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Development of STEM Educational Application with Easy Java Simulation in Mining & Metallurgical Engineering—Case Study on Mineral Processing †

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† Presented at the International Conference on Raw Materials and Circular Economy, Athens, Greece, 5–9 September 2021.

Abstract: Although there is a widely expressed need for the adoption of new didactic approaches that promote the active participation of learners, especially in tertiary-level education, research endeavors in this topic are limited. Seeking to contribute to the limited research activity on the application of innovative educational applications in university education, an EJS educational application for 'university level' engineering studies was developed and incorporated in a problem-based learning activity during the teaching of a "particle size-reduction process of ores" topic. Analysis of the research results revealed that the adoption of a STEM educational approach contributed directly to the students' performance, reaffirming the significant prospects arising with the use of modern educational approaches, as well as with the use of innovative educational tools, at tertiary-level education.

Keywords: STEM; educational application; tertiary level education; mineral processing

Citation: Syrmakezis, K.; Tsakalakis, K.; Psycharis, S. Development of STEM Educational Application with Easy Java Simulation in Mining & Metallurgical Engineering—Case Study on Mineral Processing. *Mater. Proc.* **2021**, *5*, 134. https://doi.org/10.3390/materproc2021005134

Academic Editor: Evangelos Tzamos

Published: 26 July 2022

1. Introduction

The transition of students from the secondary to tertiary level of education is accompanied with a change in educational approaches. New approaches are characterized by the strong involvement of the learner in the acquisition of new knowledge during the educational process. This reality highlights the need for change in the established teacher-based model with the adoption of new, modern didactics approaches that promote the active participation of learners.

The adoption of a STEM educational approach as an integrated approach in universities is expected to enhance the participation of the students in the educational process, motivating them towards further development of their understanding and knowledge in their specialized domains. Especially for the students of engineering schools, who use their acquired knowledge to find solutions and to develop appliances, equipment, constructions, and systems, the adoption of a STEM approach seems promising and challenging.

Seeking to contribute to the current limited research activity on the application of innovative educational applications in university education, the current research paper presents the results of the implementation of a STEM educational approach in tertiary-level education through the development and use of EJS educational applications for university-level engineering studies.

Implementation was carried out as part of thesis work for the Master of Science in 'Didactics in STEM' at the School of Pedagogical and Technological Education and focused on the case study of the teaching of "breakage process of ores" as it is taught

in the fifth semester course, 'Mechanical Preparation and Processing of Minerals and Industrial Minerals', at the Mining and Metallurgical Engineering School of National Technical University of Athens.

The research was performed among 38 students who followed the aforementioned course during the academic year 2016–2017. During its execution, the investigation concerned the change in students' performance after the implementation of an educational scenario that was based in a problem-based learning activity that exploits educational tools and applications already developed using Easy Java Simulation (EJS, Francisco Esquembre, Open Source Physics project, Murcia, Spain).

2. Research Scope

Part of the dissertation submitted in partial fulfilment of the requirements for the degree of Master of Science in Didactics in STEM at the School of Pedagogical and Technological Education involved investigation into the potential use of EJS educational applications in tertiary-level education and, more specifically, in the course of Mineral Processing as delivered in the sixth semester of the Mining and Metallurgical Engineering School of the National Technical University of Athens.

To obtain the set research scope, an evaluation framework was designed and deployed with the aim to assess the possibilities and the effects of EJS educational applications in tertiary-level education. The specific framework sought not only to assess the potential benefits of EJS educational application in the teaching process of the specific module, but also to identify the attitudes of the students regarding their adoption in their learning process. In this context, attempts were made to identify answers for the following research questions:

1. What are the attitudes of students who participated in the research sample regarding the adoption of the proposed teaching approach?
2. Is it possible that there was improvement in student performance in the selected module after the use of specific training scenarios that included STEM EJS training applications?
3. Are there differences in performance improvement among students who followed the specific course for the first time and students who repeated the specific course for a second year?

