information

MDPI

Article

Gamified Evaluation in STEAM for Higher Education: A Case Study

Pavel Boytchev [1,*,†,‡] **and Svetla Boytcheva** [2,‡]

1 Faculty of Mathematics and Informatics, Sofia University, 1164 Sofia, Bulgaria
2 Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, 1113 Sofia, Bulgaria; svetla.boytcheva@gmail.com
* Correspondence: boytchev@fmi.uni-sofia.bg; Tel.: +359-2-8161-553
† Current address: FMI-KIT, 5, James Bourchier blvd, 1164 Sofia, Bulgaria.
‡ These authors contributed equally to this work.

Received: 30 April 2020; Accepted: 7 June 2020; Published: 11 June 2020

Abstract: The process of converting non-game educational content and processes into game-like educational content and processes is called gamification. This article describes a gamified evaluation software for university students in Science, Technology, Engineering, the Arts and Mathematics (STEAM) courses, based on competence profiles of students and problems. The traditional learning management systems and learning tools cannot handle gamification to its full potential because of the unique requirements of gamified environments. We designed a novel gamification evaluation and assessment methodology implemented in a STEAM course through specially designed software. The results from end-user tests show a positive expectation of students' performance and motivation. The preliminary results of over 100 students in the Fundamentals of Computer Graphics course are presented and the results of quantitative analysis are discussed. In addition we present an analysis of students' surveys, where students expressed in free text form observations about the software.

Keywords: gamification in education; STEAM education; educational software; student evaluation

1. Introduction

As a technological society we strive to introduce technology in all aspects of our life. This includes education. However, just using technology does not lead to better teaching or better learning. Traditionally, children's education relies on Game-Based Learning (GBL), shown as arrow (1) in Figure 1. On the other hand, university and adult education is more focused on specific problems, thus allowing easier implementation of Project-Based Learning (PBL)—this is arrow (2). The introduction of PBL to the education of pupils and young students is a way to provide a fruitful context for learning. This approach is represented by arrow (3). PBL for children requires significant modification of the educational content in order to simplify the management of a project and make it comprehensible by young students. Educators and researchers also explore ways of applying GBL to university-level and adult education, as indicated by arrow (4). This application of GBL is the main focus of our article.

Some non-gaming elements can be successfully implemented in an educational context and used as game mechanics, such as badges, reward systems and points. They are often used in the corporate sector to increase the loyalty of employees. Many game elements are also presented in the traditional educational environment, such as (i) different levels of difficulties; (ii) sandbox mode, where users freely explore task without penalties; and (iii) time restrictions for completion of tasks. Despite the many interrelationships between traditional learning and games, the main content of the lessons is still in non-game form. This requires gamification—a conversion of non-gaming entities into gaming entities.

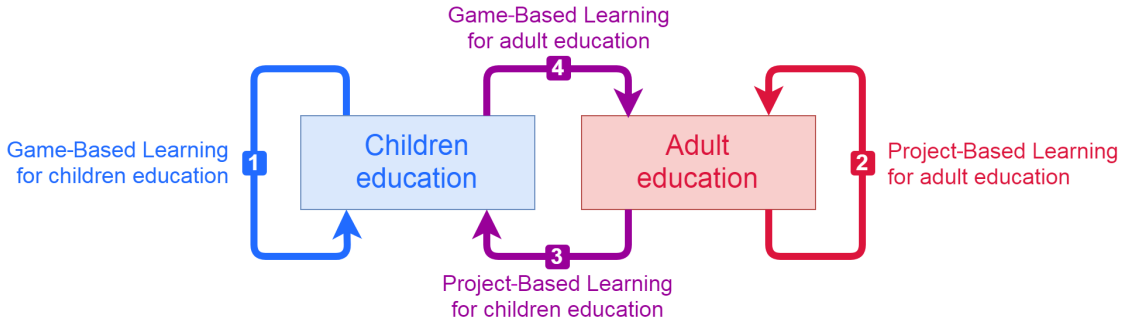


Figure 1. Project-Based Learning and Game-Based Learning approaches.

Gamification is one of the emerging learning paradigms that is gaining popularity. It has been successfully applied at different levels and subjects in education equally or in combination with traditional teaching methods. A systematic review of gamification is presented in Reference [1], while a systematic mapping study can be found in Reference [2]. A comprehensive study for gamification in Science, Technology, Engineering, and Mathematics (STEM) learning is presented by Kim et al. [3]. Although the application of gamification in STEM courses seems straight forward, there are several examples of how technology dominates and lacks important pedagogical aspects. Researchers and educators provide examples of successful application of gamification in STEM university courses covering a wide range of topics, such as fundamental computer programming courses with gamification [4] or online frameworks [5], C–programming [6], Software Engineering [7], Computer Organization [8], and some more specialized advanced courses in the computer science curricula like Computer Graphics with WebGL [9], Game Development [10], Emerging Technology of Cloud Computing [8]. In this article we present software, developed by us, which is used by Computer Sciences (CS) students learning Computer Graphics. Apart from programming and mathematics, such learning requires many artistic activities, like working with colours, managing proportions, building virtual scenes, defining natural-looking motion and so on. Thus we consider our software and our approach not just STEM-oriented, but also Science, Technology, Engineering, the Arts and Mathematics (STEAM)-oriented.

Learning outcomes and student needs are the key in effective learning through gamification. It is also important to take into account the specific aspects of the subject being taught. The authors of Reference [11] explore different types of issues encountered while applying gamification. Based on their analyses, they propose various heuristics regarding the characteristics of the target audience, the contextual requirements, the design and the properties of the system.

Student engagement, motivation and active participation play a central role in such courses. The study in Reference [12] shows the gamification impact can vary depending on the types of student motivation. One of the most effective ways of learning is through the engagement and active participation of students in the perception and understanding of the nature of the learning material. A comparative analysis of traditional and active learning confirms this hypothesis [13], the results of which are based on a meta-analysis of a large body of research on student learning in STEM courses. Alongside with gamification, some other commonly used methods for active learning are Instruction-Based Learning (IBL), PBL and learning by doing.

Based on a literature review and our yearslong experience in teaching we formulated a working hypothesis that gamification evaluation can be improved by dynamic evaluation of all steps during the whole timespan of the gameplay. The formal description of this type of gamification evaluation inspired us to develop a new student evaluation methodology. It is used as a basis for designing and implementing software and evaluation tools. End-user tests are conducted with different cohorts of students. The quantitative methods (e.g., surveys) for assessment are used for measuring the efficiency and feasibility of the proposed gamified evaluation.

Although Game-Based Learning could be implemented in university-level education by mere technologisation of the educational content, this article focuses on using technology for student evaluation in a gamified educational environment and proposes a new evaluation method. We want to capture and automatically evaluate streaming scores generated by students as they explore educational content. This provides new challenges, which do not appear in the traditional evaluation.

Our gaming environment consists of several interactive 3D models that evaluate a set of 17 competences related to Computer Graphics—this is our initial test-bed environment. If the proposed gaming evaluation provides acceptable results, then it will be linked to the existing Learning Management System (LMS) and it will be applied to several disciplines, taught at Sofia University.

This article is structured as follows—Section 2 describes the main characteristics of the evaluation in gamification; Section 3 outlines the methodology, describes the implementation of the gamified evaluation system, defines the student competences profiles and the formal model for aggregation of streaming scores; Section 4 presents the design concept of the 3D models and details about some of them; Section 5 discusses some of the preliminary results of the end-user tests conducted with students; Section 6 summarizes the presented evaluation method and the virtual models and briefly sketches plans for further work.

2. Gamification of Evaluation

Most educational courses include elements of student assessment, such as feedback on the quality of understanding and perception of teaching material. Of course, this process can be gamified as well. Some evaluation activities like quizzes and tests can be converted into game activities by providing a proper gaming environment.

There are different positive impacts on gamified student evaluation, like cheating reduction and combining both course evaluation and assessment into a single activity. A framework for game design patterns drawing parallels with academic achievement during the completion of the course is presented in Reference [14]. Heilbrunn et al. [15] present a comprehensive study of different gamification analytics tools that allows monitoring students behaviour and on its base to perform students' evaluation by Key performance indicators and game states. Different aspects of gamified evaluation—feedback, student journals, and student progress are investigated in Reference [16]. Gañán et al. present an e-assessment platform providing formative assessment tools for learning analytics [17].

