SedLMS: LMS extension for Sedimentology teaching and learning

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Abstract—Nowadays, there is no computer support associated with educational platforms for content presentation and evaluation in Sedimentology. Tests and exams rely on complex and expensive laboratory support (samples and binocular microscopes) and paper-based material. In this thesis, an extension to the Moodle platform is created, in which there are used several features to virtualize some laboratory practices in Sedimentology and to be used by the students in order to complement conventional learning in this subject. With this extension, teachers can create virtual sediment samples and then create SedLMS activities with specific contents of one or more existing samples which are shown to the students. In addition, question types that can be used in online surveys are developed. With these tools, it is possible to simulate some laboratory practices which are sometimes expensive and not available anywhere and at any time. Furthermore, not only can teachers submit several types of sedimentary contents (photos, text or laboratory results) but also interact with students in a simple and economic way.

Index Terms—Sedimentology, educational platforms, e-learning, LMS, Moodle, virtual microscopy

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I. INTRODUCTION

Nowadays, the use of information technologies in the sciences education is increasingly important. Furthermore, internet has created opportunities to extend traditional education through a new concept that is called e-learning [1].

E-learning can be defined as “Learning and teaching that is facilitated by or supported through the smart use of information and communication technologies” [2]. These technologies include tools such as interactive whiteboards, voice recorders, computers and specific software applications.

Currently, web-based systems are used with the participation of students and teachers to perform activities, such as sharing course materials and making assessment tests. These systems are called Learning Management System (LMS) [3] and consist of a set of tools and software applications which are able to complement a real teaching/learning environment. This allows learners to study anywhere, anytime and in individual pace. LMSs are used in educational institutions in order to manage e-learning processes and, essentially, to improve the quality of education [4].

E-learning concept is used in several areas, such as Biology, Cytology and Medicine, but has not been explored in Geology (particularly in Sedimentology).

In Sedimentology education, besides regular learning activities, there are more practical aspects because students study and manipulate sediment samples in the labs with microscopes and other laboratory materials.

Taking into account that the materials used in Sedimentology are expensive and due to the wealth of information in several formats, it would be good if a learning platform enabled the collection of Sedimentology material to be delivered and used in the students’ learning and evaluation, in a practical and interactive way for students and teachers.

In Sedimentology, like in other areas such as Biology, Cytology and Medicine, binocular microscopes are used. These equipments are expensive and not available anytime and anywhere. Because of this, a new concept called virtual microscope [5] was created and has been improved over the past years, especially in Health disciplines. Virtual microscopes are computer-based programs that enable viewing, navigating and annotating digital slides acquired from a camera-equipped microscope or a commercial digital slide scanning system.

Moreover, studies indicate that online environments are as good as the traditional environments in the measured learning outcomes and, when administered with care and continually assessed, online laboratories have the potential to complement and enrich geoscience education [6].

A. Problem statement

In Sedimentology, there is a lack of work on specific online learning platforms targeted at the delivery of contents and evaluation of students in geology, in an interactive way.

In practice, currently only complex and expensive laboratory material (loupes and sediment samples), and paper material are used, which in certain educational circumstances could be complemented with online tools and contents given in a less expensive and didactic way.

Furthermore, binocular microscopes and sediment samples may not be available at any time, which implies that students are divided into laboratory sessions.

Sometimes it can be hard for the students to use binocular microscopes in the right way to identify sediments with specific characteristics that teachers want to show. Furthermore, a sample has always differences at different times (as a sample is shaken, sands configuration can be easily changed, which creates difficulties to the teachers when they want to show some sample characteristics). The use of a virtual microscope could improve this by allowing the professor to select appropriate samples with the clear identification of relevant features.

Virtual microscopes have many benefits [5] for learners because they have ubiquitous availability, photos and other data.
of relevant slides or rare samples can be digitized just once and then made available to large audiences simultaneously, among others.

In Sedimentology education, there are used several samples, which differentiate themselves with each other in certain concepts, like the environment and sediment characteristics. In this way, it would be more effective if teachers organized these samples by environment or certain sediment characteristic to be presented to students for learning and evaluation (samples divided by modules) in an online platform, which could be done at any time. These samples could be used for learning and evaluation purposes.

B. Solution

In order to solve the presented problems, the Sedimentology Learning Management System (SedLMS) is developed, allowing the presentation of sediment contents in an organized and didactic way and the students’ evaluation with some of these contents.

As mentioned previously, several types of contents in Sedimentology education are used, such as sample photos obtained in binocular microscopes, histograms and other plots related to relative frequencies of sediments by grain sizes, and videos showing laboratorial procedures. The slide images obtained in microscopes have been successfully implemented in other areas, such as Cytology, however, this solution has not been explored in Sedimentology education (and Geology in general) [5].

In this thesis, it is created a system that focuses on taking advantage of online resources and concepts that emerged in the last years, such as the e-learning. Consequently, an online educational platform is provided in order to improve Sedimentology education.

