Developing gamified interactive content for medical training in cytopathology

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***Abstract*— Cytologists at Massachusetts General Hospital want to improve training of both medical students at Harvard Medical School and cytologists in resource-limited areas of the world. The approach is to use medical imaging game-like interactive content but that could be developed within a limited budget and meeting some challenging technical requirement (to be deployable on both PCs and in low-cost Android tablets without a continuous connection to the internet). We reviewed some of the existing games or gamified e-learning modules to create a shared understanding between medical experts and developers about possible game mechanics and to identify which of those approaches can be suitable for our case. We have applied the acquired knowledge in the creation of an integrated system composed of a web-based content editor for cytologists from where the interactive game-like application can be semi-automatically generated. Once the system has been developed we are carrying out tests with professors and students at an Introduction to Cytopathology course at Harvard Medical School to ensure both the usability of the system and that the learning goals are satisfied.**

Keywords— e-learning; serious games for health; training simulations; design; medical imaging; best practices; cytopathology; gamification

I. INTRODUCTION

Games and game-like contents for health have been increasingly used in the past years for improving medical education (those games are usually called Serious Games). There are examples in very different areas as games are being targeted at HIV prevention education, cancer diagnosis, dental pain, etc. [1]. ´SICKO´ [2] is a web-based game, developed at the Stanford University School of Medicine, in which players must take care of three virtual patients while making critical decisions in the operating room at the same time. Serious games are not only intended for medical personnel as playing serious games can also help patients with different medical conditions. For instance, veterans are using games to treat their post-traumatic stress disorder and burn patients are using games to relieve their trauma and pain [3]. Game applicability benefits from the proliferation of mobile devices (i.e. smartphones and tablets) that has greatly increased the number of gamers and the possibility of playing games in different environments, which was more difficult using only computers [4]. Currently, the average age of today´s gamers is 35 and 73% of gamers are over 18 years old [5].

The goal of the project is to research how to improve the training of cytologists in resource-limited areas of the world but with a gamified content that could also be used and tested at the Harvard Medical School. The budget is limited and the requirements are challenging since the application has to be deployed on multiple platforms. Furthermore, we are considering other aspects such as code maintainability, gameplay mechanics, application design, etc. The application will be tested in PCs at the Introduction to Cytopathology Course and using low-cost Android tablets in resource-limited areas of the world, not depending on a reliable internet connection.

The training of medical personnel in cytopathology using serious games is a relatively unexplored field. The design phase is focused on using medical imaging content that incorporates specific game mechanics and gamification techniques. Gamification can increase the student motivation but effort must be put in the design and implementation phases [6] while also considering our project's challenging technical requirements.

The main learning objective is to develop the skills to be able to efficiently identify normal and abnormal cells in medical images from tissue samples. This is usually the most difficult skill to teach to students and the most difficult for them to learn.

We decided to do a specific analysis of serious games based on medical imaging for medical training taking into consideration students' game personalities to identify appropriate game mechanics for our system [7]. To improve the long-term maintainability of the gamified content and to reduce the dependency from the application developers, we have created an integrated system. This system includes a web-based

editor where cytologists can author and edit the content. Based on that content the interactive game-like application can be semi-automatically generated.

II. GAME-LIKE APPLICATIONS FOR MEDICAL TRAINING USING MEDICAL IMAGING

As previously stated, our goal is to develop a serious game for cytopathology training of medical personnel applicable in very different environments. The game should run on both PC and low-cost Android tablets (e.g., 50$ Kindle Fire). The tablet game should be fully functional without a continuous reliable internet connection. This means that all the game assets must be packed with the game and cannot be downloaded dynamically, which may imply size-related concerns for the Android version of the game.

Trying to identify best practices and design methodologies for serious games in ehealth and more specifically in games for training medical personnel we have reviewed applications that have the purpose of training personnel (expert or non-expert) in medical related domains relying on medical imaging.

A. *Malaria Spot – Cell Map Explorer*

MalariaSpot is a gamified application focused on Malaria diagnosis done by non-medical experts [8]. It is available online for free [9].