The classical evaluation methods in gamification [18], the so-called game mechanics, include points (experience, redeemable, skill, karma, reputation), badges, levels, progress bars, leader boards, virtual currency, and avatars. More sophisticated models for student assessment can be applied when traditional teaching is combined with gaming in a blended learning format. In such a way the evaluation process includes both teacher monitoring methods and self-assessment evaluation methods [3]. A gamification evaluation in a Software Engineering course is presented in Reference [7], where different types of game mechanics are used, that is, badges and leaderboards. Unlike a game system with multi-agents, the proposed solution in Reference [19] cannot distribute grades or assignments between agents (students). Each student is assigned a separate task and students cannot help each other. Another limitation is that agents (students) cannot collide while studying the gaming environment.

In our previous research we presented how traditional lecturing in Computer Graphics courses can be enhanced by gamification methods and how some game mechanics like badges can be implemented in student evaluations [20]. We also introduced the temporal average metric in Reference [21]. This metric is suitable for gaming evaluation and is briefly presented in Section 3.4.

3. Gaming Environment

This section presents our development methodology of a gamified evaluation. It is tailored to the educational goals of the course Fundamentals of Computer Graphics (FCG), taught at the Faculty of Mathematics and Informatics (FMI), Sofia University. We describe the implementation of a gamified

evaluation system, which is based on our gamified educational environment Meiro and the popular Learning Management System (LMS) Moodle. The competence profiles and their use for evaluation are discussed, as well as how the scores are aggregated into grades.

3.1. Methodology

Traditionally, the evaluation of students at FMI relies on paper tests. For the last decade most of these tests have been converted to online tests. However, both paper and online tests are inappropriate for evaluation in a gaming environment. The reason for this is that the process of learning and the process of evaluation happen concurrently in a game. This reshapes the evaluation in many aspects, because: (i) evaluation is performed at any time and in any place; modern hardware and software support interactive mobile 3D graphics; and (iii) evaluation is done on-the-fly and sharing evaluation experience is highly encouraged.

The design of the gaming environment relies on already existing software solutions at FMI. The LMS Moodle is widely used to support e-learning, especially during the COVID-19 outbreak in early 2020. The Meiro virtual environment, that we developed a few years earlier, provides a gamified medium for presentation and self-studying of concepts from Computer Graphics. It is used solely in the course Fundamentals of Computer Graphics. The work, described in this paper, started with extending Meiro to support evaluation via 3D models. In December 2019 and January 2020 we conducted real-time tests of the models with 100+ students. There were also surveys about the students' experience with the system.

The analysis of the gathered data will be completed by June 2020. The gameplay of each student (both log files and survey answers) will be analyzed and the estimated gamified evaluation will be compared to the evaluation if more traditional testing methods would have been used. The result of the analysis will be used to improve the software and to use it in the next academic year, starting in October 2020. Additionally, the analysis will help us to fine-tune the gamified evaluation and to assess the evaluation from technological and educational viewpoints.

3.2. Architecture

Meiro is a multilevel 3D maze with configurable topological complexity. It is a host for our interactive 3D models that are used in the FCG course. Two of these models are presented in Figure 2—a model demonstrating the construction of central projection using projective matrices and a model presenting deformations via object layering. Meiro is not only the maze, but it is a framework for defining such models. Currently, there are almost 300 interactive 3D models covering all topics from the course FCG.

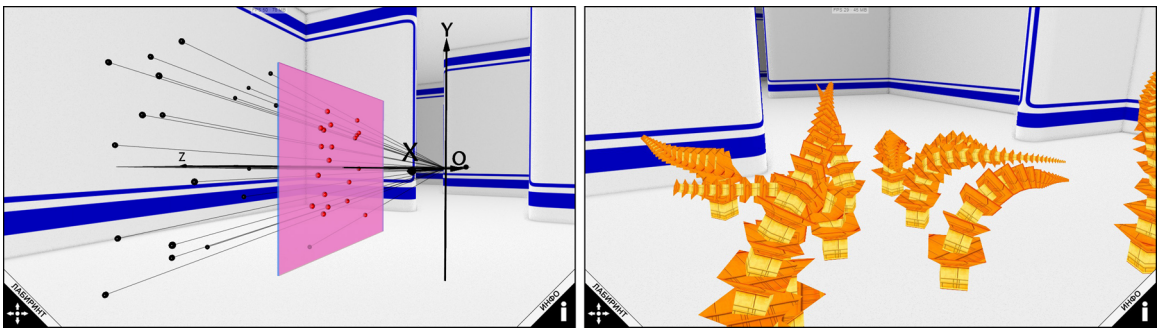


Figure 2. Examples of 3D models in Meiro—central projection (**left**) and multilayered objects (**right**).

Extending Meiro into an evaluation environment is done by adding new modules to its architecture, handling the visual representation of models, their configuration, and the evaluation of the gameplay. Some processes, like authentication and profile management, are handled by Moodle.

Figure 3 sketches the architecture of the system. The 3D evaluation models are models that are treated by the maze generator the same way as all the other 3D models. Each evaluation model represents one problem to solve. Section 4 describes four of these models. The model configurator customizes the evaluation models and fine-tunes their configuration parameters according to a given difficulty level. The game engine sends gameplay data to the streaming evaluation model, which converts user's interactions into evaluation-aware values, stored in a custom gradebook. In principle, these values could be aggregated and pushed back to the Moodle's gradebook, however, this functionality is not implemented, because it will convert vectored scores into scalar scores.

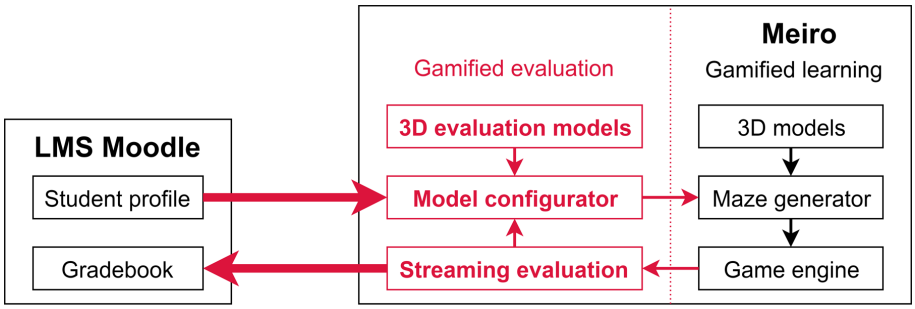


Figure 3. Extending Meiro to support gamified evaluation.

The three most notable features of the gamified evaluation are: (i) streaming evaluation—the gameplay generates a continuous stream of scores as the students explore the evaluation models; (ii) vectored scores—the stream is not a stream of single scores, but a stream of vectors and each element of these vectors represents the score for individual competence; and (iii) in-game visualization of the aggregated scores within each competence. The following subsections provide more details about these features.

3.3. Competence Profiles

Scores represented as vectors are used to capture, store and process both students' competences and problems' competences. The term "competence" in the context of FCG refers to a list of 17 specific computer graphics competences shown in Table 1. These competences have been identified during the more than 10 years of experience in teaching FCG for CS students. The competences are clustered in 4 groups revealing the multidisciplinary nature of Computer Graphics.

Table 1. Computer graphics competences.

1. Mathematics	2. Computer Sciences	3. Physics	4. Art
1.1. Math objects	2.1. Rasterization	3.1. Physics laws	4.1. Colours
1.2. Equations	2.2. Geometrical data	3.2. Simulations	4.2. Shapes
1.3. Parameters	2.3. Animation	3.3. Phenomena	4.3. Orientation
1.4. Relations	2.4. Graphical objects		4.4. Synchronization
1.5. Approximation			4.5. Graphical effects

A suitable way to visualize the competence set of a student is a radar diagram. One of our models is focused on representing radar diagrams. Figure 4 shows examples of the competence profiles of two students. Both students are competent in Mathematics and have minimal skills in Physics, however, student A is more artistic, while student B is more CS-oriented. The vectored evaluation via radar diagrams has two main advantages over the traditional scalar evaluation: it reflects the individuality of students and it indicates competence gaps of students.

