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CONTRIBUTIONS IN THE FIELD OF GENERATIVE MODELS APPLIED IN ELEARNING

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1. INTRODUCTION

This thesis focuses on the development and implementation of an approach based on auto-generative learning objects (AGLO) to facilitate e-learning and assessment for the disciplines of science, technology, engineering, and mathematics (STEM). The topic is even more topical as the use of e-learning objects has seen a huge increase in 2020 amid the restrictions imposed by the pandemic generated by the Sars-CoV-2 virus.

The e-learning term has become an important concept in the evolution of education. Broadly speaking, eLearning (or e-learning) means the totality of educational situations in which the means of Information and Communication Technology (ICT) are used significantly [1]. The computer and electronic/multimedia materials are used as support in teaching, learning, evaluation, or as a means of communication. Currently, the e-learning term has practically replaced all the terms that designate a new way of integrating ICT in the training process.

Digital technology produces certain changes in the learning environment through:

- the virtual learning space, which creates the possibility of students' imagination and creativity, the information can be visualized, simulated procedural, making these materials more attractive and easier to understand;
- independent learning, students do not spend time searching for information, but using it;
- the individualization of learning, the personal pace of each one is respected;
- real-time monitoring of learner's activity.

Learning objects (LO) have emerged as a new way of thinking about learning content. Traditionally, the content comes in a matter of hours. Learning objects are much smaller learning units, lasting even just a few minutes. The concept of learning objects is broadly defined. The Institute of Electrical and Electronics Engineers (IEEE) standardization defines learning objects as: "a learning object is defined as any entity, digital or non-digital, that may be used for learning, education or training" [2].

There is a variety of learning object models and new proposals are continuously appearing. The most widely used e-learning standards are

- Sharable Content Object Reference Model or SCORM [3];
- The Institute of Electrical and Electronics Engineers Learning Object Metadata or IEEE LOM [4];
- Information Management System or IMS [5];
- Learning Resource Metadata Initiative or LRMI [6];
- Computer Information System Company or CISCO [7].

A learning management system (LMS) is an adapted environment for disseminating learning objects. It is a software application that provides, among other things, educational courses and learning programs. The teacher can use this software to create structured courses and manage them to meet various requirements. LMS is considered to be the foundation for building today's e-learning practice [8]. Some open-source LMS are Moodle [9], Ilias [10], Canvas [11].

LOs are difficult to reuse and difficult to adapt to each discipline, as it requires access to source code, programming knowledge for content modification, testing, and deployment [12]. To improve the use of learning objects, the generative model was created. "Generative Learning Objects (GLOs) are generic and reusable LOs from which the specific LO content can be generated on-demand" [13].

In the field of generative objects there are two clear directions:

- GLO based on templates, developed by Tom Boyle in [14], [15], [16].
- GLO based on meta-programs developed by Damaševičius and Štuikys in [17], [18], [13].

Auto-generative learning objects (AGLOs) are "reusable pedagogical patterns to be instantiated with generated content based on random numbers to fulfill the learning objectives" [12]. In this thesis, we propose an AGLO based approach to facilitate learning and automatic assessment for science, technology, engineering, and mathematics (STEM) disciplines.

The AGLO approach involves the development by the tutor of an AGLO template that aims at a specific learning objective. It develops the meta-model using accessible media: Eclipse and Notepad ++. When templates are created, they are stored in a MySQL database. Templates are saved in XML files. From the database, the student through the web frontend application can select AGLOs.

Students access the web application using a web browser on a workstation, tablet, or smartphone. In the assessment process, the student will access several AGLOs. At this step, the accessed AGLOs are instantiated with random numbers, the formulas are evaluated to meet the learning or testing scenario. Methods from domain-specific JavaScript libraries are also called. The evaluation of the correctness of the answers is done automatically. The answers given by the students are stored in a repository of learning objects (RLO).

1.2. Thesis objective

The purpose of the research being to create AGLOs that can be used in the instructive-educational process, the following specific objectives were formulated.