The players must explore an image of a blood sample in search for parasites. The goal is to find as many parasites as possible before the timer expires. Fig. 1 displays the instructions screen from the tutorial at the beginning of the game explaining how to identify a parasite and how to interact with the game. A tutorial is a useful game mechanic that explains the rules that must be followed by the player. Finding all the available parasites of the current image automatically progresses the player to the next level with a new image. A level-based game mechanic allows the user to have a sense of progression. Furthermore, it helps developers to display the content of the game story in a structured way and it can be easily integrated with an analytics system to track the game.

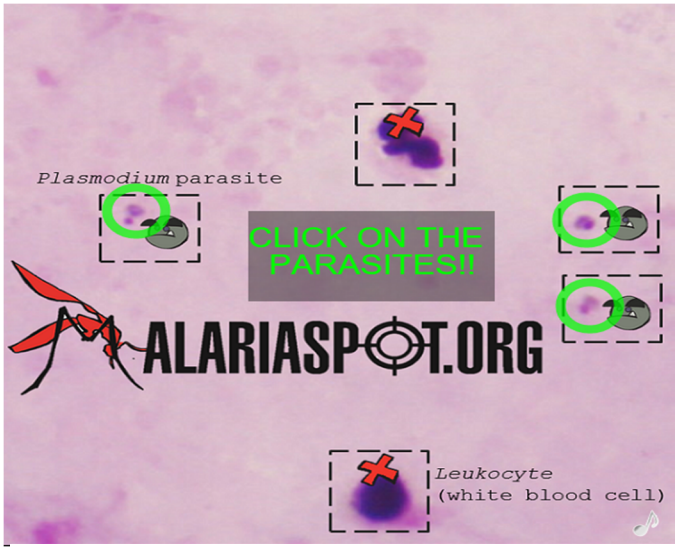

Fig. 1 Screenshot of the MalariaSpot game tutorial explaining the game mechanics and interaction.

There are other game mechanics to reinforce the player engagement, such as:

1. Continuous immediate feedback. Most player interactions are displayed as an element of the user interface. The player identifies parasites, getting penalized in case it misidentifies (e.g. a leukocyte) reducing the remaining time available and the final score of the level.
2. Leveling up. The difficulty is increased with each level by increasing the score and time penalty for wrong targets identified. Only one part of that image is shown at the screen at a time and the user can move around it looking for all the parasites.
3. Gamification. The players' score is tracked and included in a table of high scores (*leaderboard*) for the latest day and week.

B. *Virtual Microscopy Adaptive Tutorials – Quiz Challenge*

The cytopathology virtual microscopy adaptive tutorials (VMATs) focus on training students and pathology specialists [10]. VMATs display a two vertical columns layout with text on the left column and an interactive slide on the right column. The left column is composed of a question with different formats (e.g., multiple-choice, drop-down lists, drag and drop type questions, fill-in-the-blank) and a note clarifying the context. The mechanic is pretty simple yet is integrated with different gamification methods:

1. To increase the engagement, the question format can change (e.g., multiple-choice, drop-down lists, drag and drop type questions, fill-in-the-blank).
2. Immediate feedback is provided following the user's/learner's submission of responses. The feedback may contain useful educational information about the quiz or a specific area on the slide. The area can be highlighted using different colors or shapes on the feedback screen.
3. The players are challenged to answer as many quizzes as possible (and accumulate points for correct answers) in a one-minute round.

Some of these gameplay mechanics can be used for our project but with a different design, adapting them to work on low-cost Android devices and not depending on a continuous internet connection. The size of the slide image can also present technical problems for the Android device hardware if it is too large.

C. *BioGames*

BioGames is a game focused on identifying cells infected with malaria [11] and it is a project to transform an image library into a training and educational module. The player classifies cells in three categories: "positive", "questionable" or "negative". We have identified the following game mechanics

1. Level-based gameplay where a set of images are displayed in a grid layout as we can see in Fig. 2.
2. An optional timer is available during the level to increase focus. The player must identify the infected cells before the time runs out.
3. The players receive a score depending on the performance classifying cells. The score is displayed in a leaderboard system.
4. A progress bar provides visual feedback of the advance in the game.
5. A tutorial guides the user through the initial steps of the game.

We plan on using similar mechanics on our project taking into consideration that all the images must be packed inside the game (cannot be downloaded dynamically). If there are too many images available, the size of the final game can grow considerably.