The same radar visualization is applied to problems as they are bound to the same set of competences as students. This enables the direct mapping of problems' profiles onto students' profiles

and vice versa. Let us consider that profile B in Figure 4 is the competence profile of a problem used for student evaluation. Mapping B onto A establishes a direct notion of the potential effect of the problem to the student. Complementing areas indicate potential for developing new competences, while overlapping areas indicate potential for consolidating knowledge. In the case of the profiles in Figure 4, problem B will consolidate the Mathematics competences of student A, it will develop (hopefully) student's competences in CS and it will have no effect on A's Physics and Art competences.

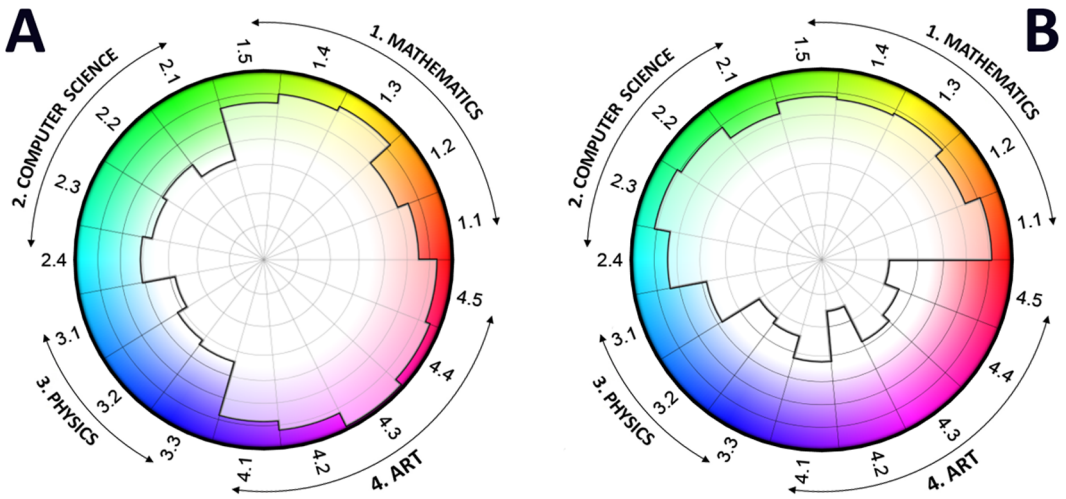


Figure 4. Two examples of radar diagrams representing competence profiles.

3.4. Aggregation of Streaming Evaluation

When a game is played, the player explores the same 3D gaming task many times, similarly to playing a level of a traditional game. The result of this interaction generates data with multiple values of each of the 17 competences from Table 1. Let us consider a single competence X. For this competence the student's gameplay produces n scores $\{x_1, x_2, \ldots, x_n\}$, which must be aggregated into a single score X_n. Common LMS aggregation functions are not tailored for calculating X_n and they do not meet the requirements for gamified evaluation: (i) easy incremental calculation as new scores arrive continuously; (ii) respect to individual scores, but suppressing incidental fluctuations; and (iii) possibility to capture tendencies over time. This prompts us to propose a metric, which is called "temporal average" [21]. The "average" component expresses the concept that a collection of numbers are aggregated (averaged) into a single number, similarly to all other averaging functions. The "temporal" component implies that the order of the numbers, as they are generated along the game timeline, affects the result. The actual timestamps of scores are not important for the evaluation.

Temporal average is easy to calculate, sensitivity to fluctuations can be controlled via parameter $\alpha \in (0, 1)$ and it allows incremental updates. The temporal average X_n is represented recurrently as a linear combination between the previous aggregated score X_{n-1} and the new individual score x_n:

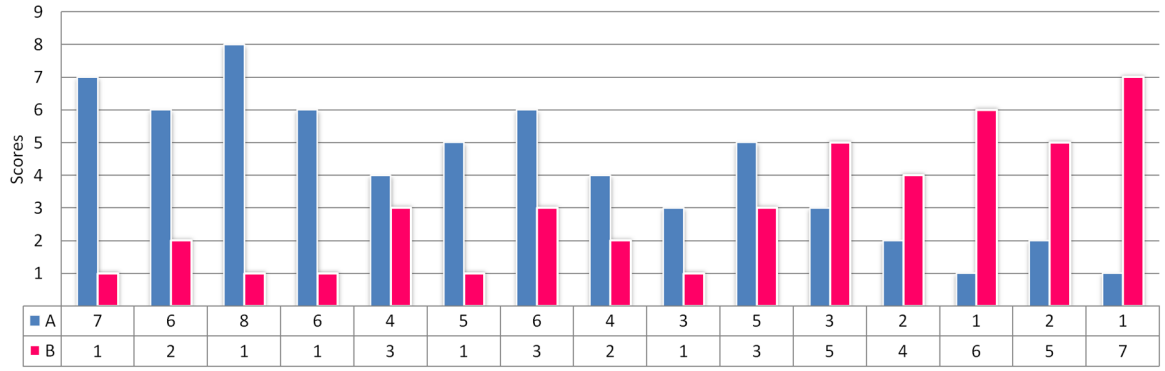
$$\begin{aligned} X_0 &= 0 \\ X_n &= (1-\alpha)x_n + \alpha X_{n-1}. \end{aligned} \tag{1}$$

Because timestamps are not used, there is no explicit parameter t for time. Instead, the indexing of scores $\{x_1, x_2, \ldots, x_n\}$ sets their order and implicitly encodes time.

To demonstrate the properties of the temporal average let us consider the multiple scores of two students over the course of 15 academic weeks—see Figure 5. Student A starts with good scores, which worsen towards the end. Student B starts with low scores, but gradually improves them. What should the final score be for each of these students? The average score of student A is 4.20, which is significantly higher than the average score 3.00 of student B. However, student B demonstrates

a tendency of steady improvement and according to our experience, this should be awarded with a higher score.

The temporal average assigns different weights of recent and past scores (this can be shown if the recurrent formula is unrolled). For example, when $\alpha = 0.7$ the temporal average of student A is 2.04, but the temporal average of student B is 5.15, which adheres adequately to our expectations. The role of the α coefficient is to define the sensitivity of the metric—how quickly the weight of past scores decays. There is no optimal value for α because it depends on the specific goals of the evaluation and the expected number of played games.



A	7	6	8	6	4	5	6	4	3	5	3	2	1	2	1
B	1	2	1	1	3	1	3	2	1	3	5	4	6	5	7

Figure 5. Scores of students A and B along 15 week semester.

Although the proposed temporal average fulfills the requirements, there are situations when it should be avoided. The temporal average metric provides meaningful results only if the same student solves multiple times one or more problems with compatible competence profiles. If the problems are not compatible at the competence level, then the series of scores do not represent the learning curve of the student and the calculated temporal average score will have no pedagogical value. Similarly, if many students solve the same problem, the collection of their scores should not be aggregated by a temporal average, because the individual scores in the collection do not represent the development of competences over time.

A gamified evaluation based on vectored scores generates enough data to build the competence profile of a student, which supports assessment. The competence profile is the boundary that measures all achieved competences—Figure 6. Areas inside this profile are used for the evaluation of the student. Areas outside the profile are used for the assessment of the student, because they provide sufficient information for planning future improvements.

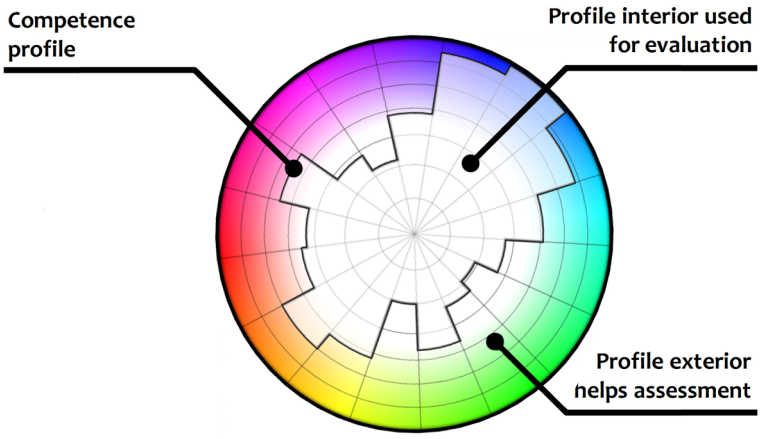


Figure 6. Blending evaluation and assessment.

