Learning Analytics and Educational Games: Lessons Learned from Practical Experience

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Abstract. Learning Analytics (LA) is an emerging discipline focused on obtaining information by analyzing students' interactions with on-line educational contents. Data is usually collected from online activities such as forums or virtualized courses hosted on Learning Management Systems (e.g. Moodle). Educational games are emerging as a popular type of e-learning content and their high interactivity makes them potential sources for relevant educational user data. However, it is still uncertain how to deploy and combine these two incipient technologies, as multiple challenges remain unresolved. This paper reports on our practical experience using LA to improve assessment of experimental research on educational game-based instruction. In the last year, we conducted four experiments evaluating game-based instruction under different conditions (using three adventure games and a puzzle game respectively) in 13 educational institutions including schools, universities and vocational training organizations. A LA system was used to track interaction around six hundred students. In these experiences, we encountered several problems in each of the steps of the process, from issues related to the design of the experiment and the game to different technical and practical problems, derived from the very diverse conditions of the facilities and policies of each institution (computer laboratories, computers hardware, software installed, irregular Internet access), which hinders the data collecting process (e.g. the system had to deal with high latency Internet connections and backup plans had to be devised for collecting data when no Internet access was available). We present the lessons learned and propose guidelines from a technical and practical perspective for the design of experimental research using both LA systems and educational games.

1 Introduction

This paper aims to be a practical guide for researchers interested in conducting experimental research on educational gaming who might also want to explore the opportunities that embedding a learning analytics system provides to improve the research. Building on our experience, we identify potential issues that can arise while conducting this kind of research, and also provide recommendations to tackle them. Some of the issues discussed are technical, related to the implementation and

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deployment of the technology, while others are rather logistical, operational and related to the design of the experiments.

The field of learning analytics (LA) refers to the collection, analysis and visualization of large amounts of data related to educational processes. In its heart, LA aims to harness the power of big data and data-mining techniques to improve the assessment of the learning processes. LA also can create new opportunities for adaptive and personalized learning, which has remained an unfulfilled promise of the e-learning field for years. As an incipient new era of online learning, promoted by Massive Online Open Courses (MOOCs) comes upon our shoulders, LA could find the perfect conditions to make an impact in education in the next few years [1].

As any big data system, LA requires gathering a wealth of data from different sources. It usually uses data generated from tracking students' interactions with the online platform used to support learning (e.g. a Learning Management System like Moodle or Sakai). For example created posts, pages and resources accessed or time spent on each piece of content. Research in the LA field is currently exploring how to leverage other data sources to improve the effectiveness of the paradigm. One of the proposals is to use educational games, which are another pushing educational technology. Although educational games are still far from reaching massive adoption due to unresolved limitations [2–4], their effectiveness to improve learning is accepted among the academic community [5], as attributed benefits to educational games like increased student motivation, improved engagement and better knowledge acquisition have been recently backed up with experimental research [6–9]. Serious games can pose an advantage to feed LA systems as they are inherently highly interactive pieces of software which can produce massive user data.

Achieving a successful synergy between serious games and learning analytics poses significant challenges that are added to the difficulties of designing and conducting experimental research in education. In the next sections we will present an overview of our recent research and discuss the issues found and the solutions we came up with.

2 Overview of Games Used in the Experiences

During the last year, we have conducted 4 experimental research studies using educational games. In round numbers, 4 games have been deployed at 13 educational institutions including universities, high schools and vocational training institutions, involving more than 600 students.

The four games were independently developed and cover different knowledge areas. Three of them were conversational point-and-click games developed with the eAdventure platform [10, 11], while the fourth was programmed from scratch.

Experiments carried out with these games followed a similar process. In a starting phase, the games were designed. The games were implemented and then internally tested. Once the games were polished and ready for distribution, they were deployed to conduct experiments in several educational institutions. During the experiments, students completed a pre-test to measure initial levels of motivation and knowledge on the subject. Then they played the game while the LA system collected data gathered from their interaction with the game. At the end of the session, students completed a post-test. Differences between pre and post tests were measured to estimate effect of instruction.