D. *Cell Slider – Help Cancer Research*

Cell Slider is a game focused on classifying archived cell samples in order to greatly reduce the amount of information scientists have to classify. The game was developed by Cancer Research UK and Zooniverse [12] to aid the breast cancer research considering different types of breast cancer and how well they respond to different forms of treatment.

The players are asked to classify and identify cells on archived cell samples. Players must examine tumor tissue samples and identify cancerous cells. In order to ease the identification process, players are asked simple questions about what they can see in the image of a tissue sample. To increase the validity of the answers the images are reviewed by several players.

Cell Slider combines game mechanics from BioGames, by asking its players to identify specific tissue samples with a higher focus on each image individually, and VMATs, by displaying a user interface similar to a quiz challenge composed of a text-based question and a related image. We can use a similar approach by asking the student questions using different formats such as multiple choices for questions and interacting with images.

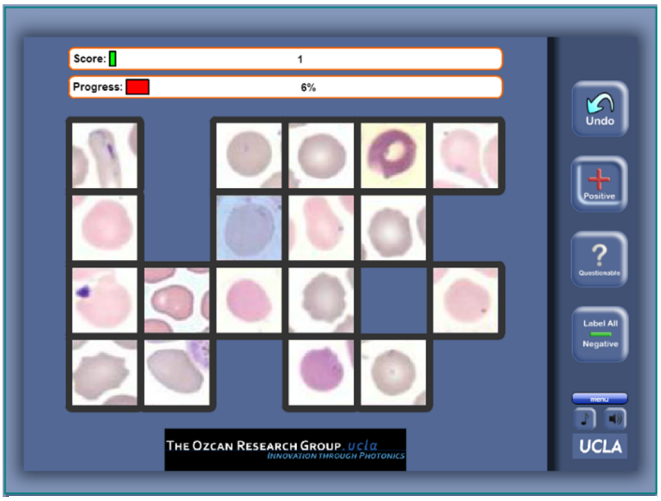

Fig. 2 BioGames in-game example of a game that helps identify malaria infected cells.

III. INTEGRATED SYSTEM

We have reviewed games and game-like applications to identify the best game mechanics for our project, the common mechanics are:

1. An initial story to set up the context of the game.
2. Introductory tutorial to guide the player through the first steps of the game.
3. Level based gameplay. Incremental difficulty depending on the unlocked level and overall progress of the game.
4. Use of several types of interactive questions. The questions can have multiple formats: multiple choice question, multiple choices based on images, interact with areas of the medical image, classify parts of an image, etc.
5. Each level should have the option to give feedback to the player depending on the answer.
6. Additional gamification mechanics such as progress tracking for completion, score, and leaderboards.
7. Possibility to track the player's interactions using a learning analytics infrastructure.

We have considered how to integrate the previous game mechanics in our project to create a gamified application to train students and medical personnel in cytopathology.

We have also identified the strong dependency between domain experts and developers in this type of projects. Domain experts continuously depend on developers to manage the content of the applications. This is caused because of the lack of an easy to use content management system. A management system for the application focused on the content creation and edition easily accessible and usable so that the domain experts can take care of the creation of new content or the update of the current content. Our system includes a web-based editor where cytologists can author and edit the content in order to facilitate the content management by the domain experts. For instance, the preview functionality allows the creator to play the challenge from the point of view of a student and it also shows the results screen as well as the configured hints. The preview functionality shows how a challenge is viewed exactly inside the game application. Facilitates the edition by giving an exact view of the challenge that is being created inside the game. This view displays the student's experience to the teacher or the content creator when playing the challenge. Currently, there are five different types of challenges, with different mechanics and structures.