C. Results

In general terms, the main result is the virtualization of laboratory work in Sedimentology, namely the creation of a virtual microscope and virtual samples. This results in an independence of binocular microscopes and other materials that are expensive and not available at any time and anywhere.

Moreover, this can be used in learning and evaluation contexts. In the learning context, teachers can create SedLMS activities with contents of one or more samples (such as photos to be used with the virtual microscope, plots of relative and cumulative frequencies by grain size, and descriptions) which can be used by the students. In the evaluation context, teachers can make quizzes with questions related to Sedimentology which include the application of a virtual microscope or even the students drawing plots. In the virtual microscope, teachers can add markers into the samples’ photos and make questions about these markers. Consequently, evaluations can be different for each student since used samples and markers can vary.

In addition, these evaluations are more precise because teachers can indicate specific points of the sediment samples’ photos with markers (sediments), in contrast to the real binocular microscopes, in which the samples change over time.

D. Document outline

In this document, we begin by studying the state of conventional teaching in Geology, particularly the Sedimentology.

Then, in the background chapter (Chapter II), we analyse the e-learning concept: how it is generally used in education and how it can be applied to Sedimentology, in particular. To finalize the background chapter, we present supporting tools that are already used in education of subjects similar to Sedimentology.

Moreover, in the Chapter III, we describe the design (requirements and architecture) and the implementation of the Sedimentology Learning Management System (SedLMS) and the question types to be used in online tests. These modules allow the virtualization of laboratory practices in Sedimentology.

Finally, the main achievements of this work are described, which correspond to the accomplishment of the proposed work, and we analyse at which point this system can be improved in the future, with suggestions of work that could be done.

II. BACKGROUND

In this chapter, we study the actual state of the concepts and areas related to this work. We start by describing the conventional learning and teaching in Geology and, particularly, in Sedimentology, focusing on the type of materials delivered in schools for Sedimentology learning and teaching purposes.

Then, we research how e-learning is described in literature: how it is defined and, essentially, the advantages and disadvantages of e-learning relatively to the traditional teaching.

Finally, we present some of the existing educational tools used in other fields that can be relevant in the presentation of contents through technologies in an interactive way, namely those which use the virtual microscope concept and LMS.

A. Sedimentology teaching

Sedimentology learning in Portugal is done in several degrees of education, from elementary to university one. At high school level sedimentary rocks are studied in different contexts [7] considering the frequent presence of body and/or trace fossils in these rocks. The study of these fossils provides information about ancient organisms that once lived on Earth and, simultaneously, this study could give valuable paleoecologic insights.

Consequently, the study of sedimentary rocks is very useful. It is stated on the Geology high school program that the appreciation of the practical work as fundamental in learning and teaching processes is a great challenge, which includes several activities, going from activities dependent on paper to those requiring a laboratory presence or field trips. With these activities, students can develop diversified skills, such as the use of stereo or petrographic microscopes, the graphical presentation of data and the elaboration of practical reports. In the following subsections, the topics covered in Geology (Sedimentology in particular) higher education are explained.
The conventional education of Geology in schools involves lessons related to the following subjects: Petrology, Mineralogy, Sedimentology, Paleontology, among others [7], [8].

Specifically in Sedimentology and other areas related to rocks and minerals, there are several processes in learning and assessment of the students, which can be divided into four categories: learning objectives, activities, resources and assessment [9].

In learning objectives, we need to consider the type of concepts a student must learn, such as: the origin, composition and classification of sedimentary rocks; mineral chemistry and classification; optical properties of minerals in thin sections; relationship between mineral associations; and rock textures and tectonic environments.

To consolidate these concepts, the students must participate in several activities in class or even through an online educational platform, responding to quizzes.

These activities include the use of some physical materials in class, such as mineral samples and microscopes, and the use of some online resources, such as web pages and other documents.

Finally, in assessment, it is time to test the students knowledge through practical exams in labs, which involves the allocation of students into laboratory sessions [7]–[9].

This implies that the materials’ availability is not full-time and depends on the number of people using the same material.

Furthermore, the process of collecting several samples and the use of complex materials such as the microscope can be very expensive.

One solution to mitigate these problems is the use of virtual microscopes to replace traditional teaching strategies.

Virtual microscopes have been adopted in several areas, such as health professions including medicine, dentistry and veterinary sciences [5], and these are computer-based programs that enable viewing, navigating and annotating digital slides (photos) acquired from a camera-equipped microscope.

On the other hand, plots of several types are frequently used in Sedimentology classes, such as the plots of relative and cumulative frequencies by grain size, and the ternary diagrams for samples composition classification purposes.

The use of these contents (such as photos and plots) can be highly improved with online platforms.

B. E-learning

There are several definitions of e-learning in literature: to Gogan [10], this term represents the use of new multimedia technologies and the internet to improve the quality of learning by facilitating access to resources and services, as well as remote exchange and collaboration.

We have had an increasingly high interest in e-learning in the last years, not only from the commercial organizations, but also from the academic institutions. At a global level, it can be well observed that the market for educational products and services is rapidly expanding.