Objective O1 is to make a bibliographic study of LOs and a comparative analysis of the studied models;

Objective O2 is to propose a step-by-step methodology based on abstractions to create reusable AGLO templates;

Objective O3 is to abstract multiple learning concepts from STEM disciplines (Arithmetics, Data Structures, Algorithm Analysis, Operating Systems) into instantiable AGLOs (at least 150 objects);

Objective O4 is to develop domain-specific libraries modeling concepts (at least 15 JavaScript classes) to assist the instantiation of AGLOs;

Objective O5 is to validate our AGLO approach in practice, on groups of students showing their effectiveness;

Subobjective O51 is to show that AGLOs are effective in the learning process compared to classical approaches;

Subobjective O52 is to show that the AGLO's automatic assessment mechanisms are very close to the evaluation given by tutors.

1.3. The structure of the thesis

The thesis is organized as follows:

Chapter 1 presents the context of the thesis, the objectives of the thesis, and the structure of the thesis.

Chapter 2 presents state-of-the-art in the field of learning objects to which this paper is addressed.

Chapter 3 presents the research methodology applied in this research project.

Chapter 4 presents step by step the process of abstraction. The abstraction process is then presented practically on an example from the disciplines Mathematics, Data Structures and Algorithms, Analysis and Design of Algorithms and Operating Systems. Next is presented the structure of the model, and further its semantics.

Chapter 5 presents the AGLO model applied in the field of middle school arithmetic. The topics covered by these AGLOs are fractions, interval operations, solving equations and inequalities with modulus, solving different types of inequalities, and abbreviated calculation formulas.

Chapter 6 presents the AGLO model applied in the field of IT disciplines. The chapter begins with an exposition of AGLOs targeting four types of searches, namely linear search, linear flag search, binary search, and interpolation search. The chapter continues with the presentation of AGLOs targeting different types of sorting. Working with single-stranded linear lists and double-stranded linear lists is the topic discussed further in this chapter. The notions related to trees and graphs are addressed below. Finally, the AGLOs that describe notions related to different basic commands used in Linux are described.

Chapter 7 presents the implementation of the prototype. The chapter presents how we managed to connect students with our AGLOs using the DSEL platform. The domain-specific JavaScript libraries we have developed are listed below.

Chapter 8 presents the validation of the AGLO model through two case studies, one conducted on a group of 12 students in the 5th grade and one conducted on a group of 50 students in the 8th grade.

Chapter 9 presents the final conclusions, the original contributions from the thesis, the dissemination of the results, as well as some perspectives.

2. STATE OF THE ART

A study was conducted on a variety of learning object models: SCORM model, IEEE Learning Object Metadata standard, CISCO model, Dublin Core model, Learnativity model,

NETg model, ALOCoM model, H5P plugin. As well as generative learning objects (GLOs), objects developed by Tom Boyle, the model developed by Damasevicius and Stuikys, and the Moodle Coordinate Question and Calculated Question plugins.

IEEE learning objects are represented by any content used for learning or training. The content can be any text, images, audio. They have no feedback, no evaluation, and require no programming knowledge.

SCORM is a set of technical standards that ensures that eLearning content works properly on an LMS platform. LO content is static, an electronic representation of media, text, images, audio, web pages, or other data that can be presented in a web client. LOs can have automatic feedback and evaluation. SCORM allows tutors to distribute their content in a variety of LMSs, but to create this content the tutor must have a minimum of programming knowledge.

CISCO is a content model that restricts the number of learning components to seven. The LO content is also static, it can contain sentences or paragraphs, images, animations, etc. Cisco has a strategy for developing and implementing RLOs, but the tutor needs to have some basic programming knowledge.

Learnativity is a content model in which raw media elements, such as a single sentence or paragraph, illustration, animation, and others are grouped up to the course level. The LOs created with Learnativity contain only static content. How to combine objects at different levels of granularity follows a few rules, but you do not need programming skills to meet them.

The term LO used by NETg comprises three parts: a learning objective, an activity to teach the objective, and an evaluation unit that measures the objective. These are abstract types, which can be mapped and aggregated on four levels, up to the course level. The content can be any text, images, audio. They have automatic evaluation. LOs do not require programming knowledge to be realized.

H5P is an open-source tool focused on creating interactive HTML5 content. Depending on the type of task, the difficulty of creating it differs, so the process of creating interactive learning tasks requires minimal programming knowledge.