Next subsections briefly introduce each experiment and the games used.

2.1 The Big Party

The Big Party [12] is an eAdventure game (Fig. 1) that aims to teach persons with different levels of cognitive disabilities life management skills related to personal hygiene, safety, social interaction and transportation. The goal of the game is to reach a party organized by the player's company for all the staff. To complete the game, players must find their way through different common situations of daily life until they reach the venue of the party. This game was played by 19 players of different ages and with different levels of cognitive disabilities.

Fig. 1. Screenshots of the game "The Big Party".

2.2 Lost in Space <XML>

This puzzle, level-based game (Fig. 2) was designed to teach XML syntax to students with different programming backgrounds. In the game, players control a spaceship they must lead to a target point by writing little XML documents with instructions (e.g. move spaceship two units forward, rotate 90º, shoot, etc.). 89 students from computer science and social science studies played this game distributed in two different settings.

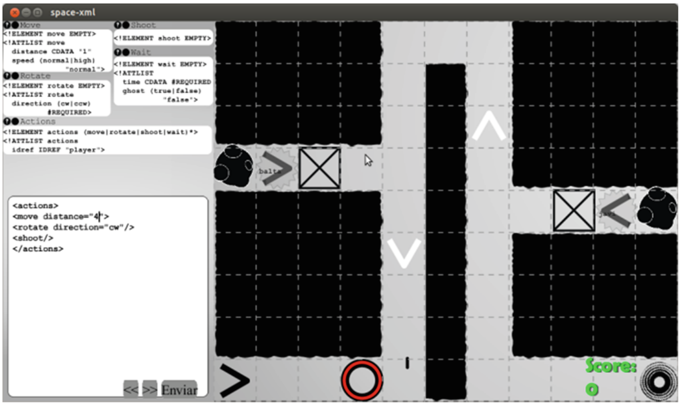

Fig. 2. Screenshot from the game “Lost in Space <XML>”.

2.3 La Dama Boba

The game La Dama Boba [13] is an eAdventure game (Fig. 3) that was designed to motivate youngsters on classic theater plays. This goal is achieved making avatars interesting to players, by incorporating different theater techniques within their personalities and including the elements that can be used as audiovisual contents, such as music, scenery and dressing.

The game is based on the equally named comedy by the Spanish playwright Lope de Vega, wrote in 1613. The player becomes Laurencio, the main male character of the comedy, and has to live the story through his eyes. As the plot unveils, several minigames about grammar and literature are also introduced.

This game has been deployed in 9 different high schools in Madrid where 370 students aged from 11 to 15 played it.

2.4 Donations

Donations is an eAdventure game-like simulation (Fig. 4) developed in collaboration with the Spanish National Transplant Organization (ONT). This game simulates the process that the ONT staff follow for deceased donation management. These steps are (1) organ and donor evaluation, (2) the organ distribution and (3) the organ transportation. The game was developed to facilitate instruction of new personnel within the organization as well as to support transferring this successful workflow to other transplant coordinators. The game has been evaluated by 150 students in three training courses.

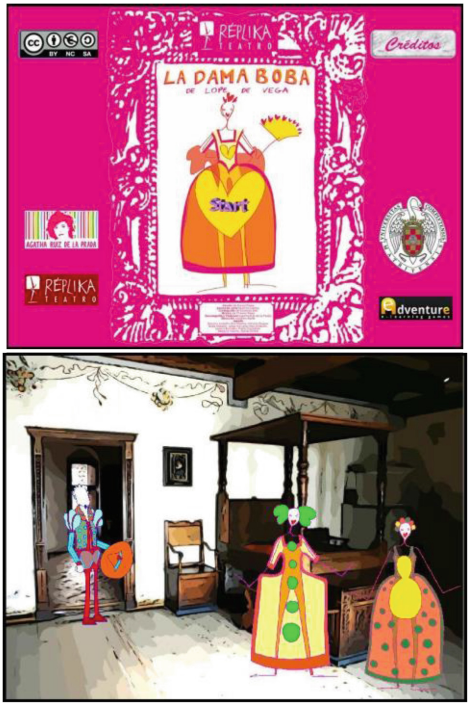

Fig. 3. Screenshots of the game La Dama Boba. Character design inspired in customs by Agatha Ruiz de la Prada for an adapted version of the play.

