Virtual Laboratory for Teaching Calculus:

an Immersive Experience

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Abstract - **This paper discusses and describes the implementation of a Virtual Learning Laboratory (VLL) for teaching Calculus for Engineering Courses. The VLL is hosted in the virtual world (or metaverse) OpenSim, which is based on free software derived from the proprietary tool Second Life, widespread in the context of virtual worlds. The purpose of this research consists in the integration of a Learning Object (LO) for teaching Calculus in OpenSim metaverse. This solution offers the student collaborative, interactive and dynamic learning situations environment contributing to increase the motivation and resulting in a better quality of learning. The laboratory is being finalized and thereafter will be submitted to efficiency evaluations of its performance as a teaching tool, as well as the usability of its interfaces.**

Keywords: *Virtual Laboratory. Immersion. Calculus.*

I. INTRODUCTION

Data from [8] point to the fact that the Brazilian educational reality still faces a big gap when it comes to the understanding of concepts related to the mathematics discipline. This situation directly affects the performance of students who enter higher education, compromising the qualification of professionals trained by the institutions of the country in the field of Exact Sciences. This situation is also highlighted in several studies [1;6], which point to a high failure rate in the disciplines of Differential Integral Calculus that causes(cause) the evasion in Engineering Courses, not only in Brazil but also in other countries [2].

Once Calculus knowledge is the basis of the Exact Sciences courses and, in particular, for training in Engineering, it is evident the importance of researching strategies that may contribute to solve the students' difficulty in learning Calculus.

In this sense, this research involves the development of a Virtual Calculus Laboratory in an immersive environment, integrating in the metaverse a Learning Object that has been previously validated and approved by mathematics teachers [3]. The integration of the learning objects in the metaverse entails to provide an immersive learning environment that offers the possibility of collaborative learning and high degree of interactivity.

The described work in this article is organized as follows: in section A is elicited the importance of teaching Calculus in Engineering Courses; in section B are presented and discussed some related works; in section C is presented the methodology used to construct the laboratory; in section D are mentioned the preliminary results obtained in this study so far, and finally the considerations and some future work prospections.

II. THEORICAL FRAMEWORK

A. Teaching Calculus for Engeneering Courses

The Differential and Integral Calculus disciplines are present in most higher education courses, in various institutions and are responsible for the necessary theoretical basis for future professionals in the fields of Exact Sciences such as engineering. However, despite its obvious importance, it has been observed throughout the years that these subjects are the cause of most failures in these courses, resulting in several problems such as evasion.

Analyzing the difficulties presented by the students in such disciplines [1] it is said that:

> It is known that most of these difficulties are in basic mathematics contents that are prerequisites for studying limits and derivatives, for example. But it is also believed that the specific contents of Calculus should be exploited in the sense of providing the student a more significant knowledge building, diminishing the specific difficulties of these topics (p. 4).

According to [14], the evasion of students in courses such as engineering, especially in the first year, as well as the lack of basic knowledge, it makes indispensable to seek for ways to meet the students' needs at the same time as the curricular requirements are addressed and the demands of the new information society are maintained.

Also according to [14], trends in the teaching of mathematics have been changed and, among the methodologies discussed are mathematical modeling and the use of computers. This trend can be seen even in Calculus textbooks, Linear Algebra and Differential Equations, which have emphasized the use of mathematical models, the contextualization of the exercises and the possibilities of software use.

Not just for Calculus, but for teaching and learning of mathematics in general, it must be strongly considered the use of technology as a support in this process. For [14]

> [...] Even though the use of technology is not the solution to the problems of teaching and learning of mathematics, there are indications that it will slowly become a catalyst agent in the changing process of mathematics education (p.92).

The use of technology in mathematics allows something fundamental in the formulation of hypotheses and conjectures: the experimentation. The act of experiencing facilitates the student's visualization, of the situation in question, testing several possibilities, which is much more difficult when using only pencil and paper. In addition, as highlighted by [16]:

> This practice is also in harmony with the building knowledge vision that focuses on process rather than product-result in the classroom, and with an epistemological position that understands knowledge as always having a component that depends on the individual (p.46).

Another aspect to be considered is the use of learning objects, a resource that has proven to be very efficient to support students and teachers. Taking into account all these aspects we began the research presented here.