In Fig. 3, the project's architecture is divided into the following main modules, (A) a gamified application focused on training students and medical personnel in cytopathology, and (B) a web-based content editor designed to be easy to use by

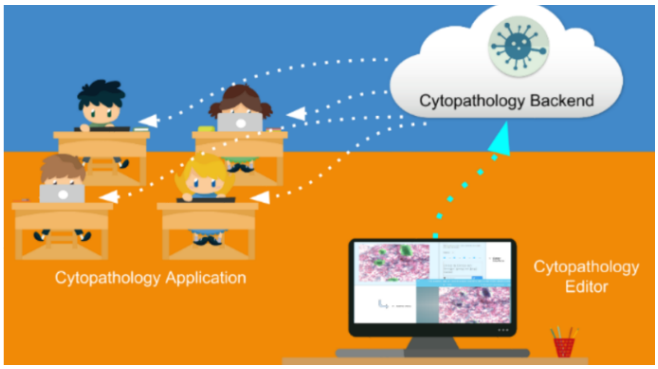

Fig. 3 Integrated system with (A) Cytopathology Application, and (B) a Cytopathology Editor backed by the Cytopathology Backend service.

domain experts (cytopathologists). Furthermore, a backend service is used to semi-automatically generate the gamified application deployed on different platforms and reduce the dependency of developers.

A. *Cytopathology Application*

Cytopathology Challenge is a gamified application composed of different challenges that the student must solve to receive a grade based on the solution given. A challenge-based game mechanic allows us to structure the displayed content easily in different types of gameplay mechanics described below. Each challenge can be seen as a small level in a video game. Our design also groups challenges by courses. A course is a group of challenges that share the same topic. By grouping challenges, we were able to define exams for each course. An exam is a gameplay mechanic where the student must answer different challenges in a row from the same course. The grade received when the student performs an exam can be considered differently than the one received when solving challenges freely.

The gamified application is composed of different screens available for the student to explore. At the beginning, there is an introductory story to set up the context of the story for the student followed up by the course and challenge selection screen where the initial challenges must be gradually unlocked by the student as it progresses. The gameplay screen is where the actual challenge is played and finally, its score is displayed at the results screen.

We decided to improve the feedback the players receive by displaying customizable information about each challenge solved by the student. The content creator (e.g. teacher) can set up and manage the feedback information shown to the students as shown in, Fig. 4. Explanations are displayed to the student once a challenge has been completed as a means to give feedback to the student and learn more information about the specific answer. This greatly increases the feedback a student receives after completing a challenge. Hints are composed of a list of either text paragraphs or images displayed from top to down in a vertical layout.

Each challenge has an associated difficulty mechanism that is used to establish the initial time available for the student to complete the challenge. The difficulty is established by the creator of the challenge. Another gamification layer is to use the difficulty mechanism so that some challenges are unlocked only

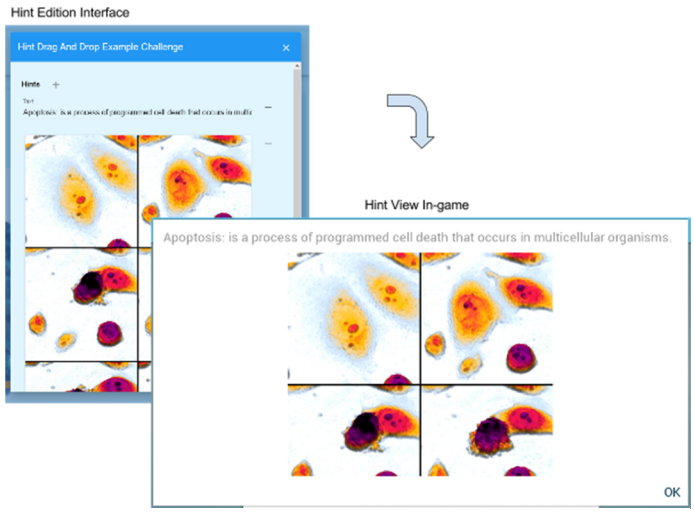

Fig. 4 Explanation user interface, web editor (left) and the preview of how this content finally appears.

when a certain amount of challenges of lower difficulty are completed. Moreover, a timer based mechanism increases the engagement of the players. Each challenge the student has to solve must be solved before a timer finishes. The initial time of the timer changes depending on the difficulty of each challenge so that a challenge with higher difficulty has a lower amount of time available to be solved compared to another challenge of lower difficulty. An interesting gamification layer is the students ranking based on their overall score and the number of challenges solved. Finally, an introductory tutorial guides the player with the game mechanics and sets up the initial story with the purpose to establish a base context for the student to start.