E-learning has become increasingly important in the field of higher education and educational communities for various reasons, such as the rise of information and global economy.

E-learning is advantageous in time and costs reduction, in contribution to student independence, self-motivation, creativity and other characteristics [11]. It also allows the repetition of subjects for the students as much as they want and an unlimited number of participants to benefit from the same training [3].

Despite the indubitable advantages of using this concept, there are some studies about inquiries done to students and teachers, like the one made in New Zealand by Guiney [12], which concludes that the delivery of web-based courses (courses fully taught via e-learning) has grown, but this mode has had lower growth than the delivery that blends e-learning and other modes.

Relatively to e-learning concept, it is necessary that there is an online platform supporting teaching and learning in an educational institution, which provides management, distribution and sharing of learning contents, student tracking, assignment management and online peer collaboration. This platform is called as Learning Management System (LMS) [13].

The two most used LMSs are the Blackboard and Moodle platforms [14].

The Blackboard platform [13], developed by Blackboard Inc., is a web-based LMS designed for students, allowing them to participate in online classes and providing a complete course management system in a flexible way.

This system offers features that allow the delivery of education through internet, such as:

- **Creating courses**: through easy workflow, it is possible for instructors to use the wizard to complete the initial setup of a course;
- **Course management**: allows teachers to update any feature of the course;
- **Course content**: allows teachers to post articles, materials, assignments, videos, etc;
- **Assessments and surveys**: allows instructors to deliver online, automatically scored assessments and surveys;
- **Assignments**: can be posted and the students are able to complete and submit assignments online.

The main problem of this platform is the fact that it is closed and the price depends on how many licenses are used. However, this platform is a powerful system and in the last years, over 20000 organizations signed up with more than 20 million users which show the popularity of this company.

When the expenses are not relevant to a company, this is a good solution because an institution can pay to have the features as they want [14]. Apart from educational solutions, due to its flexibility, efficiency, customization and completeness, this platform can be used by governments or business associations [15].

The Moodle platform represents one of the most widely used open-source e-learning platforms, that enables the creation of a course website, ensuring their access only to enrolled students. In a functional perspective, it has easily configurable features, allowing the creation of student assessment processes (quizzes, online tests and surveys), besides offering a wide variety of complementary tools to support the teaching and learning process [16].

Moodle, as a robust open-source e-learning platform, was used and developed in the last years by global collaborative
effort of international community. Moodle is designed and continually improved to provide educators, administrators and learners with a single, robust, secure and integrated system to create customized learning environments [17].

Like many successful open-source systems, Moodle is structured as an application core [18], surrounded by numerous plugins to provide specific functionality. Moodle is designed to be highly extensible and customizable without modifying the core libraries, as doing so would create problems when upgrading Moodle to a newer version. In this way, the ones who want to extend Moodle core functionalities can create their own plugins. Plugins in Moodle can be of different types: authentication, activity modules, among others.

C. Supporting tools

In this section, we present an overview of some of existing tools, platforms and other work related to online support in education and virtual microscopy which can be relevant in this thesis.

1) Virtual Microscope for Earth Sciences Project: The Virtual Microscope for Earth Sciences Project [19], owned by The Open University, is a teaching tool in Earth Sciences that gives access to rock collections. This tool allows users to examine and explore minerals and microscopic features of rocks.

Every rock sample is accompanied by a virtual thin section so that it is possible to study the mineral optical properties. For each sample, it is possible to use several tools, such as zoom feature, simulation of lightning conditions and measuring tools. In the Figure 1, it is shown an example of a rock’s virtual thin section in which can be used some features, marked with red lettered circles:

- A: Choose the source light, which can be Plane Polarised Light (PPL) or Cross Polarised Light (XPL);
- B: Zoom feature;
- C: Measuring tool (angles or distances);
- D: Rotation feature.

![Figure 1. Virtual microscope’s features [19].](image)

However, this platform is not integrated into a LMS.

2) NYU School of Medicine Virtual Microscope: The New York University (NYU) School of Medicine Virtual Microscope [5] is an online platform that makes use of the virtual microscope concept in the Histopathology discipline. This project is divided into two components: a script to convert images produced by commercial slide scanners into a specific format and a web-based viewer application.

Relatively to the web-based viewer application, the window consists of a main viewing area with a mini-map to provide a navigational overview. One of the main features is the permission to any user to annotate slides with both markers and metadata in the following categories: source organism, tissue/organ type, stain, developmental stage, preparation, section type, among others.

At the end, after one semester of piloting this system, the school chose to abandon the use of traditional microscopes in favor of this virtual microscope system, having this solution empowered learners to have greater control over their content and work together in collaborative groups [5].

However, this platform is not integrated into a LMS.

III. SedLMS

In this chapter, we first present the requirements which the SedLMS system has to accomplish regarding to data and functionalities.

Moreover, we describe an architecture that must be used to solve the problem proposed in this work and the implementation of the entire system, composed by the learning (SedLMS activities) and evaluation (question types) components, including the used technologies.

Furthermore, we analyse the results of the test done by some specialists with our system.