Once learning management was transferred from the classroom to a new level of development, classroom experiences had to be reconfigured for computerized delivery and distributed over the Internet. E-learning platforms mainly comprise LMSs that focus heavily on creating and standardizing learning content, distributing materials to learners, and providing functionality for self-assessment exercises and examination purposes [8]. The teacher can create course content by adding text, images, tables, links, slide shows, etc On an LMS they can manage their courses and modules, enroll students or configure their self-enrollment, as well as import students to their online courses.

Other approaches have also been developed for the development of this field. Thus, in addition, the LOs were grouped in sequences, the LOs were improved by object-oriented design or were mapped and represented as a cloud package in the CLAVIRE e-Science platform.

GLOs coined by Tom Boyle is reutilizable patterns. These patterns are accessible from any device. The GLO-Maker is a tool that offers the tutors the possibility to create concrete LOs base on these patterns, by adding static content. The student's answer is appreciated with a grade.

The GLOs proposed by Vytautas Štuikys and Robertas Damaševičius is a model expanded with meta-programming technologies, quite general and accessible. The templates were regarding only to IT disciplines. The content is static, and the student response gets a mark.

Moodle coordinate questions and Moodle calculated questions are two plugins, in which the question is made from static content combined with dynamic numerical variables. The tutor can set automatic feedback to each question. After evaluating the student's answer, a grade is returned. No programming knowledge is required to create such questions. The Moodle platform provides the necessary documentation for their realization.

After comparing the studied models with the AGLO model, it was concluded that AGLOs are templates accessible from any device, which provides feedback and automatic evaluation that are worth studying and developing. Exercises obtained by this model are dynamic, made by combining static text with automatically initialized variables with random values at each instantiation. Variables can be numbers expressed in several formats, quoted strings, lists of numbers associated with matrices, lists of characters associated with matrices, lists of strings associated with matrices, objects: intervals, fractions, list nodes, simply chained linear lists, double linked linear lists, trees, graphs, SVG representations.

3. STRATEGY FOR ACHIEVING THE OBJECTIVES

The steps carried out in this scientific research are presented below:

1. Realization of an abstraction algorithm for obtaining AGLO templates;
2. Design of the AGLO model;
3. Development and implementation of models for STEM disciplines;
4. Development of domain-specific JavaScript libraries;
5. Evaluation of the model by applying the AGLOs in the learning-assessment process in the classroom.

The first step of the research methodology 1. The realization of an abstraction algorithm for obtaining AGLO templates has the role of approaching O2, as described in the first chapter of the thesis: to propose a step-by-step methodology based on abstractions to create reusable AGLO templates.

The next two steps of the methodology 2. Design of the AGLO model and 3. Development and implementation of models for STEM disciplines have the role to address O3, formulated in the first chapter of the thesis: to achieve instantaneous AGLOs by abstracting several learning concepts from STEM disciplines (arithmetic, data structures, algorithmic analysis, operating systems), at least 150 objects.

The fourth step of the research methodology 4. The development of domain-specific JavaScript libraries has the role of addressing O4, as described in the first chapter of the thesis: to develop modeling concepts of domain-specific libraries (at least 15 JavaScript classes) to help instantiate AGLOs.

The fifth step of the research methodology 5. The evaluation of the model by applying the AGLOs in the learning-assessment process in the classroom has the role of approaching O5, as described in the first chapter of the thesis: to validate our AGLO approach in practice, on groups of students, showing the effectiveness of the model. The fifth step of the research methodology 5. The evaluation of the model by applying the AGLOs in the learning-assessment process in the classroom has the role of addressing O51 and O52, as described in the first chapter of the thesis: to show that the AGLOs are effective in the learning process compared to classical approaches; and to show that the AGLO's automatic evaluation mechanisms are very close to the evaluation given by the tutors.

4. THE MODEL OF AUTO-GENERATIVE LEARNING OBJECTS

4.1. The abstraction algorithm

The abstraction process is performed in the form of an 11-step algorithm that can be followed by tutors to develop reusable AGLO templates. The process of achieving these AGLOs includes the following stages:

Step 1: The learning objective identification.