Other applications such as *Angry Birds* [13] have a rating system that gives the players stars (up to three) based on how well they have solved the challenge. We have decided to use a score-based system where each challenge receives a score between 0 and 100 and depending on that value we display a number of stars (between 1 and 3). The final challenge score can be considered as a grade. We displayed the grades to the student following the academic grading system in the United States. Another gamified application is *Duolingo* [14]that rewards the player after each 'mini-challenge' and has a badge system, so that every time a player achieves a certain goal, he receives a reward competing against the friends [15].

We have implemented two different gameplay mechanics (exam mode and training mode). The training mode allows challenges from a course to be played individually as a way of training. The challenges are disabled initially and they must be unlocked progressively while the "exam mode" is played. The learner can choose what challenge to play from a list of challenges, once the challenges have been unlocked.

The exam mode is composed of multiple challenges of a course that must be solved in order before a timer expires. After completing an exam the learner receives a grade. This mechanic is used to test out the learner's knowledge about a given course. The "exam mode" is directly related to the challenges of a given course. In order to configure the "exam mode" the estimated time available per challenge can be optionally defined in the

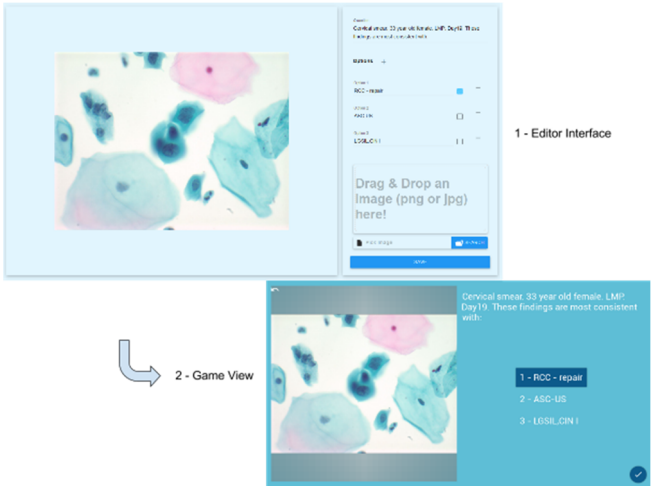

Fig. 5 Multiple Choice Question user interface, web editor (left) and preview of the game-like application (right).

editor. The estimated time available per challenge is an approximation of how much time is going to take to complete each challenge. This will be used to establish a timeout of completion of the "exam mode" based on how many challenges are available during the exam and the estimated time of completion of a challenge. The maximum time available for the exam is configurable from the editor and depends on the number of challenges of the given exam. By default unlimited time is given to the learner to complete the "exam mode".

We have reused some of VMATs gameplay mechanics to create different formats of displaying the content to the student. We have also added our own formats, that we considered are important for students. The five different types of formats displayed as challenges are the following:

1. Multiple Choice Question (see Fig. 5). A text question with multiple choices is displayed on the right and a related image on the left. The image can be explored using common interactions (drag, zoom in/out, etc) to give a better understanding of its content. The order of the multiple choices can be randomized to increase the replayability of the challenge.
2. Multiple Choice Question with Images. A challenge dynamic similar to the previous one (Multiple Choice Question) to answer a question choosing from four different image-based choices instead of text options. There can be more than one correct answers.
3. Drag and Drop. The learner must drag objects from the right part of the screen and drop them on the correct blank option of the image.
4. Fill the Options. A text area is displayed with different label options. A label option is composed of different tags from which the correct one must be chosen to complete the challenge.
5. Select an Area of the Image. This challenge asks the learner to mark a certain area from the image. With a click, a marker is placed. A mark can be removed by clicking it. The result is computed depending on the number of markers placed correctly (within the correct predefined polygon area from the image) and incorrectly.

A challenge-based gameplay can be easily integrated with an analytics framework to track the progress of the students and improve the feedback teachers receive through detailed dashboards. The dashboards can display detailed information about the game such as students' progress, visualizations about each challenge (and course), completion rate and general information about the gameplay session.

B. *Cytopathology Editor*

The Cytopathology Challenge web editor is a web platform designed to facilitate the creation of challenges that can be integrated within the game-like application.

1) Frontend

The user interface offers management of courses and the challenges of a given course. For the creation of a new course, a new name should be provided.

