calculate everything and did not have time to really answer the exercise; they did not realize that it was not necessary to do lots of calculation to solve the questions. That's was one of the reasons to have several null answers in the questions.

In most exercises applied in the learning strategies it not asked to students answer the questions using the same solution strategy they usually apply. It may one of the reasons to students make so many mistakes. According to Bloom taxonomy, the hypothesis could indicate students just apply knowledge, but cannot analyze or evaluate a scenario and could think about it.

The next steps of this work include the development of a communication mechanism in order to students could help each other during the studies. The objective is to use the peer tutoring concepts to create a rich learning environment and evaluate the student's development. Other learning strategies will be applied in order to evaluate the SimStructure features to more complex students reasoning, taking into consideration the analysis, evaluation and creation of Bloom’s taxonomy.

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