A. *Related Studies*

Areas of knowledge such as Engineering have intense need for laboratory practices, enabling to make viable its understanding [6]. For this purpose, [7] developed a remote application for distance education in the curriculum of Engineering. According to the authors, a differential of their remote laboratory was the offering of a space for collaboration among students, leading them to feel closer and therefore providing a better performance in the proposed experiments.

Nowadays, with the advent of immersive environments, the collaborative practices are widely incited, since the virtual world includes a group of participants who share a workspace, interacting with the same objects and experiencing simultaneous events. Moreover, the sense of active participation is enhanced by offering immersive resources that promote the engagement in practices within virtual worlds [5].

There are several platforms available for the construction of virtual worlds, Second Life (proprietary tool) is one of the most widespread/known nowadays, for example. In the search for solutions that do not entail high costs for educational institutions, [21] performed a comparative study between the metaverse Second Life and OpenSim [22], aiming at investigating the possibilities of implementation of learning spaces in a tool based on open source. Among the advantages of OpenSim, and financial issues, it was also identified the possibility of including different programming languages and the easy usage and installation of a server for the use of interested institutions.

Considering the pedagogical advantages of metaverses, [4] implemented a remote laboratory in OpenSim, which is intended to support students of Engineering Courses of the Federal University of Rio Grande do Sul - Brazil. In this laboratory, the user interacts in the virtual world with replicas of instruments of the educational institution, then his actions are performed in the real laboratory and his results can be visualized on the remote laboratory where the student is allocated.

When it comes to learning objects focused on the learning of calculus [3] describe the construction process of the E_2D Learning Object, developed specifically for teaching Derived. The authors present a set of integrated technologies in the project development, emphasizing the process of building interactive graphics with the support of Geogebra tool.

Due to the fact that Calculus is a discipline of abstract concepts that does not necessarily require concrete practices for its teaching, this research proposes for its study the implementation of a virtual laboratory in an immersive environment that, unlike [4], has no link with the real laboratory. The methodology for its construction and results until the present moment are described in the following sections.

III. RESEARCH DESCRIPTION

A. *Methodology*

The methodology adopted for the development of this study is organized in 4 stages, each one according to its complexity and time. In the first stage are identified the inherent theoretical methods for teaching Calculus in Engineering, learning objects and new computer technologies for education. The second stage involves a survey of solutions in terms of educational software aimed at the area in focus, in addition to the implementation and testing of the necessary infrastructure to allow the use of these tools, such as virtual learning laboratories and immersive environments technologies. The third stage, has a technical characteristic involving the construction of the virtual world, integration of the authoring software related to the immersive environment and, finally, additional programming that needs to be aggregated to the objects inserted in the virtual world to react appropriately to forms of interactivity provided to users and display the provided behavior and reactions. The last step involves the adjustment of the prototype in order to improve it based on the evaluation of teachers and students in terms of the quality of their experience. Fig 1 shows an infographic with the structure of the methodology, presenting the authors, technologies and project implementation in each stage.

We emphasize that this image as the others are presented in Portuguese due to the fact that the Learning Object and the Laboratory derivative from it are destined to Brazilian students, so it does not present versions of its content in other languages.

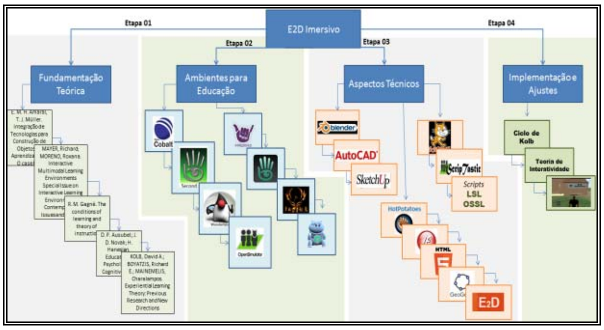

Figure 1. Methodology Infographic

In the attempt to promote a viable learning space for distance learning, the environments that compose the laboratory contain a series of guidelines aimed both to navigational support, such as to promote domain of the content approached in each room, offering guided learning situations, as emphasized by Brito, Tavares and Meneses (2002, p.117):

> [...] the tools to support the distance learning process should provide a mean of efficient multidirectional communication among its participants (mediators, learners and collaborators), to replace the personal interaction between them by a systematic and group action of various teaching resources, providing an independent and flexible learning to students.