The user interface is designed using Google Material design guidelines. Material Design is composed of different layers and follows Google's conceptual design philosophy that outlines how apps should look and work on mobile devices. It breaks down everything (such as animation, style, layout, etc.) and gives guidance on patterns, components, and usability. Material Design has borrowed plenty of design concepts from the flat aesthetic and other trendy techniques. In fact, some would argue that Material Design is a close cousin to Flat Design because many of the visual treatments are quite similar.

2) Backend

The backend serves to semi-automatically generate the game-like application by domain experts, greatly reducing the dependency of developers. The domain experts use the web editor, previously described, to generate the content that is going to be played by the students (or cytologists). The content is generated following different previously studied formats (multiple choice question, drag and drop, select an area of the image, etc) that have been used successfully in examples such as VMATs. The content is stored in the backend in order to semi-automatically generate the gamified application. During the generation process, the gamified cytopathology application when it's generated retrieves the content from the backend and stores it locally, in order to properly work in resource-limited areas of the world where there is not a continuous internet connection. The backend service exposes a RESTful API that stores the underlying data model and files (images) attached to each challenge. The data model is stored using an extensible JSON format that facilitates the generation of the application for the Android and HTML 5 game clients, and other possible clients in the future, improving the integration across different platforms (Android, Windows, Mac, Linux, HTML 5, etc.). The main technology stack used for the backend service development is NodeJS, a framework aimed at improving the implementation of RESTful APIs using JavaScript language and offers a fully developed platform of extensions to improve the speed of the development.

GitHub was used for the framework development as a version control system that facilitates the management of code repositories and can be easily integrated with other services for the system deployment. The web editor is packaged inside Docker images. Improving the server deployment and reinforcing the security of the data since the services are encapsulated inside Docker containers that are only accessible from a defined virtual network. This solution facilitates the control of access points to the system increasing the security of the data. Docker is growing at a very accelerated pace and offers an automatic building, integration and management service connected directly to the GitHub repository [16], improving the speed of the process from the development of the system all the way to the deployment.

IV. CONCLUSIONS

There are different approaches and game mechanics that can be used in a game or game-like application to train medical personnel on how to use medical imaging for cytopathology. In this paper, in order to identify the best practices for designing a game to train pathology personnel, we reviewed several games and game-like applications designed to train personnel in the analysis of medical images (e.g. MalariaSpot, BioGames, Cell Slider).

We have defined a design that presents the learner with a short story to set up the context, followed by a concise tutorial explaining the game mechanics and ending with the player having to overcome different challenges (i.e. levels) that can be measured to assess the student´s progress. A challenge, in its simplest form, could be a multiple choice question about a concept, an image or a specific region of an image where the student should identify any anomalies or special circumstances. There is a set of challenges, questions or puzzles from which a randomized sample is taken every time the learner starts playing a session. The challenges also vary in difficulty as the student progresses and have a gamification metric associated (allowing the creation of rankings between players) increasing the content diversity for each gameplay session. This design presents the content as a progression of events (initial story, basic concepts description, progressive challenges) that can be easily understood by the student. The initial story is a key element in the game's design, it provides a supporting narrative meant to address the student's motivation and interest.

This initial design considered the hardware and software restrictions of our project as the game should run both in PCs and low-cost Android tablets and had to be used to train cytologists in low-resource countries where the availability of a stable internet connection is low. Some of the analyzed systems capture user interaction data with different purposes (e.g. adaptation, leaderboard and feedback [17]) and we consider that this is the way to go even if in our case the game deployed in tablets cannot rely on a continuous internet connection. This will allow the inclusion of learning analytics techniques to better analyze the interaction for different purposes such as evaluating the student´s progress and learning and improving the actual game.

To conclude, we have developed an integrated system that satisfies the initial requirements of our project dividing it into a gamified application focused on training students and medical personnel in cytopathology and a web-based content editor designed to be easy to use by domain experts without the need of developer's incursion. The application can be semi-automatically generated due to a backend service that stores all the editor data using a standardized format. The evaluation of the system will consist of performing a pre-post evaluation of students. We believe that the integrated system provides a solid ground for the training and evaluation of medical students at the Harvard Medical School.

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