4. Virtual Models

This section presents the overall design concepts of the models with respect to their visual appearance, interaction with the user and the major pedagogical properties. Five of the models are described, including primary information about what they do and how they support the gameplay.

4.1. Design Concepts

The essence of our evaluation and assessment models is to recreate the feel and touch of games. This imposes specific requirements to visual, interactional and pedagogical designs of the models.

- Visual design—the models are expected to be 3D models with relatively sufficient graphical effects, like texturing and lighting. The models themselves should resemble actual objects from our everyday life, so that students can easily understand their expected functionalities.
- Interactional design—the models should provide game-like interactivity, this includes walking around the models, getting close to them and getting away from them. Additionally, all models provide their own specific interactivity, because they represent virtual devices and mechanisms, which can be controlled.
- Pedagogical design—this design encompasses four distinct features: (i) the model should provide sufficient clues that help students, but should still provoke decision making and problem solving efforts as each problem could be solved in different ways; (ii) the model is generated with some randomness of its configuration, however, it is possible to define the desired level of difficulty by limiting the scope of the randomness of individual parameters; (iii) each model should report back general data about the gameplay, like how many clicks are done, how much time is used, how accurate is the solution, and so forth, and (iv) models can be used for evaluation and assessment of students' theoretical knowledge and practical skills as well as they develop the sense-and-feeling soft-skill in the domain of computer graphics.

We created ten assessment models and embedded them in Meiro — nine of the models represent 3D devices with problems to solve; the last model is used to represent the accumulated results, including the temporal average. The topics from the course Fundamentals of Computer Graphics include: colour composition in the CMY colour space; observing differences in motion of objects; building objects using algebraic expressions from constructive geometry; evaluating the Euler characteristic of a 3D object; defining bit-masks of the Cohen-Sutherland line-clipping algorithm; calculating the area of a planar polygon; mapping basic matrices to geometrical transformations; estimating positions of new vertices in Loop's subdivision and designing navigational trajectory based on avionic rotations. Figure 7 represents a thumbnail gallery of these nine models and the score visualization model.

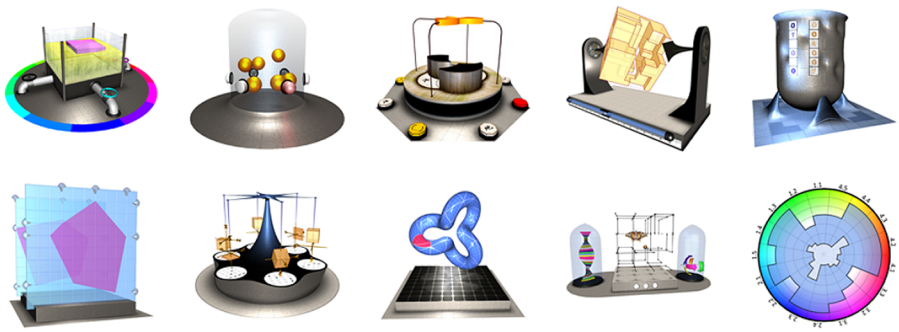


Figure 7. Gallery of developed models.

4.2. The CMY Reservoir

The CMY reservoir is our first evaluation and assessment model. It displays a tank with four pipes—Figure 8, left. Three of the pipes are used to introduce coloured water in the tank—cyan, magenta and yellow. The fourth, black pipe is used to drain the tank. A colour plate is inside the reservoir. The challenge is to fill the tank with water of the same colour as the plate by mixing the correct proportions of the colour water.

The difficulty can be configured by the number and proportions of different inks. Students are presented with several clues—there is a colour ring around the tank, which shows the primary colours and their first and second degree mixtures; the frame of the reservoir is made of tiles that serve as marks at every quarter of the volume. In case of the wrong mixture, students can drain partly or completely the tank and start over.

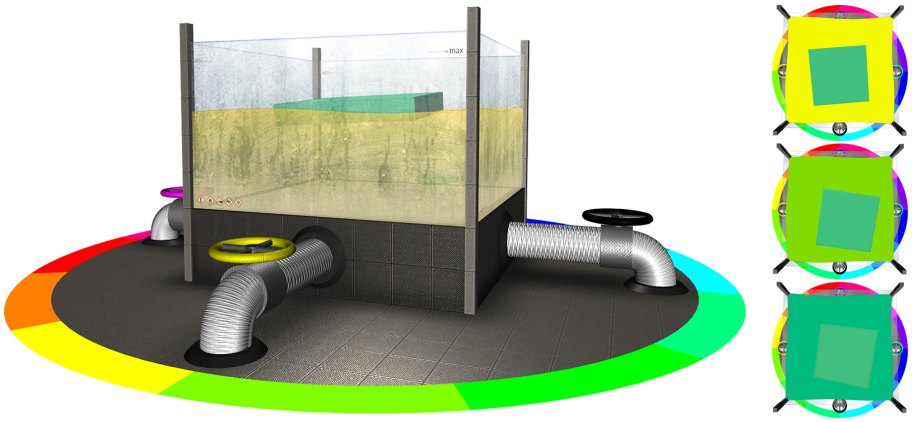


Figure 8. A snapshot of the CMY reservoir (**left**) and disappearing plate reaching a solution (**right**).

The design of this model allows different paths of solutions ranging from random experiments with adding and draining liquid (until the plate blends with the water and "disappears") to calculating proportions of inks and pouring in the correct amounts of colour water. Figure 8, right, illustrates three steps towards a solution. The plate in the third image is almost invisible. The ink proportions of the liquid are close to 4:1:2, while the plate has CMY proportions 3:1:2.

4.3. The Euler's Grill

Leonhard Euler is a Swiss mathematician who studied polyhedra in the 18-th century. Polyhedra are 3D shapes made of polygons. One of the most important topological invariant of polyhedra is named after Euler—the Euler characteristics χ defined by the Euler's polyhedron formula:

$$\chi = V - E + F, \tag{2}$$

where V is the number of vertices, E is the number of edges and F is the number of faces. For shapes like the Platonic polyhedra, as well as all other convex polyhedrons, the Euler characteristic is $\chi = 2$. Figure 9 shows the cube ($V = 8, E = 12, F = 6$), the dodecahedron ($V = 20, E = 30, F = 12$) and the icosahedron ($V = 12, E = 30, F = 20$).

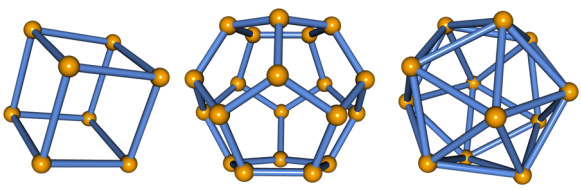


Figure 9. The cube (**left**), the dodecahedron (**center**) and the icosahedron (**right**) all have $\chi = 2$.

The Euler's grill model represents a rotating grill. The grilled object is a complex 3D shape built of faces with orthogonal edges—Figure 10, left. The object is not convex and may have holes, indentations and protrusions. The goal of the student is to calculate the Euler's characteristics and mark it via a bubble level at the bottom of the grill—there is a ruler behind the level and the bubble must be position above the correct value of χ.

There are different approaches to solving the problem and finding Euler's characteristic. The most straightforward one is to use brute force and actually count the number of faces, edges and vertices. This approach is applicable mostly to simple objects. The other approach is to use Euler's polyhedron formula. The design of the grill pushes the students towards the second approach by making it harder to count elements. For example, the object rotates continuously and this prevents students from using a divide-and-conquer approach of splitting the object into smaller parts and counting the elements in each part separately.