Step 2: The concrete exercise identification.
Step 3: The variables identification.
Step 4: Variables type and range identification.
Step 5: Primary input data identification.
Step 6: Building a computational scenario.
Step 7: The domain-specific library objects and methods identification.
Step 8: Setting up the difficulty level.
Step 9: Necessary intermediate variables.
Step 10: Answer variables and their computation formula identification.
Step 11: Testing the object.

The abstraction process is presented practically on an example from the disciplines Mathematics, Data Structures and Algorithms, Analysis and Design of Algorithms and Operating Systems.

4.2. Structure and semantics of AGLO

LOs are the digital resources with which the student interacts. AGLOs are templates from which concrete LOs are obtained at each instance.

The AGLO model is defined using the EBNF meta-language. The AGLO templates are written in XML format, and the root element is the action element.

Each AGLO object consists of six sections:

- name - contains the name of the AGLO;
- scenario - includes the presentation of how the learning object works, as well as the declaration and initialization of the symbols needed to solve the problem
- theory - contains the presentation of theoretical notions;
- question - contains the workload that is performed by combining static test and randomly instantiated variables;
- answer - contains the answer given by the student and his automatic grading;
- feedback - contains additional explanations related to the notion approached, as well as the comparison of the answer given by the student with the calculated answer.

An AGLO is a pedagogical model that instantly offers different exercises so that the pupil or student can practice the intended notion.

5. MODELS FOR MIDDLE SCHOOL ARITHMETIC

The chapter presents the AGLO model applied in the field of middle school arithmetic. The topics covered by these AGLOs are fractions (classification, comparison, operations with fractions, transformations of fractions, introduction, and extractions of integers from the fraction, finding a percentage of a number), operations with intervals, solving equations and inequations involving absolute values, solving different types of inequalities, as well as abbreviated calculation formulas.

For working with fractions, twenty-one AGLOs were performed. These exercises cover the specific competencies related to fractions required by the current curriculum in Romania for fifth-grade students.

For eighth-grade arithmetic, thirteen exercises were performed. These exercises cover specific skills related to the first two chapters of algebra required by the current curriculum in Romania for students in the eighth grade.

6. MODELS FOR IT DISCIPLINES

The chapter presents the AGLO model applied in the field of IT disciplines.

For the Data Structures and Algorithms discipline, AGLOs were performed targeting four types of searches, namely linear search, linear search with santinel, binary search and interpolation, and different types of sorting, insertion sorting, selection sorting, bubble sorting, shell sorting, and quick sorting. AGLOs were also developed for working with linear linked lists and double linear linked lists. In this case, additions to the list according to several criteria were approached, namely, before or after a specified element, at the beginning or end of the list, after a specified address, deletions from the list, also according to several criteria, as well as elementary notions, namely, recognition of list-specific items, such as the address of an item, the predecessor, or the successor of an item.

For the Analysis and Design of Algorithms discipline were approached basic notions regarding trees and graphs in several AGLOs.

For the Operating Systems discipline, AGLOs are described that approaches notions related to different basic commands used in Linux, namely, working with directories, working with files, process commands, administrative commands, network commands.

A total of 141 AGLOs covering different ITC disciplines were presented.

7. IMPLEMENTATION OF THE PROTOTYPE

Students were connected to the AGLOs through the DSEL web platform. They were able to connect via an existing g-mail or Facebook account. All login sessions, accessed exercises, and answers given are stored in a database connected to the platform.

The domain-specific JavaScript libraries implemented to support the realized AGLOs were also presented. They were made as follows:

- for the notions of Middle School Arithmetic Fractii.js and Intervale.js;
- for Data Structures and Algorithms: BinarySearch.js, LinearSearch.js, InterpolationSearch.js, SentinelLinearSearch.js, InsertSort.js, SelectSort.js, BubbleSort.js, QuickSort.js, LinkedListLink.js, LinkedListNode.js, LinkedL. js, RandomLinkedList.js, OrderedLinkedList.js, DoubleLinkedListLink.js, DoubleLinkedListNode.js, DoubleLinkedListNodeShape.js, and RandomDoubleLinkedList.js;
- for Analysis and Design of Algorithms: Circle.js, Line.js, TreeNode.js, Tree.js, and Graph.js;
- for Operating Systems File.js and Folder.js.