A. Requirements

The users of this system are students and teachers of an educational institution. Only teachers can add new data to the system. The new contents inserted by the teachers are samples, SedLMS activities and evaluations. Students will access SedLMS activities and solve evaluations.

1) Sample data: A sample should contain: a name and weights of sediments by dimensional interval (φ). These weights are acquired after the separation of sediments by grain size, using one sieve for each size. Optionally, a sample can also contain latitude and longitude coordinates of the place where the sample was collected, a generic description of the sample and binocular descriptions (texture, calibration, roundness, brightness and surface state).

Additionally, each sample can contain photos, which are stored in a file repository, and the rest of data (descriptions and others) is saved in the server database.

Relatively to the photos, some features, such as measuring tools (to estimate sediments sizes in photos) and zoom (virtual microscopy), can be used.

The weights of sediments by dimensional interval are used to construct relative and cumulative frequencies plots.

After creating a new sample, a teacher can import photos to the system to associate with this sample and, if it is supposed to use that photo in microscopy analysis, a teacher must insert a dimensional reference for each image that is used to calculate the photo’s scale, in pixels/micrometers. Students can use
measuring tools (like a scale ruler and a custom cursor) to make distance measurements in these images correctly.

For each sample, teachers can add annotations in specific points or areas in relative and cumulative frequencies plots and can add markers on photos with descriptions in the following categories: dimensions, composition, sphericity, roundness, brightness and surface state.

Up until this point, we only have a collection of samples which are not organized or even divided into modules to be shown to students.

2) Learning contents: Students do not have direct access to samples, because the samples can be used in this system for learning and evaluation purposes. After created, samples are private for students and are only available for the teachers. Then, the teachers have the possibility to choose which samples are used for learning and evaluation purposes. This way, students can only view the sample contents selected by the teachers for learning purposes. To provide samples in an organized way and/or divided into modules, a teacher can create SedLMS activities. Each SedLMS activity has a name and a description.

SedLMS activities are available for students and can contain one or more contents of one or more samples. Moreover, teachers can attach an additional description for each of these contents. The purpose of these activities is to provide a solution to organize existing samples and to allow students to compare different samples in a specific type of sample content, such as the relative and cumulative frequencies plots. Moreover, it allows to take advantage of using the same samples in all the SedLMS activities, into the same course. In other words, a sample is only created once (through an interface) and it is used over and over again, for learning and evaluation purposes.

SedLMS activities and samples are the learning component of this system.

3) Question types: An effective LMS may also provide support for the evaluation of the students. In this way, some question types related to sedimentary contents have to be created.

In Sedimentology, it is important that students can identify and classify sediment samples according to different characteristics, such as dimensions, roundness and sphericity of sands. Students use binocular microscopes in classrooms to classify sediment samples. However, this type of equipments is limited and cannot be used any time and anywhere. In addition, it can be hard to identify certain sediments and to clearly explain to the teacher certain sediments characteristics.

These problems can be solved (in evaluation contexts) by creating some question types into a LMS to explore these concepts.

Moreover, different types of plots are used in Sedimentology to quantify sediments (usually percentages are used) by grain size or even according to the type of composition, which include: 

- histograms, frequencies curves and 
- ternary diagrams.

In this work, one of the main goals is to develop interactive question types which extend the existing question types. In addition, sedimentary contents already created in the system must be easily chosen by the teachers (through an intuitive interface) to be used by the students when answering questions on quizzes.

In this thesis, we create three question types: Sedimentology markers, Sedimentology multiple choice and Draw plot. Each of these question types is divided into several sub question types. The most important sub question types are presented in the Table I, with particular emphasis for the contents that the teachers must provide in the question text, and the type of answer that the students must give.

B. Architecture

The Figure 2 presents a block diagram model composed by the components of the SedLMS system.

As we can see in a block model view, we have one component in front-end (presentation to the clients) and the others in back-end (working in the web server/servers).

Relatively to the components in back-end, we have components responsible for processing and storing data related to samples, SedLMS activities and developed question types. For each of the latter, we need an editor where content is created, modified or removed: Sample editor, Content editor and Question editor.

A dashed borderline in the question types component indicates that this is extended by us in this work. The red components are used in this work and are provided by the Moodle platforms. The other components are fully developed by us.

Samples, SedLMS activities and questions data must be stored in the file repository (images) and in a relational database, and this data can be interchanged between existing components (for example, sample data can be used in sample, SedLMS activities or question contexts).

Sample contents are the background of the SedLMS system: these contents are used in SedLMS activities and the questions developed in this work (related to Sedimentology).

To turn this system into an effective LMS, we decided to use Moodle to provide the basic features of an educational
Teachers choose a sample photo on an existing sample photo and the students give a textual answer (essay), using virtual microscopy tools (zoom and measuring tools) on the sample photo.

Q2: Teachers choose a sample photo and the students give a textual answer (essay) and mark some sediments on the sample photo, using virtual microscopy tools (zoom and measuring tools).