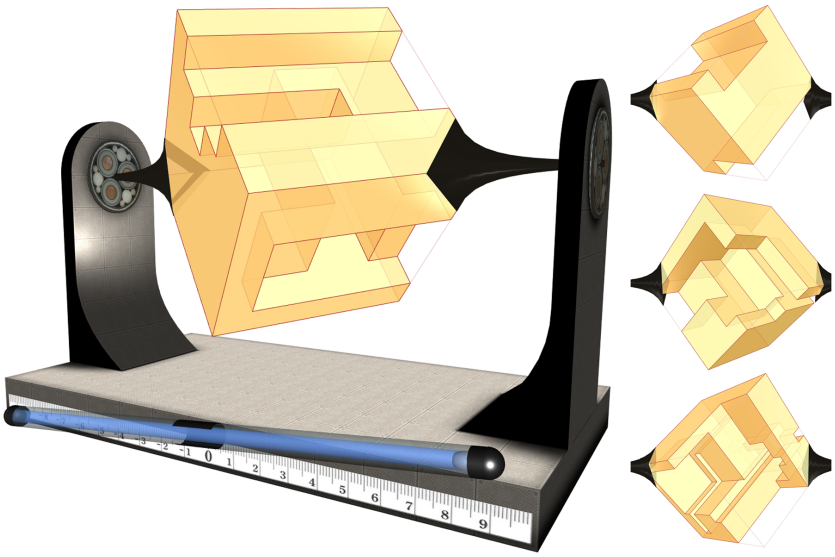


Figure 10. A snapshot of the Euler's grill (**left**) and examples of different topological complexities (**right**).

The semi-transparency of the object could be both beneficial and disadvantageous. It is useful to show the surface features even if they are on the other side of the object. At the same time, rear features mix up with the front features and make the appearance more complex.

Another, more efficient way of discouraging students to count is the progressing difficulty of the problem. Figure 10, right, shows three randomly generated objects with various degrees of topological complexities. Additionally, students are required to do some investigation which naturally transforms into research activities. The original Euler's polyhedron formula is not applicable to objects with holes (tunnels). Students may search on the web and find that the number of tunnels T changes the formula into:

$$\chi = V - E + F = 2 - 2T. \tag{3}$$

They may also find this modified formula by experimenting with different objects, as each instance of the Euler's grill generates its own random object based on the desired complexity. The increased difficulty of the problem provides the students with new configurations, which lead to new research topics:

- touching tunnels introduce an odd Euler's characteristic (as opposed to even);
- tunnels through tunnels decrease the Euler's characteristic to negative values;
- wide or colliding tunnels that split the object into separate, non-connected objects increase the Euler's characteristic;

- non-touching indentations and protrusions do not change the Euler characteristic, although they increase the number of faces, edges and vertices.

A good approach to solving complex shapes is to ignore all surface features, which do not affect the Euler characteristic, then to count features that change the characteristic by 1 and by 2.

4.4. The Cohen-Sutherland's Thimble

One of the fundamental operations in computer graphics is line clipping. This operation removes the portions of a segment, which are outside a rectangular viewport or window. In 1967 Danny Cohen and Ivan Sutherland developed an algorithm that splits the plane into nine areas by the lines that frame the viewport. Each area gets a bitmask code depending on its position in respect to the framing lines. The central area corresponds to the viewport, where lines are visible, and its bitmask code is always 0000, while the bitmasks of the other areas depend on the mapping between the framing lines and the bit positions in the bitmask.

The left image in Figure 11 represents one possible assignment of bitmasks. The framing lines are labeled X_{min}, X_{max}, Y_{min} and Y_{max}. The left-most bit of the bitmask is associated with the X_{max} line. As a result, all areas to the left of this line (i.e., $x < X_{max}$) get bitmasks 0xxx, and areas to the right—1xxx.

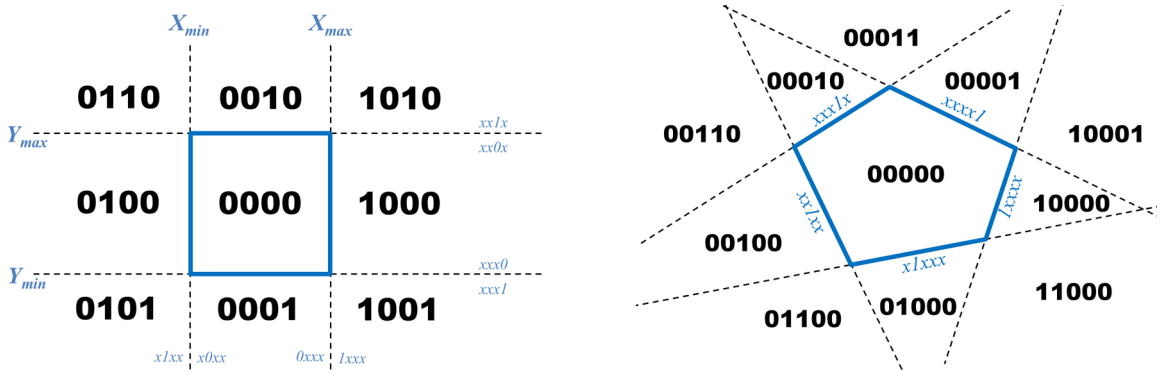


Figure 11. Bitmasks of the nine areas defined by the framing lines (**left**), extended approach to convex non-rectangular area with only some of the masks shown (**right**).

The Cohen-Sutherland algorithm uses these bitmask codes to quickly identify cases when a line is completely visible or completely invisible. In such cases the intersection with the framing lines is not performed. In all other cases, the algorithm uses the codes to identify how to clip a line, so that one of the branches can be eliminated right away.

The original Cohen-Sutherland algorithm for line clipping uses rectangular clipping areas. The algorithm could be extended for convex non-rectangular viewports by using bitmasks with length equal to the number of sides of the viewport polygon. The right illustration in Figure 11 is an example of a pentagonal viewport and some of its 5-bit bitmasks.

This extended case is transformed into a more complex visual representation in the 3D model named Cohen-Sutherland's thimble. The lines are represented as arcs, and the plane is shrunk into a circle. Figure 12 shows a snapshot of the thimble from the outside. For some of the areas there are bitmasks attached to the external surface of the thimble. The problem is to calculate the bitmask represented as empty panels.

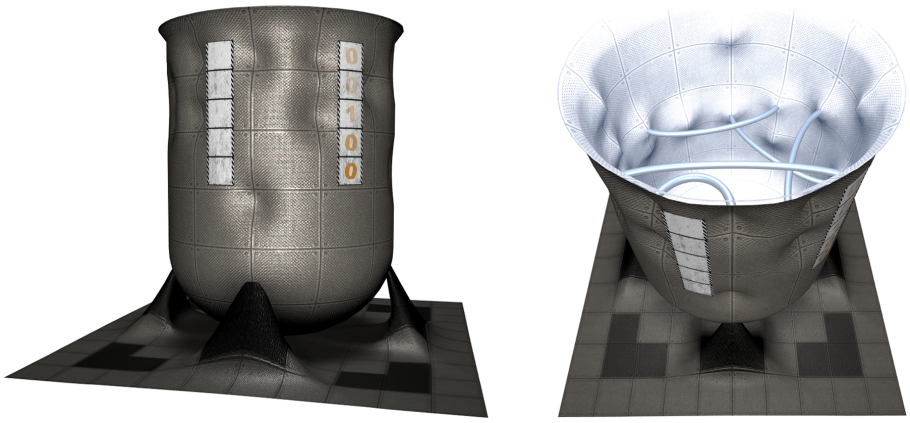


Figure 12. Snapshots of the Cohen-Sutherland's thimble.

The first issue, which students face when they try to solve the model, is the layout of areas. A top view of the model reveals the interior with the arcs, splitting the circle into areas. Figure 13 shows several configurations—the left-most one has two arcs forming 4 areas; while the right-most one has 5 arcs forming 13 areas. The curved areas and the lack of central area force the students to invent their own extension of the algorithm.

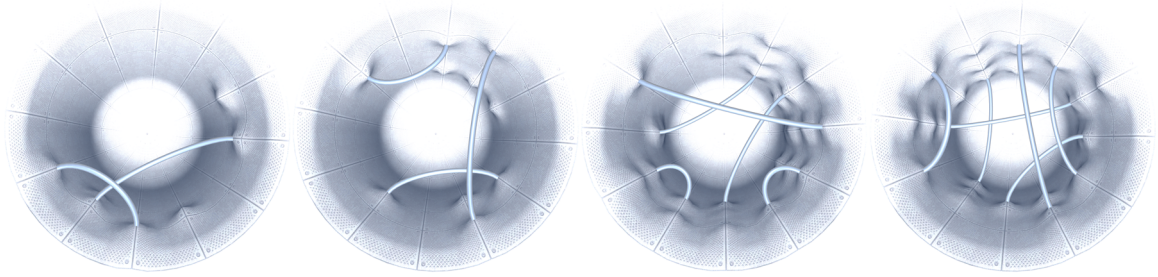


Figure 13. Randomly generated interiors with various degrees of complexities.