8. VALIDATION OF THE PROTOTYPE

The chapter presents the validation of the AGLO model through two case studies, one conducted on a group of 12 students in the 5th grade and one conducted on a group of 50 students in the 8th grade.

The hypothesis analyzed in the first case study is that there is a 5% chance that learning objects will not effectively support the learning process. Following the applied metrics, a value of 0.002 was obtained for the calculated p-value, and an accuracy of the model of 91%.

The hypothesis analyzed in the second case study is that the chances that these learning objects do not really reflect the level of knowledge acquired by students are less than 5%. And in the case of this study, applying statistical metrics, the accuracy of the model of 98% was obtained, the value of the standard deviation 0.75 and the p-value of 0.03.

The satisfaction questionnaire applied to students concluded that 97% of them positively

appreciate these types of exercises, and over 90% of them want such AGLOs in their learning activity.

9. CONCLUSIONS AND PERSPECTIVES

9.1 Conclusions

AGLOs are reusable templates that provide dynamic exercises. The use of AGLOs could be a solution for the successful integration of digital tools in the teaching evaluation process.

The proposed AGLO approach fits very well with notions specific to STEM disciplines. These models can be used both in assessment and in the learning process for practicing STEM concepts.

Students showed openness to such learning objects.

9.2. Achieving the objectives

At the beginning of the research, five objectives were formulated which were achieved one by one during the research.

In Chapter 2, a bibliographic study of learning objects and a comparative analysis of the studied models with the AGLO model was performed. Through these, O1 was approached, formulated in the first chapter of the thesis.

In Chapter 4, an abstraction algorithm was developed to create reusable AGLO templates. By performing this algorithm, O2 was approached.

Chapter 5 presented 34 AGLOs aimed at Middle School Arithmetic. The realization of these AGLOs approached O3.

Chapter 6 presented 141 AGLOs targeting specific notions of IT disciplines. The realization of these AGLOs approached O3.

Chapter 7 presented how to connect students and pupils with these AGLOs through the DSEL platform. The specific JavaScript libraries created were also presented. The achievements in this chapter addressed O4.

In Chapter 8, two case studies were presented. The first case study was conducted on a group of 12 fifth graders, and the second on a group of eighth-graders. The results obtained were favorable to the AGLO model. By conducting the two studies, O5 was approached, the first study addressing SO51, and the second SO52.

9.3. Original contributions

The original contributions are as follows:

1. An abstractization algorithm has been developed for creating AGLO templates. The algorithm was developed in the form of a process that includes eleven steps, with the help of which any tutor can make reusable AGLO templates.

2. A number of 175 AGLOs have been created for several notions of STEM disciplines. Thus, there were: 21 AGLOs for working with fractions [19], 13 AGLOs for notions related to eighth-grade algebra (operations with intervals, equations, and inequalities with the mode, inequalities, and abbreviated calculation formulas)[20], 97 AGLOs for Data Structures and Algorithms discipline (searching algorithms, sorting algorithms, linear linked lists, double linear linked lists) [26], 17 AGLOs for Algorithm Analysis and Design discipline (trees and graphs) [24] and 27 AGLOs targeting notions from the discipline Operating systems (commands for working with directories, files, process, administrative, network) [22].

3. Five JavaScript libraries have been developed, modeling 42 reusable concepts that contain the functions and methods necessary for the approached notions.

4. The AGLOs were applied in the classroom teaching-evaluation activity, thus resulting in two case studies. The first case study was conducted on a group of 12 fifth-grade students [19], and the second case study was conducted on a group of 50 eighth-grade students [21].

9.4. Future research directions

The thesis has achieved its objectives, but new research topics can continue this research, such as:

- to extend our approach to a larger number of STEM disciplines and their concepts (Geometry, Chemistry, Biology, Physics, Civil Engineering);
- develop a way to integrate AGLO into an LMS or create a mobile application for these objects;
- to make these models accessible to tutors through a tool that allows the creation and adaptation of AGLOs;
- to make the tutorials on several levels, depending on the needs of the tutors: using AGLO, modifying existing objects and / or creating your own objects;
- to publish the code / prototype with an open-source license;
- through future actions to move our model from TRL4 to TRL5.

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