3. Research Methodology

Considering the research scope and goals, the research was designed to be conducted in five stages. The proposed gradual approach was selected so that the conclusions of each research stage could be used for the further stages of the research.

Stage 1: Selection of proper learning module for the development of Easy Java Simulation Educational Application.

The first stage of the research was focused on identifying a suitable learning object of the selected course in order to develop an educational application in Easy Java Simulations with strong characteristics of the STEM educational approach.

Given research constraints, the breakage process of mineral processing comminution was selected as the learning object. Teaching of this specific training module was presenting significant challenges. Specifically, mineral or industrial ores breakage is a dynamically evolving phenomenon, the analysis of which requires knowledge and understanding of different scientific domains such as mathematics, physics, and material mechanics. Moreover, its evolution is defined by three breakage laws (Rittinger, Kick, and Bond laws).

Stage 2: Determination of students' knowledge and understanding level in the selected learning object.

The second stage of the research sought to determine the level of understanding of the students in the chosen learning unit. Following an exploratory–descriptive approach, a cognitive test with gradually elevating difficulty was created, which sought to identify the knowledge and understanding gaps of the trainees in terms of breakage process result (size

reduction phenomenon), the processes of minerals size reduction, and finally, the laws of breakage process.

The designed tests included various types of questions (multiple choice, true or false, and matching exercises). Participants completed the tests without any warnings. The given answers were used for the development of the educational EJS application and for the design of the educational scenario, which included the use of the EJS application.

Stage 3: Investigation of participants' self-regulated learning motivations and strategies.

The aim of the third research stage was to capture the students' self-regulation in terms of their motivations and learning strategies for the specific learning object. For this reason, the Motivated Strategies for Learning Questionnaire [1] was used.

This specific questionnaire was used considering its wide and reliable use [2]. It consists of 81 questions which are divided into two categories that investigate student use of metacognitive and cognitive strategies, and the management of different learning resources. Cognitive strategies are separated into Rehearsal, Elaboration, Critical Thinking, and Organization. Subscales of the metacognitive strategies are Planning, Monitoring, and Regulation. The subscales measuring resource management are Time Management, Study Environment, Effort Management, Peer Learning, and Help Seeking.

The answers of the students were analyzed quantitatively to reach conclusions about their use of metacognitive and cognitive strategies and the management of different learning resources. Based on these conclusions, the students' approach to the specific learning object and, by extension, to the selected course was captured. Therefore, these conclusions were taken into account both for the development of the educational application and for the development of the learning scenario, which was used for the needs of the present research.

Stage 4: Development of educational Easy Java Simulations application and incorporation into the learning scenario.

Based upon the results and the conclusions collected by the previous research stages, an EJS educational application was designed to be utilized in the teaching of breakage process as it is included in the curriculum of the selected course. EJS work panels of developed STEM Educational Application presented in Figure 1. The design and the development of the specific application was carried out in accordance with a STEM educational approach. In other words, its design was made to provide to students the ability to solve real-life problems, which they may face in their future professional lives. Moreover, its design took into account the acquired knowledge of students from other scientific (physics, mathematics), engineering (materials mechanics), and technological courses (mechanical elements of crushing and grinding machines).

Moreover, an educational scenario was designed that incorporated the use of the EJS educational application. The scenario was developed with consideration for participants' knowledge level on the selected learning object (Stage 2), as well as the motivations and learning strategies of the students in the specific course (Stage 3). A problem-solving educational approach was adopted in the development and the deployment of the learning scenario. In addition, the selection of the specific approach was made considering that this specific educational approach is an alternative to the teacher-centered approach, which is characterized by the traditional teaching of the learning object in the tertiary educational level [3].

Stage 5: Deployment of the developed scenario and performance assessment of the participants after the use of EJS application.

During the fifth stage of the research, the designed scenario was deployed. Its deployment took place as a refreshing lecture of the selected learning object. In addition, certain lectures were organized for students who were not able to participate in the scheduled lecture. Three to seven students participated in these lectures.