Several clues support the solving process, some of them could be observed visually, while others can be deduced by reasoning. For example, a visual clue is the mapping between arcs and bit positions. Bumps correspond to vertical positions, which are bound to bit positions in the masks. A non-visual clue is a property, which can be extracted from the bitmask code assignment in the original Cohen-Sutherland algorithm. Namely, the bitmask codes of two neighbouring areas differ by the value of exactly one bit and the position of this bit corresponds to the arc, separating the two areas.

Like all other models, the Cohen-Sutherland's thimble is related to some practical knowledge of the original algorithm, it requires research and investigation efforts of extending ideas into non-traditional layouts. It utilizes some graphical skills like mapping perspective view of arcs in the interior onto the linear relative positions of bit labels on the outside of the thimble. The right-most snapshot in Figure 13 is an illustration that challenges this particular graphical skill—finding the correct order of arcs requires a good depth perception.

4.5. The Matrix Carousel

There are three approaches to expressing animation in Computer Graphics. The descriptive approach defines explicitly the values of properties. For example, an object motion along a path is defined by a sequence of coordinates. In some cases it is easier to use the differential approach in which motion is expressed as differences between a frame and its previous frame. Internally, both of these approaches are implemented as the transformational approach that transforms coordinates and other values by matrix multiplication. Matrices can be used to implement translation, scaling, rotation, mirroring, and projection. They are widely used in Computer Graphics, because they:

- provide a unified way to represent various transformations—they are all expressed as matrices;
- allow packing several transformations into a single matrix by multiplying matrices in advance;
- control working in local or global coordinate systems by premultiplication or postmultiplication;
- support nested transformations by using a matrix stack;
- are fast to compute as there is hardware support for matrix operations in GPUs and shader languages.

Although the matrix content easily becomes very complex, transformations are usually expressed in terms of basic transformations for which the matrices are simple—they are slight modifications of the identity matrix.

We developed the Matrix carousel model as a tool for the students to explore the basic matrices and to map them to various graphical transformations. The model shows several coordinate systems riding a carousel—Figure 14. Each coordinate system represents a specific matrix transformation. There are matrices painted on the floor of the carousel. The student plays the model by spinning the carousel and stopping it so that each coordinate system is above the matrix, corresponding to the transformation.

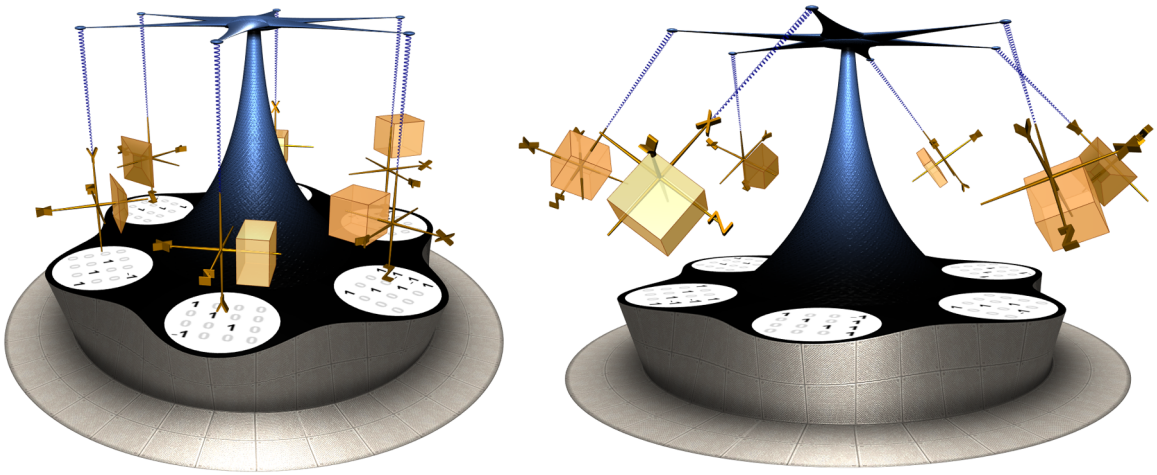


Figure 14. Snapshots of the Matrix carousel.

A design challenge in this model is the graphical representation of matrix transformations. We solve the challenge by placing unit cubes in each coordinate system. These cubes are continuously transformed via the transformation of the coordinate system—Figure 15.

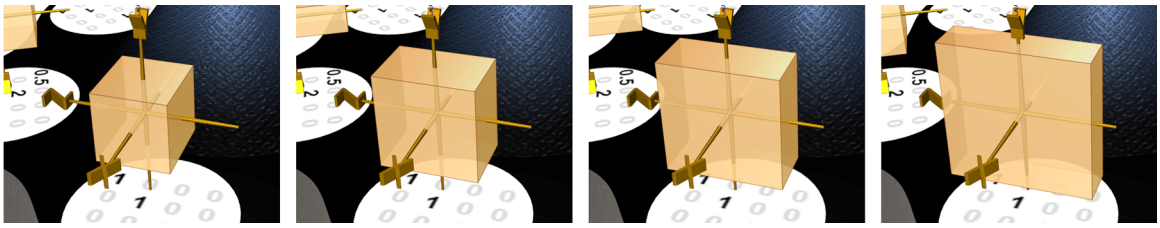


Figure 15. Transformation of a cube.

This representation of transformations is intuitive, but it forces some discrepancy between animations and painted matrices. The animation shows small steps, which accumulated produce the same result as the matrix. For example, the rotation matrix defines a 90° rotation around one of the axes, while its animation shows the initial cube for 1 s, then for 4 s smoothly rotates it to 90° and finally waits for another second before starting over. The gradual transformation of the cube is done by applying a matrix that is generated by linear interpolation of the identity matrix and the desired matrix.

Depending on the selected level of difficulty, the model is generated with a set of randomly selected types of matrices. These are a few of the 70 matrix transformations, used in the model: a translation matrix T, a scaling matrix S, a rotation matrix R and a perspective projection matrix P:

$$T = \begin{pmatrix} 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad S = \begin{pmatrix} 2 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1/2 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad R = \begin{pmatrix} 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad P = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix} \quad (4)$$

Another option to fine-tune the difficulty is the orientation of the coordinate system. Students are accustomed to specific orientations of coordinate systems. For example, in a 2D Cartesian coordinate system the $\overrightarrow{OX}$ axis points to the right and the $\overrightarrow{OY}$ axis points upwards. When the model is generated, each coordinate system is randomly rotated in one of the 24 possible orientations—$\overrightarrow{OX}$ could point up, down, left, right, front, back and for each of these orientations, there are 4 possibilities for $\overrightarrow{OY}$ and $\overrightarrow{OZ}$.

5. Preliminary Results

This section presents the preliminary results from testing the models with our FMI students. Further analyses are needed to extract all information from the tests.

The 3D models described in the previous section will be used as 3D models in Meiro for students' evaluation and assessment. The target course is Fundamentals of Computer Graphics, which is compulsory for second-year Computer Sciences students at the Faculty of Mathematics and Informatics, Sofia University. The number of enrolled students varies between 130 and 180 each year.

The ten developed models, shown in Figure 7, have been packed in a test suite open to 151 students from December 2019 until mid-January 2020. The students had to play with the models and report any positive and negative observations. This end-user testing was completely voluntary, but students get a bonus for their participation. The achieved scores by playing with the models did not affect the bonus, thus students were free from test fright.

Two types of data were collected during these tests—automatically collected data, containing general statistics of each student's gameplay, and a survey where students describe their observations and comments.

5.1. Automatically Collected Data

The gameplay of each model sends data back to the server where it is processed and stored in log files. In order to minimize the volume of these data, game data are sent only at the start and at the end of playing a model. Table 2 lists the log data when a model is closed. The parameter SCORE is the score, achieved by the student. This value is multiplied by the competence scores of the model and the result is stored in COMPETENCES, which a vectored score containing a score for each of the 17 competences in Table 1.