Q3: Students draw a histogram and give a textual answer (essay).

Q4: Students draw a curve and give a textual answer (essay) when answering to a question.

Q5: Teachers draw a ternary diagram (including a title and three axis) with some points, and students must give a textual answer (essay).

Q6: Teachers draw a ternary diagram (including a title and three axis), and students must give a textual answer (essay) and mark some points on the ternary diagram.

Q7: Teachers choose a sample photo on question text and mark some sediments (with different marker colors), and students choose one of the possible answers (multiple choice), using virtual microscopy tools (zoom and measurements) on the sample photo.

Q8: Teachers choose a sample photo on question text and draw some plots (or choose existing plots in SedLMS activities), and students choose one of the possible answers (multiple choice).

Q9: Teachers draw a ternary diagram (including a title, three axis and points), and students must choose one (or more) of the possible answers.

### Sedimentology multiple choice

<table>
<thead>
<tr>
<th>Question type</th>
<th>Description</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Teachers mark some sediments on an existing sample photo and the students give a textual answer (essay), using virtual microscopy tools (zoom and measuring tools) on the sample photo.</td>
<td>Text</td>
<td>Photograph + Markers</td>
</tr>
<tr>
<td>Q2</td>
<td>Teachers choose a sample photo and the students give a textual answer (essay) and mark some sediments on the sample photo, using virtual microscopy tools (zoom and measuring tools).</td>
<td>Text</td>
<td>Choice A, Choice B, Choice C, Choice D</td>
</tr>
<tr>
<td>Q3</td>
<td>Students draw a histogram and give a textual answer (essay).</td>
<td>Text</td>
<td>Photograph, Histogram</td>
</tr>
<tr>
<td>Q4</td>
<td>Students draw a curve and give a textual answer (essay) when answering to a question.</td>
<td>Text</td>
<td>Photograph + Curve</td>
</tr>
<tr>
<td>Q5</td>
<td>Teachers draw a ternary diagram (including a title and three axis) with some points, and students must give a textual answer (essay).</td>
<td>Text</td>
<td>Photograph + Markers</td>
</tr>
<tr>
<td>Q6</td>
<td>Teachers draw a ternary diagram (including a title and three axis), and students must give a textual answer (essay) and mark some points on the ternary diagram.</td>
<td>Text</td>
<td>Photograph + Markers</td>
</tr>
<tr>
<td>Q7</td>
<td>Teachers choose a sample photo on question text and mark some sediments (with different marker colors), and students choose one of the possible answers (multiple choice), using virtual microscopy tools (zoom and measurements) on the sample photo.</td>
<td>Photograph + Markers</td>
<td>Choice A, Choice B, Choice C, Choice D</td>
</tr>
<tr>
<td>Q8</td>
<td>Teachers choose a sample photo on question text and draw some plots (or choose existing plots in SedLMS activities), and students choose one of the possible answers (multiple choice).</td>
<td>Photograph + Plots</td>
<td>Photograph + Plots</td>
</tr>
<tr>
<td>Q9</td>
<td>Teachers draw a ternary diagram (including a title, three axis and points), and students must choose one (or more) of the possible answers.</td>
<td>Photograph + Markers</td>
<td>Photograph + Markers</td>
</tr>
</tbody>
</table>

### TABLE I

**Sub question types that can be used in Sedimentology.**

<table>
<thead>
<tr>
<th>Sub question type</th>
<th>Description</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedimentology markers</td>
<td>Teachers mark some sediments on an existing sample photo and the students give a textual answer (essay), using virtual microscopy tools (zoom and measuring tools) on the sample photo.</td>
<td>Text</td>
<td>Photograph + Markers</td>
</tr>
<tr>
<td>Q2: Teachers choose a sample photo and the students give a textual answer (essay) and mark some sediments on the sample photo, using virtual microscopy tools (zoom and measuring tools).</td>
<td>Text</td>
<td>Photograph + Markers</td>
<td></td>
</tr>
<tr>
<td>Q3: Students draw a histogram and give a textual answer (essay).</td>
<td>Text</td>
<td>Photograph, Histogram</td>
<td></td>
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<tr>
<td>Q4: Students draw a curve and give a textual answer (essay) when answering to a question.</td>
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<td>Photograph + Curve</td>
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<td>Q5: Teachers draw a ternary diagram (including a title and three axis) with some points, and students must give a textual answer (essay).</td>
<td>Text</td>
<td>Photograph + Markers</td>
<td></td>
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<td>Q6: Teachers draw a ternary diagram (including a title and three axis), and students must give a textual answer (essay) and mark some points on the ternary diagram.</td>
<td>Text</td>
<td>Photograph + Markers</td>
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<td>Q7: Teachers choose a sample photo on question text and mark some sediments (with different marker colors), and students choose one of the possible answers (multiple choice), using virtual microscopy tools (zoom and measurements) on the sample photo.</td>
<td>Photograph + Markers</td>
<td>Choice A, Choice B, Choice C, Choice D</td>
<td></td>
</tr>
<tr>
<td>Q8: Teachers choose a sample photo on question text and draw some plots (or choose existing plots in SedLMS activities), and students choose one of the possible answers (multiple choice).</td>
<td>Photograph + Plots</td>
<td>Photograph + Plots</td>
<td></td>
</tr>
<tr>
<td>Q9: Teachers draw a ternary diagram (including a title, three axis and points), and students must choose one (or more) of the possible answers.</td>
<td>Photograph + Markers</td>
<td>Photograph + Markers</td>
<td></td>
</tr>
</tbody>
</table>

This solution includes a standard Moodle database related to all the data that is necessary in an educational platform and it allows to provide an online environment which is reliable, secure, efficient, among others. Between this data, there are informations regarding the users, courses, repositories and others relevant in learning management.