3 Designing and Planning the Experiment

Our experiments are oriented to evaluate the impact that using videogames has on the learning process. Mainly, we try to measure the educational gain (knowledge acquired by the students as a consequence of the intervention) and changes in the motivation towards the subject of interest (e.g. literature or computer programming).

In this section we provide a set of considerations we take when designing the experiments.

3.1 Instruments for Measuring Variation in Knowledge and Motivation

We use a twofold approach to measure variations of motivation and educational gain. First we use questionnaires to perform an external analysis of the learning process. This type of analysis does not consider how or what makes learning happen; instead, it just focuses on the outputs. Second, GLEANER, a LA system [14], is used to perform an internal evaluation of the process, gathering insight on what aspects of the game promote learning.

Several instances of the questionnaire are used along the experiment to have multiple values to compare with. At least the questionnaire is used twice: a pre-test that

Fig. 4. Screenshots of the game Donations. Main central office of the ONT and action of organ evaluation.

is administered just before students start playing and a post-test administered after the intervention, but it can be used more times for longer or longitudinal experiments. The results of different measures of the questionnaires are compared (e.g. pre-test Vs post-test) to determine the effect of the game.

A thorough design of the questionnaire is strongly recommended. The questions included in the test must tackle exactly what it is meant to be measured in the study. We combine several strategies to iteratively design and refine our questionnaires. First, we identify the aspects that we want to capture, usually distributed in three or more sections: demographics (e.g. age, gender, video game preferences, etc.), knowledge on the subject, and motivation towards the subject and/or evaluation of the experience (for post-tests only). Second, we write a set of candidate questions exploring different wordings and evaluation scales for each of the aspects. We also design several questions oriented to measure aspects that are difficult to capture because they cannot be observed, like the knowledge or motivation. This allows us to build subscales that aggregate all the questions related to the same aspect to generate a variable that is more powerful for statistical analysis. Third, the candidate questions are distributed for iterative review among an internal team of experts in educational games and also experts in the knowledge area. Finally, one or more testing sessions are organized where the instruments and questionnaires are piloted with a group of selected students.

As a preferred format, we use 7-point Likert questions for subjective aspects (e.g. motivation) as this allows sometimes applying parametric statistical methods for analysis. For objective aspects (e.g. knowledge) we tend to use multiple-option questions to simplify evaluation.

3.2 Group Comparison

It is essential to compare the effect of game-based instruction to traditional instruction to allow drawing valid conclusions at the end of the study [2], especially if the same questionnaire is used at different points of the experiment, which introduces bias in the variation measured.

For that purpose, we distribute students in at least two groups: experimental and control. Students in the experimental group attend the session where the game is played. Students in the control group attend a traditional instruction session, which is usually a lecture driven by an experienced teacher. In some cases we use a third group where the best possible instruction is delivered to the student, which is usually driven by experts in the field using (perhaps) special equipment. All groups must use the same pre and post tests to measure variation. This allows discussing the effectiveness of the game comparing to bottom and top lines.

3.3 Duration of the Experiment and Logistics

Our experiments are designed to require an intervention of maximum 50 min, which is the typical schedule slot in education. All instruments and also the game must be designed to respect this constrain.

Longer exposure to instruction is desirable, but it is hard to achieve in many educational organizations as logistics and organizational costs for an experiment like these, which are already high, increase. It must be noted that in many cases the experiment will require taking up most of the computer resources of the institution for a while. Computer clusters in schools usually have less than one computer per student (around 20 computers per cluster) to minimize costs, which implies that students usually work in pairs. If the game under evaluation is designed for individual use, it will be needed to use two computer clusters if possible, or to split students in the experimental group in two turns, requiring to have access to the cluster for a longer period.

Some institutions will not meet these requirements. In that case, a different kind of experiment must be planned, following a qualitative approach. Students can play the game in groups, and the sessions would be recorded for later analysis. These data can be combined with interviews or debriefing sessions.