There is a separate log file for each student. The data from these logs files are used to identify the engagement of each student. A part of the bonus for the students is calculated on the aggregated data from the logs. In real tests, the log files may indicate the skill of students. For example, if a model is solved by using too many clicks, most likely it is solved by trial and error. It is yet to be analyzed whether there is a need to capture more log data or to distinguish navigational clicks (i.e., when the students rotate the model or zoom in or out) from operational clicks (i.e., when the students turn on or off parts of the model).

The other important purpose of the log files is to capture possible cheats and hack attempts. Because students have access to the source code, they might find a way to calculate the correct answer (by a script) instead of solving the problem. Such attempts could be captured if the score, the time and the clicks do not match. For example, solving the model with 0 clicks is an indication of such cheating.

Table 2. Log data when a model is closed.

Parameter	Description	Example
ACTION	Type of the log record	END
MODEL	Name of the 3D model	T001
DIFFICULTY	Level of difficulty	2
MAX_SCORE	Maximal score	0.9
SCORE	Achieved score	0.84
TIME	Number of seconds	38
CLICKS	Number of clicks	14
COMPETENCES	Vectored score	0.84, 0, 2.53, 0.84, 2.53, 0, 0.84, 0, 0, 0, 1.68, 0, 4.21, 0, 0.84, 0, 2.53
IP	IP address	188.254.xxx.xxx
TIMESTAMP	Local time	2020-01-05 18:35:00

The models are accessed through the Moodle LMS. Students log-in into Moodle and then Moodle sends data to the Extended Meiro—Figure 3. Thus, Meiro "knows" who is playing with the 3D models. However, some students accessed Meiro directly in an attempt to bypass Moodle and logging. Meiro captures these attempts and creates the log files as if it were anonymous users. Such hacking during the tests reduces the bonus of the students, as their gameplay activity is left anonymous. Using the same technique during the actual evaluation tests has no benefit, because students will have access to the test for the whole semester, so they can experiment as long as they want. The temporal average score will reduce the impact of their initial attempts to almost 0, thus the self-testing will not affect the actual testing.

During the end-user tests we observed some attempts of hard hacking—bypassing not only Moodle, but also Meiro and sending directly data packages to the evaluation generator. All such attempts were successfully captured, because the log data were malformated or incomplete—they lack the session identification data, exchanged between Moodle and Meiro.

Totally, the log files recorded 186 users playing with the 3D models, 121 of them were via Moodle and the rest 65 were anonymous. Table 3 presents general statistical information. On average a logged-in student spent about 3 h playing 150 times with the models.

Table 3. General statistical data retrieved from log files.

Parameter	Logged-In	Anonymous	Total
Unique users	121	65	186
Models played	17,663	1386	19,049
Time played (hours)	342	42	384
Clicks and taps	1,048,982	89,049	1,138,031
Incomplete records	1543	392	1935

The last row in Table 3 represents the number of incomplete records. These are log records, which are incomplete either because the students closed the browser window before the models managed to send back the data; or because of hacking attempts.

Future studies of the log data may analyze these parameters with respect to the models, thus identifying what model requires more time, clicks and taps, what models are easier to get high scores, and so forth.

5.2. Students' Survey

In addition to logging end-user tests, we conducted a simple survey, where students expressed in a free form their observations about the models. The survey contained 10 questions (one for each of the 10 models) of the same pattern: "Describe in a free form your experience with the model. What did you like or did not like about it with respect to visual appearance, implementation, gameplay, difficulty

and evaluation?" The survey included an upload form, so that students may attach images if they need to illustrate a problem.

The survey was implemented as a quiz activity in Moodle. It was available only to logged-in students. The evaluation was based on the completeness and importance of provided answers, rather than on whether they are positive or negative.

Every semester the students at Faculty of Mathematics and Informatics, Sofia University, fill anonymous optional surveys about their courses. These surveys are used for quality assessment of the educational activities. The average participation rate for the course Fundamentals of Computer Graphics was 22% in 2017, 16% in 2018 and 13% in 2019. As the survey about the 3D models was also optional, but not anonymous, we did expect that just a few students will complete it. To our surprise, we received 125 filled surveys about the 3D models, which is 83% student's activity. Table 4 shows general data about the survey answers. Model 1 is the CMY reservoir, model 4 is the Euler's grill, model 5 is the Cohen-Sutherland's thimble and model 7 is the Matrix carousel.

In total, we received 794 comments of 34 k words worth 68 pages of text. This prompted us to try Natural Language Processing methods to analyze the text using different methods for sentiment analysis. The results show that only a small proportion of students used more expressive opinions and the majority used neutral vocabulary. In general, positives for all models prevail.

Table 4. General statistical data from the survey.

Model	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Answers	91	87	85	74	71	85	78	69	83	71	794
Edits	104	103	109	88	82	104	95	80	107	85	957
Words	4581	3384	4298	2677	2401	3242	3519	2982	4242	2829	34,155
Section	Section 4.2			Section 4.3	Section 4.4		Section 4.5				

The survey was configured in a way that all answers are open for edits during the whole end-user test period, thus students could use the survey as a memo and update their answers as much as they need. The students actively used this option—for example, the CMY Reservoir got 91 answers, that were edited 104 times.

The main expectations of the survey were to get answers to four questions and more or less we got all of them answered. The questions are:

- Are there any technical issues with using mobile devices?
- Are there any difficulties caused by the user interface?
- Are gaming evaluations suitable for university students?
- Are there any suggestions for improvement of the models?

We asked the students to test the models with their personal computers and mobile devices (usually smartphones). The goal was to find whether the technology, used in the models (mobile 3D graphics) works well on students' devices of various hardware and software configurations. Only a few problems were reported, mostly related to the initial configuration of the devices.

As for the user interface, we got some really nice suggestions for improvement. Currently, the models inherit the orbiting navigational mode from the Meiro maze—that is, the model is always in the center of the screen and the player orbits around it and zooms in or out. According to survey answers, students would prefer a free navigational mode, which would allow getting closer to specific areas of the model, not necessarily its center. This would help users of smartphones, which screen area is relatively small.

The majority of answers clearly expressed students' enthusiasm for using a 3D gaming environment instead of traditional quiz-shaped tests. Of course, different students liked different aspects of the models—some liked the visual appearance, others liked the sound effects, and there were students, who liked how academic content is transformed into something that could be played.

Valuable elements of students' answers are their ideas of modifications. Students suggested some improvements of the models with respect to the user interface or the evaluation scheme. For example, they wanted more control over the camera, clearer identification of interactive elements and better support for touch screens. As for the evaluation, they would like to have a better understanding of the temporal average, as it is a new scoring technique for them and they are not accustomed to it.

During the test period we opened an online forum for all students. We asked them to share their experience that could help the other students to work with the models. The reason for this was that we gave the models to the students with very limited information and guideline. We asked them to explore the models and find by themselves what do they do and how to operate them. Thus this forum acted as mutual aid for the students.

We also encouraged them to share tricks. Some of the students' findings are particularly helpful for the future development of the models. For example, the students found a problem with the Matrix carousel. The easier configuration of the carousel used easier matrices (like translation and scaling). However, the most difficult configuration used a mixture of all matrix types . . . and this actually made the solving much easier. Students suggested the following trick—find the easiest matrix and match it to the coordinate system. Then all the other matrices will naturally match.

A further detailed study is needed to analyze the impact on computer graphics soft skills—these are skills, which are not explicitly taught in the course, but nevertheless, they are essential for the domain. Well developed soft skills could make solving the 3D models much easier. This is the reason we deliberately added some modifications in the models, so that to enforce the development of soft skills as a side effect of solving computer graphics problems. As expected, some students treated these modifications as disadvantages in the models. Some of the computer graphics soft skills and their implementation in the models are listed in Table 5.

Table 5. Some soft skills and their support in the models.

Soft Skill	Examples
Seeing similarity of colours	Model 1 (The CMY reservoir) does not provide a numeric representation of the current liquid ink proportions, so students may only inspect the colour visually.
Estimating positions in space	Model 8 (The Loop's torus) requires the students to calculate or guess positions on a curved surface without a detailed coordinate grid to guide them.
Using non-visual senses	In model 6 (the Pick's polygon) students may solve the problem more easily by listening to the sound effects—they resemble a Geiger counter depending on how accurate the solution is.
Motion synchronization	Model 2 (The Bouncing balls) requires the students to compare and identify differences in bouncing frequencies of several balls, that bounce at different time offsets.
Spacial memory	The interior and exterior of Model 5 (The Cohen-Sutherland's thimble) cannot be seen at the same time, so students must alternate between two viewpoints and remember objects' positions in space.
Chaining transformations	In model 9 (The flight of the butterfly) students construct a chain of geometrical transformations in order to define motion along a path—they do this by imagining the effect of the transformations.