Based on these assumptions, aiming to offer an interactive space able to stimulate collaborative learning, but also to promote the possibility of an individualized study, we started the building process of the Laboratory for Teaching Derivatives which is presented in the next section.

B. Results

The results are described in the following two subsections, the first aimed at presenting the learning object used for teaching and learning Calculus and the second focused on the integration of the learning object to OpenSim.

a) A Learning Object for Calculus

Aiming at encouraging the use of computers in teaching Calculus we created the learning object called E_2D - Derivative Distance Education [3]. This material has as main goal to contribute to the teaching and learning of the content of Derivatives, one of the key topics of Calculus, and can be used both to support face-to-face or distance classes.

The E_2D is a simple intuitive web tool and with a satisfactory performance access, since it is available on the Internet. Its contents, materials, navigation style and layout were designed considering the inherent recommendations in the use of multimedia in education [9, 10, 11]. A concern related to the design and implementation of the learning object was also the reduction of cognitive load, as proposed in [9], the creation of conditions for meaningful learning [10], and the internal structure of the learning object according to recommended instructional events [13].

Related to its structure the E_2D respects the established order to a solid learning Derivatives, going through a historic approach, a review of essential prerequisites, such as functions and limits, (which the student may dispense if he does not consider necessary), after exploring interactively the concept and then approaching the derivation rules, applications and exercises, as shown in Figure 2 and Figure 3.

Figure 2. Initial contact with E_2D object

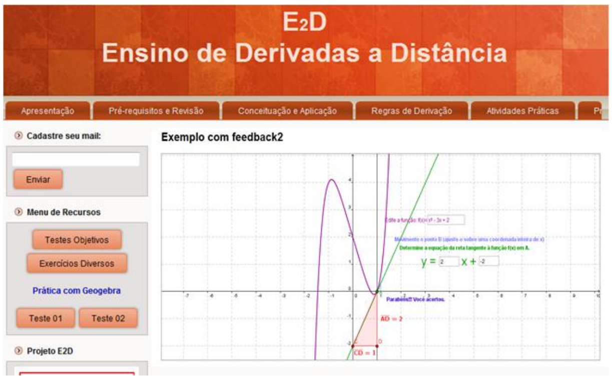

Figure 3. Practical exercises with GeoGebra in E_2D

In order to evaluate the effectiveness and possibilities of application of the object, it was created an online questionnaire, in which was asked to mathematics teachers to answer some questions related to it and, after carefully exploring all sections of the E_2D, they had to register their opinions in general.

A careful analysis of the evaluations allowed us to infer that teachers consulted approved the proposal and were satisfied regarded to the questions queried, saying the E_2D could be used in both teaching modalities mentioned above. Moreover, all showed very relevant contributions to the improvement of the work.

After this stage, the tool was tested with Engineering students in a class of Differential and Integral Calculus I at the Pontifical Catholic University of Rio Grande do Sul (PUCRS).

Once it was established the educational quality of the learning object the work started the next stage that was the integration of the learning object in OpenSim's [22] immersive environment.

b) Integrating the Object to OpenSim

To integrate the learning object in OpenSim environment it was built a classrooms' infrastructure, in Grid model, in the virtual world with access to multiusers. A vision of the Virtual World with the learning object to the teaching of Derivatives is shown in Figure 4.

Figure 4. E_2D Immersive

To meet this demand, a building was originally imported from a free online available repository. In this construction, with the support of editing tools from Imprudence viewer were inserted partitions as to have eight environments as shown in Figure 5. The environments were directed to attend to their respective modules of the original Learning Object, and two of them facing the immersive world ambiance and relaxed interaction among participants, all spaces are described throughout this section.