3.4 Getting Support from the Educational Institution

It is essential to get support from the educational organization where the experiment will take place to ensure that researchers are given access to facilities, students and personnel. Also researchers must make sure that the institution understands all the requirements for the experiment. In our experience, we have observed that sometimes researchers' and institutions' interests conflict. On the one hand, researchers want to have the facilities and support required to conduct an experiment that is as controlled and well designed as possible to ensure that the conclusions obtained are valid. On the other hand, the institution has usually tight schedules and organizing an experiment like these has a considerable impact for them. Having strong institutional support will help researchers finding a balance between both perspectives that benefits the goals of the research.

A possible strategy to get better institutional support is to make the institution and its staff understand that getting involved in the experiment adds value to all the stakeholders involved. Principals and administrative staff can be enticed by the idea of participating in a pilot study that improves innovation in the institution. Motivated teachers or early adopters may be interested in having new software available to improve their instruction for free.

3.5 Maximize Control to Reduce Error Rates

Researchers should supervise all the important parts of the experience and ensure they are in control. People out of the research can unintentionally bias the results of the experiment. In this regard, understanding teachers' perspectives before the experiment can help to foresee potential problems and develop mitigation plans. In our experience we discovered that some teachers are worried about how their students will perform compared to other institutions. In this sense, they felt their work as teachers being under examination. These teachers unintentionally tended to give students more clues to solve the tests, introducing bias.

If the experience requires randomized allocation of students in groups that will receive different instruction, we suggest not leaving the entire responsibility to the teacher, or at least researchers should supervise the process. Teacher used to consider playing the game as a reward for the best students, and this could bias data.

3.6 Ethical and Legal Issues

Ethical and legal issues must always be considered, especially when the target audience include minors. Privacy of data collected must be ensured. For that reason, we use anonymization techniques and anonymous questionnaires. To pair questionnaires and results within the game, each student is given a unique code that the write on paper tests and also introduce in the games to identify data sent to the LA system.

All students should receive the same treatment and have access to the same content. For that reason, we usually let students in control group play the games once the experiment is complete and all data have been collected. Also students in the experimental group are given traditional instruction after the experience.

3.7 Workflow

For the reader's convenience, in this section we provide a summary of the workflow with all the activities conducted in these experiments.

- Make an initial design of experiment, materials and game. This will help know the requirements of your experiment.
- Start recruitment. Approach institutions that may be interested in participating. This process may be long and tedious, until the desired number of participants is ensured for the project. Contact institutions, get their attention and explain your needs. Make sure to explain that they have the opportunity of participating in a research project for free (teachers are used to companies offering different services for the schools, and tend to refuse them immediately).
- Meeting the teachers that will participate. Normally, in a school, there are several teachers for a single subject. The meeting must be planned to involve the maximum number of teachers. Explain the requirements and schedule activities according to the needs of the institution. Also get information about the facilities of the institution, special requirements, etc.
- Refine or adapt the design of the experiment and materials to fit the needs or limitations of each institution, if necessary.
- Install the software and revise the computers in advance. We strongly recommend testing the computers and to install the game in advance as not all the institutions have maintenance plans for the computers. All software and computers must be installed and ready before the experiment takes place.
- The day of the experiment. We suggest a minimum of two researchers to carry out the experience. They should arrive ten minutes in advance. One researcher will lead the experimental group and check that the computer facilities are ready. The other researcher will lead the control group and supervise all activities conducted by teachers.
- Post-mortem activities. After the experiment, link data collected from questionnaires and data obtained from the LA system and analyze the results. Then, conduct debriefing sessions and interviews with teachers involved to get insight on their impressions about the experience and present the results obtained.

4 Designing and Implementing the Game

In this section we provide an overview of technical issues that must be considered when designing and implementing the game to ensure that (1) data collected from LA will be of interest and (2) the game is as easy to deploy as possible to meet the varying conditions and requirements of the institutions.