6. Conclusions and Further Work

This article presents a method for a gamified evaluation based on competence profiles of students and problems, describes the software, which we developed for this gamified evaluation, and discusses the preliminary results of the software test with over 100 students. The extended Meiro allows quantitative analysis of students' competences and skills in the Computer Graphics domain.

Meiro contains almost 300 interactive 3D models used for in-class demonstration and off-class exploration. We extended Meiro with models for gamified evaluation and representation of competences. The proposed gamified evaluation was tested in December 2019 and January 2020 with undergraduate students in Computer Sciences, providing us with data about the applicability and the limitation of our temporal average scoring metric.

The preliminary results from the analysis of the tests confirm that the temporal average is a suitable evaluation metric if it is applied correctly. This allows us to continue our work on the gamified evaluation in several aspects. We will first complete the analysis of all data—automatically collected via log files, answers in the students' surveys and the information shared in the forum. Then we will improve the existing 3D models and embed them in the educational content of the next course Fundamentals of Computer Graphics, which will start in October 2020. In December 2020 and January 2021 the models will be used for the actual evaluation and students' results will be one of the scoring components in their FCG grades.

In addition to these activities we plan to develop other models, so that the whole range of topics in the course are covered. A survey from 2018/2019 asked CS students for ideas of how topics from FCG could be gamified. We will revisit these ideas for any gems that could help up design and develop new 3D models. If the outcome of the gamified evaluation is positive, we will expand our efforts in both educational and technological aspects. Educationally, we will try to apply gamified evaluation in some of our other courses. Technologically, we will convert the models to utilize the full power of WebXR—the new standard for mobile virtual and augmented reality applications.

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

Funding: The research is partially funded by Sofia University "St. Kliment Ohridski" Research Science Fund project N80-10-18/18.03.2020 "Use of high-tech tools for development of competency models in training" and by the National Scientific Program "Information and Communication Technologies in Science, Education and Security" (ICTinSES) financed by the Ministry of Education and Science.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

CMY	Cyan, magenta, yellow
CS	Computer Sciences
FCG	Fundamentals of Computer Graphics
FMI	Faculty of Mathematics and Informatics
GBL	Game-Based Learning
GPU	Graphical Processing Unit
IBL	Instruction-Based Learning
LMS	Learning Management System
PBL	Project-Based Learning
STEAM	Science, Technology, Engineering, the Arts and Mathematics
STEM	Science, Technology, Engineering and Mathematics
WebGL	Web Graphics Library

References

1. Ortiz Rojas, M.E.; Chiluiza, K.; Valcke, M. Gamification in higher education and stem: A systematic review of literature. In Proceedings of the 8th International Conference on Education and New Learning Technologies (EDULEARN), Barcelona, Spain, 4–6 July 2016; IATED—International Academy of Technology, Education and Development: Valencia, Spain, 2016; pp. 6548–6558.
2. Dicheva, D.; Dichev, C.; Agre, G.; Angelova, G. Gamification in Education: A Systematic Mapping Study. *J. Educ. Technol. Soc.* **2015**, *18*, 75–88.
3. Kim, S.; Song, K.; Lockee, B.; Burton, J. Gamification Cases in Education. In *Gamification in Learning and Education*; Springer: Berlin, Germany, 2018; pp. 117–123.

4. Fotaris, P.; Mastoras, T.; Leinfellner, R.; Rosunally, Y. Climbing up the Leaderboard: An Empirical Study of Applying Gamification Techniques to a Computer Programming Class. *Electron. J. E-Learn.* **2016**, *14*, 94–110.
5. Piteira, M.; Costa, C.J. Gamification: Conceptual framework to online courses of learning computer programming. In Proceedings of the 2017 12th Iberian Conference on Information Systems and Technologies (CISTI), Lisbon, Portugal, 14–17 June 2017; IEEE: Piscataway, NJ, USA, 2017; pp. 1–7.
6. Ibáñez, M.B.; Di-Serio, A.; Delgado-Kloos, C. Gamification for engaging computer science students in learning activities: A case study. *IEEE Trans. Learn. Technol.* **2014**, *7*, 291–301. [CrossRef]
7. de Almeida Souza, M.R.; Constantino, K.F.; Veado, L.F.; Figueiredo, E.M.L. Gamification in software engineering education: An empirical study. In Proceedings of the 2017 IEEE 30th Conference on Software Engineering Education and Training (CSEE&T), Savannah, GA, USA, 7–9 November 2017; IEEE: Piscataway, NJ, USA, 2017; pp. 276–284.
8. Iosup, A.; Epema, D. An experience report on using gamification in technical higher education. In Proceedings of the 45th ACM Technical Symposium on Computer Science Education, Atlanta, GA, USA, 5–8 March 2014; ACM: New York, NY, USA, 2014; pp. 27–32.
9. Villagrasa, S.; Duran, J. Gamification for learning 3D computer graphics arts. In Proceedings of the First International Conference on Technological Ecosystem for Enhancing Multiculturality, Salamanca, Spain, 14–15 November 2013; ACM: New York, NY, USA, 2013; pp. 429–433.
10. O'Donovan, S.; Gain, J.; Marais, P. A case study in the gamification of a university-level games development course. In *Proceedings of the South African Institute for Computer Scientists and Information Technologists Conference*; ACM: New York, NY, USA, 2013; pp. 242–251.
11. van Roy, R.; Zaman, B. Why gamification fails in education and how to make it successful: introducing nine gamification heuristics based on self-determination theory. In *Serious Games and Edutainment Applications*; Springer: Berlin, Germany, 2017; pp. 485–509.
12. Buckley, P.; Doyle, E. Gamification and student motivation. *Interact. Learn. Environ.* **2016**, *24*, 1162–1175. [CrossRef]
13. Freeman, S.; Eddy, S.L.; McDonough, M.; Smith, M.K.; Okoroafor, N.; Jordt, H.; Wenderoth, M.P. Active learning increases student performance in science, engineering, and mathematics. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 8410–8415. [CrossRef] [PubMed]
14. Hamari, J.; Eranti, V. Framework for Designing and Evaluating Game Achievements. In Proceedings of the 2011 Digra Conference, Hilversum, The Netherlands, 14–17 September 2011.
15. Heilbrunn, B.; Herzig, P.; Schill, A. Tools for gamification analytics: A survey. In Proceedings of the 2014 IEEE/ACM 7th International Conference on Utility and Cloud Computing, London, UK, 8–11 December 2014; IEEE: Piscataway, NJ, USA, 2014; pp. 603–608.
16. Menezes, C.C.N.; Bortoli, R.d. Potential of gamification as assessment tool. *Creat. Educ.* **2016**, *7*, 561–566. [CrossRef]
17. Gañán, D.; Caballé, S.; Clarisó, R.; Conesa, J.; Bañeres, D. ICT-FLAG: A web-based e-assessment platform featuring learning analytics and gamification. *Int. J. Web Inf. Syst.* **2017**, *13*, 25–54. [CrossRef]
18. Zichermann, G.; Cunningham, C. *Gamification by Design: Implementing Game Mechanics in Web and Mobile Apps*; O'Reilly Media, Inc.: Sebastopol, CA, USA, 2011.
19. Winnicka, A.; Kęsik, K.; Połap, D.; Woźniak, M.; Marszałek, Z. A Multi–Agent Gamification System for Managing Smart Homes. *Sensors* **2019**, *19*, 1249. [CrossRef] [PubMed]
20. Boytchev, P.; Boytcheva, S. Evaluation and assessment in TEL courses. *AIP Conf. Proc.* **2018**, *2048*, 020035.
21. Boytchev, P.; Boytcheva, S. Gamified Evaluation in STEAM. In *International Conference on Information and Software Technologies*; Springer: Berlin, Germany, 2019; pp. 369–382.