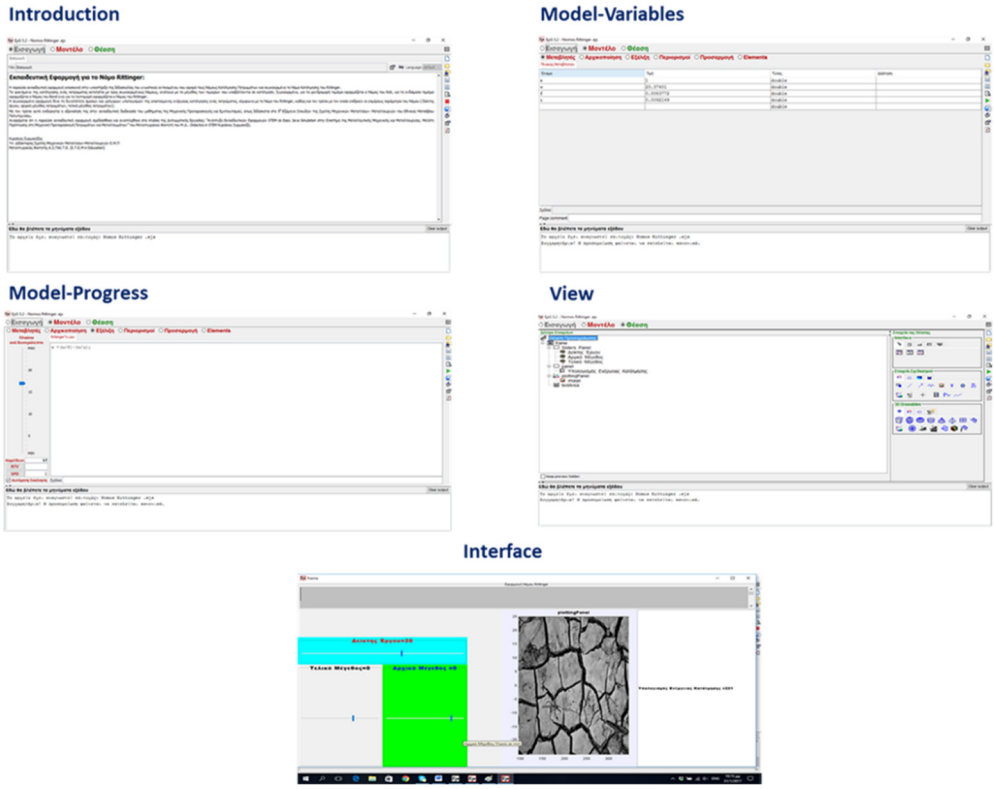

Figure 1. EJS work panels of developed STEM Educational Application.

In all cases, upon the completion of lecture sections, all participants underwent a diagnostic test. The results of the diagnostic tests were used for the determination of educational scenario implementation in student performance.

After statistical analysis, initially, the level of knowledge and understanding that students have acquired about the breakage process after using the EJS application was recorded. Given that the participation of students was anonymous, it was not possible to assess changes in performance at an individual level. For this reason, a comparative assessment of students' performance change took place between the students, who followed the specific course, for first time and for students, who have followed the specific course previous year(s).

4. Research Results

4.1. Analysis of MSL Questionnaires Results

Pintrirch et al. [1] was used to answer the first research question about the attitudes of students in the research sample regarding the adoption of the proposed teaching approach. The given answers were analyzed statistically to reach reliable conclusions about student learning cognitive strategy and resource management.

The most significant ones, which contributed significantly to the development of the EJS application, as well as in the design of the learning scenario, were the following.

- Students want the training material of a course to challenge them to learn new things and stimulate their curiosity, even in cases for which the learning process is difficult.
- The majority of the students consider understanding the curriculum of this course to be their responsibility and it is influenced by their appropriate study.
- Students seek to relate a learning module with other learning modules from other courses already taught, to link different sources in order to understand a learning module in the course, and to relate ideas/concepts from learning modules of different courses, as well as from their own past knowledge.