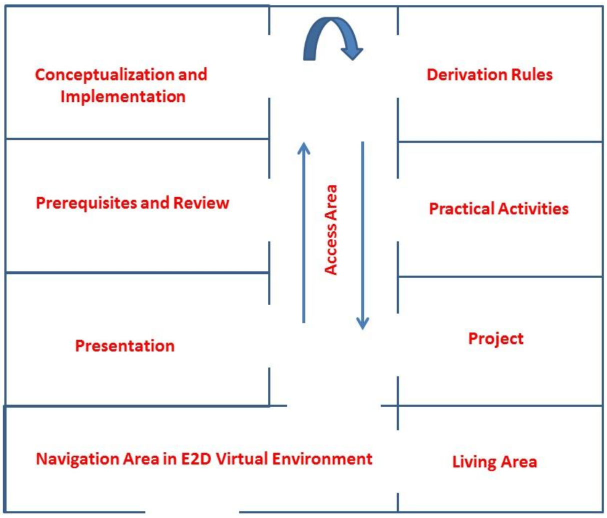

Figure 5. Map of the proposed environment for the E_2D Immersive World.

The first environment is focused on the functional knowledge of the adopted tool viewer, once it was designed to provide familiarity to those who have no knowledge of navigation within virtual worlds. To facilitate the usage of this kind of environment we developed supportive tutorials with step by step demonstrations, created from Wink tool (freeware).

The tutorials built were exported to HTML, stored on the server and loaded in the immersive environment through their links, being possible to be accessed in the same way that videos were uploaded into the environment. The tutorials developed from this tool offer interactivity in their navigation, enabling to forward and backward along the demonstrations, beyond the insertion of audio features.

Besides the available interactive tutorials, images with screenshots and tips of how to exploit it were released into the environment in the form of textures. Along with the tips were proposed some practical activities, such as changing settings viewer and the appearance of the avatar, aiming at promoting familiarity with the resources from the environment. An example it is shown in Figure 6, where the map of the structure of the E_2D environment is initially exposed to students in the lobby.

Figure 6. E_2D structure map available in the Virtual World.

The room 01 is focused on presenting the theme and offers a content-oriented to the contextualization of the knowledge of Derivatives. In this space, we sought to clarify the importance of the application of this knowledge in the several human activities. Based on [12], the purpose of this room was based on the stimulation of integrating the new information to previous knowledge of the student, trying to associate it and to motivate him in his search for knowledge.

To viable this proposal murals were built with information about the applicability of concepts under study, along with supplementary images to the explanations. Additionally, short presentations were built with Voki[1] tool, aimed at discussing the content and also as a navigation support for student in the available rooms in the environment. Voki offers animated avatars, for the verbalization of short texts. The audio is produced by a synthesizer or by the voice of the author of the message. Due to its irreverence and multiplicity of forms adopted by the avatars (which can be changed and customized by the user), Voki becomes a highlighted tool to motivate the

[1] Voki: http://www.voki.com/

student, who gets involved in its creation, or simply in the interaction with it. Fig.7 shows Voki screen, when the avatar enters the E$_2$D environment.

Figure 7. Voki Application makes the environment presentation in room 01.

The animated avatars, built in Voki, have audio and are online stored on the server of the tool itself. Thus, to insert them in the virtual world, it is necessary to associate them with textures and apply them, following the same process done with the videos on the environment. Its interactivity is also maintained, offering the possibility to stop or play the audio as well as to forward or backward it.

In room 1 were available videos about Calculus history and additional links containing information about Isaac Newton and Gottfried Leibniz, notable characters in this area of knowledge.

In room 02 was intended to review the contents necessary for learning the theme, trying to activate previous knowledge of the student, according Ausubel's Subsumption Theory [17], to establish connections to new knowledge that will be constructed during the interaction in this environment. Furthermore, the access to a review of the content-based learning of Derivatives allows overcoming the gaps if the previous knowledge were not well established in the cognitive structure of the student.

For this review, videos from Khan Academy Organization were widely exploited, whose collection is already partly available in Portuguese. The free available videos offered by the organization, have already exceeded the number of 3500, approaching several areas of knowledge, including mathematics.

Besides inserting videos reviewing areas of Mathematics as Sense and Proportion, Trigonometry, Functions, Operations with real numbers, Ranges and Limits, we selected on the web a set of complementary pages to resumption the Derivatives learning concepts. The selection of this material was according to the content that was available in the learning object originated from this study unit.