### C. Implementation

In this section, we explain Moodle and the complementary libraries used.

1) **Moodle:** First of all, we start by the LMS we use: the Moodle platform (version 3.1). Besides being open-source, this platform provides all the features that we need (previously described). In general, there are developed one activity module/plugin (SedLMS) and three question types to work in quizzes of the Moodle platform. Each of these question types is divided in several variants. These modules follow the same standards/practices of the other activities and question types in Moodle. Each of these modules is composed by back-end code, in PHP: Hypertext Preprocessor (PHP) language, and front-end code, in JavaScript, Hypertext Markup Language (HTML) and Cascading Style Sheets (CSS).

   a) **Server-side implementation:** In the server-side (for testing purposes), it is used XAMPP (installed locally on a personal computer), which is a fully functional web server package including a web server (Apache, version 2.4), a database (MySQL, version 5.5) and a scripting language (PHP, version 5.4) [18]. The Moodle platform (including the file repository) is installed in this Apache server and a MySQL database is created to be used in the Moodle platform (which can be managed through the phpMyAdmin utility included with XAMPP or even an external resource, such as MySQL Workbench).

   b) **Client-side implementation:** In the client-side, the users need to have a web browser that supports JavaScript and other languages related to the layout of the pages (HTML, CSS), jQuery, among others. In the SedLMS system architecture, there are several Uniform Resource Locator (URL) endpoints to which the clients can access.

2) **Complementary Libraries:** Some complementary libraries are used in the SedLMS system, namely the Leaflet 0.6.4 [20] and Plotly 1.23.1 [21].

   **Leaflet** is an open-source JavaScript library that allows the use of virtual microscopes and works efficiently in most existing computers and mobile platforms, besides being easily extensible to most plugins. Leaflet API [20] is well-documented and divided into categories, has a simple and readable source code, and is similar to Google Maps API [22], with the difference that the first is totally free. These libraries are mainly used with geographic maps, but not only in these cases. It is possible to use all the functionalities that are used in geographic maps (such as the zoom feature) in images that are not geographic: in customized images. In Sedimentology, these functionalities can be applied in the virtualization of real microscopes and sediment samples photos.

   **Plotly** is an open-source JavaScript library [21] that allows the creation of plots into web pages, developed in the top of d3.js and WebGL. Mostly plotly graphs are drawn with SVG (Scalable Vector Graphics), which offers great compatibility across browsers and uses stack.gl for high performance 2D
and 3D charting. This library allows the use of 20 chart types, which include 3D charts, statistical graphs and SVG maps. In Sedimentology, this can be helpful in the construction of plots of relative and cumulative frequencies by grain size and ternary diagrams.

Moreover, the OpenStreetMap is used to provide geographic maps to show the places where the samples are collected.

D. Evaluation

In this section, two main topics are explained: functional and user validation.

1) Functional validation: This subsection describes the implementation of the functional requirements.

a) Install the modules into the Moodle system: Before anything else, the administrator needs to put the SedLMS folder in the “mod” directory and install it, which can be done in the administration page into Moodle. With this module, it is possible to create samples and SedLMS activities related to Sedimentology. Then, the question types developed in this thesis (which are based on the SedLMS module) must be placed in the “question/type” directory and installed in the same way (in the administration page). After that, it is possible to use questions related to Sedimentology in quizzes. This procedure follows the good practices and standards related to the installation of new modules into Moodle.

b) Create a sample: In this system, a sample is a group of specific contents related to a real sediment sample. These contents are based on photos, plots and descriptions. As it is intended to use this type of contents in both learning and evaluation contexts, these samples are initially private. Teachers can reuse some or all the contents from one or more samples with ease, supplied to the students in a didactic and organized way, for learning purposes or even used in quizzes.