- Students acquire their knowledge by reading and memorizing information included in their training material. Meanwhile, they try to understand the curriculum of the course, linking the meanings and information they read with the concepts presented by their professor(s) during their lectures.
- Students want to experiment with different ideas and use their critical skills during their learning process.

4.2. Investigation of STEM Educational Application Effect in Student Performance in Understanding and Acquiring Knowledge of the Selected Learning Module

During the second stage of the research, all participants completed a cognitive test with the aim to determine the level of knowledge and understanding of the students in the selected learning module regarding breakage process outcome (size reduction phenomenon), the processes of minerals size reduction, and finally, the laws of breakage process. Their results were used as the performance baseline of the sample. To investigate the effect of STEM educational application incorporation in the teaching of the selected learning module, the test repeated after the intervention of STEM educational application, at the end of the semester.

Analysis results showed that the average performance of the sample increased by one point out of twenty. Seeking to deepen the analysis, the correlation of student performance before and after the use of the learning scenario, which included the EjS educational application, was investigated. For this reason, Pearson correlation coefficient was calculated for the performance of the students in the first and the second test. The calculation of Pearson correlation coefficient showed correlation between the performance of students during the first and the second test.

Based on this fact, a linear regression analysis was conducted with the aim to define the relationship between the performance of the students before and after the use of the EJS educational application. Based on these calculations, the equation that defines the relationship of the performance of students before and after the use of the STEM educational approach is:

$$y = 9.898 + 0.296x, \quad (1)$$

where y is the performance of students' sample after the training intervention and y is the performance of students' sample before the training intervention.

Further statistical analysis showed that the linear regression is statistically important, while ANOVA analysis reached the conclusion that the equation presents strong adaptation.

4.3. Comparative Analysis of Students Who Followed the Selected Module for the First Time and of Students Who Had Followed the Selected Module in Previous Years

Upon the completion of collected answers analysis and the determination of the sample's performance in the different parts of the module, a comparative analysis was carried out with the aim to identify differences in the performance of the students who followed the selected course for the first time and students who had followed the selected course in previous years.

The normality of the two samples tests was tested using Shapiro–Wilk test. Then, Levene's Test for Equality of Variances was applied, reaching the conclusion that the group of students who had followed the selected module in the past presented higher improvement performance compared to the students who followed the selected module for the first time.

5. Conclusions

The principal goal of the present research was to contribute to the investigation of potential deployment of STEM educational approaches in tertiary-level education and, more specifically, in engineering schools. In this context, an evaluation framework was designed and deployed with the aim to assess the possibilities and the effects of EJS educational applications in tertiary-level education.

Reliable conclusions were extracted by analyzing research participant attitudes in terms of their learning motivations and strategies. According to these conclusions, there was a plurality of motivations and learning strategies among the students. This fact supports the argument that engineering students' attitudes and motivations support the adoption of new educational approaches founded on differentiated teaching approaches, such as the exploratory approach and the problem-solving approach.

In this context, the use of innovative educational applications is crucial and helpful, as it proved that there was improvement in student performance in the selected knowledge area. Research results proved performance improvement after the use of STEM educational applications with the use of EJS. The conclusions of the present results are in accordance with similar research that was carried out in other Greek tertiary-level educational institutes in the past [4,5], providing further reassurance that there are significant potential opportunities for the incorporation of STEM approaches in university curricula.

Author Contributions: Conceptualization, K.S., K.T. and S.P.; methodology, K.S. and S.P.; software, K.S.; validation, K.S., K.T. and S.P.; formal analysis, K.S. and S.P.; investigation, K.S.; resources, K.S.; data curation, K.S.; writing—original draft preparation, K.S.; writing—review and editing, K.S., K.T. and S.P.; visualization, K.S.; supervision, K.T. and S.P.; project administration, K.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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