In room 03 we begin the presentation of the Derivatives content. Therefore, it presents the derivation concept via text and images, distributed in different panels and by spoken explanations, built with Voki tool.
In order to further elucidate related concepts, graphics built from Geogebra[2] software were made available in the virtual world. This tool allows the construction of interactive graphics, contributing to education in several areas of mathematics, including basic education up to higher education levels.

The graphics created with Geogebra in order to explain concepts more clearly like slope, the tangent line, among others, are stored on a server and uploaded to the environment as web content. As in a Learning Object in the immersive environment the student has the opportunity to interact with graphics offered by testing values and observing results, performing an experimentation, which is widely recommended by [17] for the teaching and learning process. In addition to the mentioned materials in this room, videos designed to teach the derivation process were also explored.

The room 04 is intended to teach different techniques of derivation, as Derivatives of basic functions, Product rule, Quotient rule and the Chain rule. This module aims to provide the student cognitive tools able to assist him in the derivation process of various functions. To achieve this goal, it was released a set of solved exercises through text and image, serving as examples for further problem solving. The provision of problems previously solved meets Kolb's cycle [18], more precisely in the framing stage where the learner is in the process of abstraction of the study object.

Besides the examples developed by researchers, we can also count on a collection of web pages, properly selected for the environment. Among the pages there are those belonging to the Khan Academy videos and other content in the selected tool for storing Youtube videos.

As in the other rooms in this environment Voki presentations were inserted, discussing its theme, and specifically instructing the student about his navigation through the environment.

Practical activities have been arranged in room 05, containing a set of first fixation exercises, built in HotPotatoes[3] tool. This tool is based on free software that enables the development of interactive exercises, approaching the following procedures: filling gaps, multiple choice, crossword puzzles, pool and shuffle phrases as it is shown in Figure 8.

[2] Geogebra: http:// http://www.geogebra.org/cms/
[3] HotPotatoes: http://hotpot.uvic.ca/

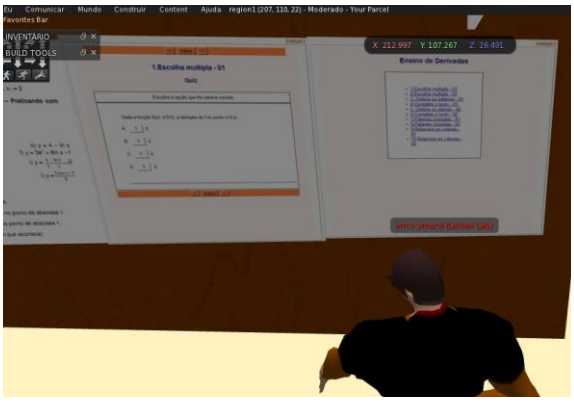

Figure 8. Practical activities on environment

Although these exercises do not have at their core an emphasis on authorship, they serve as a way for the resumption of the content, when the student realizes some knowledge gap when interacting with it. Fixation exercises may also be useful to arouse the student interest, when he finds a space in the educational material to test his knowledge.

Aiming to promote a constructivist approach in learning situations in the immersive environment, a set of ill-structured problems were proposed, considering [19] recommendations. Problems of this type allow the maturation of knowledge at the time that the student not only has predetermined data, but also finds himself compelled to infer information that fill the present gaps in the statements.

In the virtual environment, also textual and audio chat are used and exploited as another educational resource. Students are asked to organize themselves into groups to solve proposed problems. Collaborative learning is emphasized in the immersive learning environment as well as other characteristics of meaningful learning as proposed in [20]: active (manipulative), constructive (articulative / reflective), intentional (goal-directed), authentic (complex/contextual), cooperative (collaborative/convertacional). All these strategies contributed to increase motivation. Motivation is a key-ingredient in human learning. Moreover the immersion sensation that this kind of virtual environment may provide, is a key factor once it could enable permanence, and motivate exploration, thus increasing the possibility of knowledge building.

In room 06, Figure 9, users have at their disposal a test laboratory, where they can exchange information with other students, again using the available tools for synchronous communication in the environment.

Figure 9. Testing Laboratory Prototype

In this space, students will also be able to create objects and upload their content to compose the room. Thus, the environment may aggregate relevant content to the study of derivatives, sharing it with other classmates, thereby increasing the level of interaction of the proposed structure.