When creating a new sample, the teacher has to introduce a name to the new sample. Moreover, the teacher can introduce latitude and longitude coordinates of the place where the sample was collected, sample descriptions and weights of sediments (in grams) by grain size \(\phi\) acquired in a granulometric analysis.

c) Edit sample: Teachers can edit existing samples by changing sample data: sample descriptions and weights of sediments (in grams) by grain size \(\phi\). Moreover, teachers can import photos to be associated with a sample and they can add markers on that photos containing descriptions in several categories, such as composition and roundness, or even annotations to plots that are shown to the students.

d) View a sample: While viewing a sample, several contents are presented, which are following described. Relatively to the descriptions within a sample, there are presented, in addition to a general description, two tables: one of them contains sample descriptions and another contains statistical parameters calculated through the method of moments. Moreover, it is displayed a map to show the location where the sample was collected. One of the samples’ contents is a virtual microscope, which is used with sample photos and additional features. The main purpose of this virtual microscope is to simulate some features of the real binocular microscope. In the Figure 3, it is shown an example of virtual microscope with several functionalities. It is possible to use measuring tools, such as a customized cursor which can be useful in the determination of grains size categories (letters A, C and D) and a scale ruler (letters F and G) to calculate more exact dimensions. Moreover, an user can: switch between existing photos (letter B) and select the markers of a specific category (letter E).

In addition, it is also possible to view specific category descriptions by markers: dimensions, composition, roundness, sphericity, brightness and surface state (letter E).

Finally, the weights of sediments inserted by the teacher are used to construct automatically the relative and cumulative frequency graphs. In these graphs, the teacher can enter annotations in specific points or in specific areas (rectangular or free-form).

After creating several samples, the teacher can create SedLMS activities that are made available to the students. A SedLMS activity is made up of specific contents of one or more samples and additional text. Teachers can, for example, create an activity only with relative and/or cumulative frequency graphs of several samples and another only with virtual microscopes, among others. They can also create SedLMS activities with, for each activity, sediment samples collected from a specific place or environment. When creating a new SedLMS activity, the teacher has to introduce a name and a description. After this, the teacher is redirected to a web page with the possibility of adding new contents.

e) Create a SedLMS activity: The SedLMS activity allows the creation and edition of Sedimentology contents into Moodle (SedLMS activities). These contents are based on the existing sample contents: teachers can select partial/total contents of existing samples and they can attach a description to these contents. Then, these contents are presented to students for learning purposes. With this type of activity, teachers can also organize the existing samples according to a specific parameter (for example: the environment where the sample is collected).
Teachers can create SedLMS activities, which is done similarly to the other Moodle’s modules, like quizzes and lessons.

f) Define quizzes: Using the tools previously described, it is possible to create quizzes with questions related to Sedimentology. Thus, three types of questions (Draw plot, Sedimentology markers and Sedimentology multiple choice) related to Sedimentology are developed, with several variants which are following described.

Questions of Draw plot type can be used to evaluate the knowledge of the students relatively to granulometry (relative and cumulative frequencies of sediments by grain size). These questions allow the students to draw a plot of relative and/or cumulative frequencies. For example, the teacher can choose sample photos or textual descriptions in which a student has to draw a plot corresponding to the requirements stated in the question text. To add a new question of this type, a teacher must give a question text, and choose a default mark and a general feedback to the question. Moreover, the teacher must choose the type of plot that students have to draw (relative or cumulative frequencies plot). These questions can be done just for practice of the students, in which the teacher provides an example of possible answer that can be shown to the students after the conclusion of the exercise, or in evaluation mode, which must be corrected manually by the teacher.

The second type of question (Sedimentology markers) is based on the introduction of markers on a virtual microscope. In this type of question, the teacher can define who adds the markers on the map, that can be the teacher himself or the student (two variants). Teachers define also the sample that is used. This type of question is useful for questions where the student has to describe certain sediments on a sample’s photo according to their sedimentological characteristics or the student has to add markers on the virtual microscope to highlight sands that have certain characteristics specified by the teacher in the question statement.

Finally, Sedimentology multiple choice question type can be used to evaluate knowledge involved in the previous question types: identification and classification of sediment samples with certain sedimentological characteristics, and granulometry. To add a new question of this type, a teacher may give a question text, choose a default mark to the question and a general feedback like in the other questions. Moreover, the teacher must choose the type of question (variant), related to the type of answer that the students must choose in these multiple choice questions (simple answer, markers, plots or points in ternary diagrams), and a sample (like in the Sedimentology markers questions) that is used on the virtual microscope.

g) Solve quizzes: First of all, while answering to Draw plot questions related to plots of relative and cumulative frequencies, there are a select and an input box elements. In the select element, a student can choose a \( \phi \) (phi) value, related to a dimensional interval of grains size and in the input box the student must introduce a decimal value (from 0 to 100\%) and, finally, a click on a button introduces this new value to the plot. Plot is rebuilt as a student introduces new values, clicking on the “Add Point” button. Moreover, in their response, students can text some lines to justify the plot they draw (Figure 4).

Another variant of this question type is related to ternary diagrams. In these cases, the student marks points on a ternary diagram through an interface, like it is shown in the Figure 5 with red lettered circles. The students must mark points through clicks on the ternary diagram (red circle with the letter C). These points can have different colors: red, green, blue, yellow or black (red circle with the letter A). Moreover, students can clean all the points introduced on the ternary diagram (red circle with the letter B) and, in their response (circle with the letter D), students can text some lines to justify the plot they draw.

In the second question type (Sedimentology markers), the interface presented to the students is shown in the Figure 6, which is composed by a virtual microscope and other features which are described previously. The student must answer in the blank space which type of sediments are those which were marked by the teacher or the student has to mark sediments with certain characteristics proposed by the teacher.
Finally, in relation to the interface presented to students in Sedimentology multiple choice questions, a virtual microscope can be used, containing a sample photo and some utilities which can be also used in the samples, like a custom cursor and a scale ruler.

In the case that the choices are markers, these markers are identified on the virtual microscope (Figure 7). Otherwise (in the cases that the choices are simple text or plots), the use of a virtual microscope is optional.

2) User validation: In order to evaluate our system, we asked people related to Geology to experiment some questions developed with our system, and to give their opinions regarding the usability, potentiality and innovation of the system (evaluation component). In these questions, the main features developed in the SedLMS system, related to virtual microscopes, ternary diagrams and histograms are tested. We had the contribute of five specialists in Geology that tested a quiz with questions developed with the SedLMS system. From their responses, we conclude that probably some of the specialists have reluctance to see e-learning substituting/changing the traditional teaching of Sedimentology, but they have no doubts that e-learning solutions would be a great complement to traditional teaching. In general terms, they think that the virtual microscope is the most innovative and motivating feature, besides being useful in the identification of sediments and determination of grain sizes. Furthermore, almost all the interviewed specialists consider that this feature is really helpful for the study of rare samples. In relation to ternary diagrams, the specialists think that it is an innovating and motivating tool.

Finally, when asked about global questions of the system, almost all consider that the SedLMS system is easily used, it is advantageous in Sedimentology learning and evaluation and it has great potential to be successful.

IV. CONCLUSION

The work described in this thesis consists in the creation of a system composed by a plugin and extended question types to work in the Moodle platform, which allow the display of contents (learning component) and evaluation in topics related to Sedimentology in schools (evaluation component), using concepts that have been implemented successfully in other areas, such as virtual microscopy and e-learning. The main result is the virtualization of laboratory practices in Sedimentology subjects. This system improves Sedimentology teaching and it allows teachers to deliver new content and make complete tests.

The tests and exams used in the conventional teaching of Sedimentology rely on complex and expensive laboratory equipment (binocular microscopes and sediment samples) and paper material. In addition, conventional laboratory sessions do not allow for ubiquity, that is, these cannot be accessed any time and anywhere. Some tools created in this work allow to simulate topics related to Sedimentology and can eliminate/complement real sediment samples through the use of virtual microscopy concept and virtual samples. These virtual samples are composed by photos, descriptions and other data, and the teachers can create markers on sample photos to highlight sediments with specific characteristics.

Although the virtual microscope is not equal to the real binocular microscopes and the virtual samples are not equal to real sediment samples, our system has the advantage of allowing a more precise and complete evaluation: samples are well defined (with photos and markers highlighting some sediments) and, this way, it is possible to evaluate more concepts.

Unfortunately, there was no time to test this system with Geology students to measure how this system can be effective and an alternative to conventional teaching. The system was only tested with Geology specialists. However, this system follows the standards of Moodle relatively to the SedLMS
activity and the developed question types. Furthermore, the concepts used in this thesis (such as e-learning and the virtual microscope) were implemented successfully in other areas.

The modules developed in this thesis can be seen as a background, composed by a learning component in which the sediment samples are well defined (with photos, descriptions and others) and an evaluation component (with several question types exclusively dedicated to Sedimentology), from which it would be possible to easily develop additional features and extend the existing ones.

A. Future work

In the future, in order to increase the detail of zoom, it would be interesting if more images were used in the construction of virtual microscopes instead of static images. The Leaflet library has support for the use of pyramidal tiles, which is widely used in other areas, namely cytology and medicine. With this solution, the virtual microscope would be more similar to the real binocular microscopes. Moreover, a camera with a Computer Numerical Control (CNC) machine [23] must be used, which allows a more precise movement of the camera (in the x, y and z axis) to take pictures in several zooms automatically. Moreover, the photos imported to the system can have higher quality in order to improve the user experience. The main goal in the development of the SedLMS modules was the achievement of the functionalities. However, the User Interface should also be taken into consideration. In the future, some improvements can be done in order to provide a more beautiful interface to the users.

Other methods can be used to import samples: an integration with an external database should be great. It can also be studied the possibility of adding some interactivity between students in the SedLMS activities. For example, the markers on samples’ photos are only introduced by teachers in this thesis. However, it can be well accepted if the students also introduced markers on samples photos (in the learning component) to promote interactivity between students, with discussion about sediments contained on samples photos, among others (gamification concept).

Moreover, the addition of more didactic contents in samples and SedLMS activities or the extension of existing ones would be great. Additional types of contents explored in Sedimentology, in particular, and in Geology, in general, can be used.

Furthermore, these modules can be improved through tests with Geology students, which can show us the effectiveness of the modules.

In addition, it is possible to develop more question types associated with Sedimentology by extending the question types already existent in the Moodle platform.

REFERENCES