Finally, the living area is devoted exclusively to an extracurricular interaction, assuming the role of recreation area for members of the laboratory. This room consists of comfort items like sofa, coffee table, stereo and other resources related to the idea of rest. These elements enhance the immersion feeling and contribute to increase motivation.

For the composition of the room, we searched for 3D models, freely offered on image stock of SketchUp [4] tool. The mentioned tool allows the construction of 3D models that can be exported to COLLADA format (.dae) and imported by viewers like Firestorm.

With this environment, we sought to promote an interaction space that can make students closer in the attempt of group formation and collaborative activities proposed to be accomplished in group.

It is necessary to highlight that in all environments we aimed to explore OpenSim's potential, to ensure greater effectiveness of this solution for offering a virtual learning laboratory.

A set of scripts and programs developed in the metaverse itself, with scripting languages LSL (Linden Scripting Language) [24] and OSSL (OpenSim Scripting Language) was also developed allowing us to add specific features and behaviors to certain elements of the environment.

IV. Considerations

Previous studies of the research group, focused on the use of immersive environments for implementing Virtual Laboratories have shown the effectiveness of these resources as providers of interactive learning spaces with an emphasis on collaborative practices. Other studies like [26] also point that Impact of MUVEs on Students' Motivation results in

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[4] SketchUp: http://www.sketchup.com/

reduction of drop-out rates in Engineering Education. This study also points that immersive environment with collaborative capabilities where students can interact with other peers in a natural way, enable the implementation of learning strategies that foster the development of teamwork skills. This skill is one of the most important abilities that future engineers will require. Despite that importance a research between engineers, presented in [27] showed that interpersonal and personal skills in leadership, management, and multidisciplinary teamwork were the most overlooked aptitudes in college despite their importance in work settings

Based on open source platforms such as OpenSim enable the composition of virtual worlds without the need of costs of software itself, which tends to encourage the creation communities involved in its development. The OpenSim already has a community of developers, engaged in the improvement of this metaverse functionality.

Considering both factors, related to the absence of cost and found support for the use of the tool, this research group has been seeking to develop laboratory practices aligned to this immersive environment.

This context propitiated the resumption of a previous project, which core was the development and evaluation of a learning object for teaching Calculus. Learning object about Derivatives by students registered in a Calculus course, showed that their perception on usefulness of the instructional resource was mostly positive as Table 1 shows.

TABLE I – Learning Object on Derivatives (E_2D) evaluation by students

Question	Answers		
	Yes	***Partially***	***Rarely***
Do you believe that the use of interactive tools for learning is relevant in Calculus course?	38	14	2
Do you believe that using only the E_2D could efficiently assist in the understanding of the subject Derivative?	15	29	1
The E_2D provides enough subsidies so that you can perform the activities envisaged in the environment?	32	22	0
The E_2D introduces the concepts necessary prior to its use?	39	14	2
The E_2D piqued your interest and curiosity?	27	20	3

Taking into consideration the good acceptance of the learning object in assessments related to its content and usability, we chose to migrate it to a virtual world, using its qualities and adding more interactivity to it. Interactivity is a very important feature in any learning environment as stated by [28] . This research reports improvements, derived from intrinsic features of technology based learning environments like: individualization, adaptation and interactivity, intensity and pace of instruction. It also states that when compared with reduced class size, increased instructional time, peer tutoring, and professional tutoring, technology–based instruction was found to be the most cost-effective approach among these alternatives.

The Immersive Virtual Laboratory built aimed allows the student the feeling of active participation in the educational process and possibilitating him/her to even contribute to the settlement of the educational environment with objects and items becoming a more personalized context, fostering his/her greater engagement in learning situations. Moreover, the feeling of virtual presence entails participation in collaborative activities, which increases the learning potential as reported in different studies [29; 30].

Thus, it is believed that the new Virtual Laboratory originated from the integration of E_2D Learning Object with an immersive environment provides a tool to supplement face-to-face classroom teaching and to support distance learning.

The new version of learning object Derivatives using immersive environment, based on the pedagogical model addressed by E_2D learning object, is currently in trial use.

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