4.1 Designing the Game for Learning Analytics

Educational game design is a complex activity and it is not our intention to delve into all the considerations that make a game both educational and entertaining. For further reading on this matter we would recommend some of the articles that can be found in the literature [15, 16]. Instead, in this section, we elaborate on the requirements that a game design must meet to allow effective use of LA.

In short, the game must interlace mechanics oriented to facilitate building new knowledge with mechanics oriented to assess the new knowledge acquired. This behavior is frequently present in video games where players acquire new skills throughout a game level and at the end they have to apply these skills in a new way to defeat a final “boss”.

We did not consider this issue when we designed The Big Party. The game was linear and students did not have to apply any new piece of knowledge acquired. We learned from this experience, and the following games were designed having two phases: one to let the student build new knowledge, one to assess. The Table 1 shows a summary with each game and how the two phases were distributed.

Table 1. Description of the learning and assessment phases

Game	Educating phase	Assessment phase
Lost in Space < XML>	Phase presenting a new power-up (representing a new syntax structure to be learned)	Phases not presenting any new power-up (players must use structures already learned)
La Dama Boba	Several text screens explaining literature concepts, mini-games about grammar and spelling	Direct questions at the end of the game, mini-games repetition. Final assessment is shown to the player
Donations	First phase, where players are guided through all the donation process, allowing them to commit mistakes and correcting them	Second phase, where players go through all the donation process, with no help and no mistakes allowed

4.2 Game Technical Requirements

The game must be implemented using a technology that can be easily deployed using the computers of the institution(s) where the experiment will be held. Having a detailed description of the settings can be used to make an informed decision on the appropriate technology. However, it is not always possible to get this information. Our recommendation is to choose a technology that is lightweight, flexible and easy to deploy across platforms (Windows, Linux and Mac). In our games, we use two technologies that meet this requirement: Java, and the Web Browser (HTML plus JavaScript).

Educational institutions may also have different hardware configurations. Especial attention must be placed on the dimension of the displays and audio support. While some institutions may have modern high definition displays, others may support low resolution applications. Similarly, some institutions may provide headsets while in others sound may be disabled. For these reasons, we use an 800 × 600 resolution which works well in low resolution screens and which also looks nice in larger screens. We also design the games so that they can be played with or without sound.

4.3 Tracking System Requirements

This section presents some of the technical considerations to bear in mind when deploying a videogame that communicates with a LA system.

The game must establish communication with a remote server and also univocally identify the player in a way that allows pairing data collected through all the instruments of the experiment. If a good Internet connection is available identification can be done on the server side. However, in many educational institutions Internet access is not reliable or bandwidth is insufficient. To deal with these situations, an offline alternative must be designed. For example, the game can store the information locally and the identification can be done using a code provided by the researchers. After the experiment researchers can collect the files storing tracking information and upload it manually to the LA system.

The server is in charge of receiving and storing the traces. To facilitate the analysis of the data, the server must store not only the traces but also the user id, game id, session id (continuous period of time where the user plays the game), user's group and learning activity/experience. These metadata allows the researcher to contextualize the statistical analysis of the data giving other variables to the analysis.

Depending on the size of the experiment and the data collected, the data traffic generated can be significant. Hence, it is needed to prepare the server to manage quite high workloads efficiently. The server must minimize the response time, and must use a storage system specifically optimized for writing loads of data. For that purpose, it is handy to use a NoSQL database (e.g. Apache Cassandra, Apache HBase, MongoDB, etc.) because they are particularly optimized for writing throughput. However it is possible to use a traditional relational database system, usually by mixing clustering and sharding techniques. Note that the storage system used to store the traces received by the tracking system may not be the same used to analyze the data, that is, the received data can transformed to another representation (e.g. graph, relational, etc.) and stored into another database that can facilitate the analysis of the data.

Finally, in order to minimize the response time and to avoid the collapse of the tracking system, it is usually needed to throttle the requests to the tracking system (limit the number of request per second) and limit the amount of data to be sent per request. This request throttling requires a close collaboration between the client and the server, on one hand the server can control (even dynamically) the number of allowed request per second and notifies with an especial error that the game has reached this limit or that the request cannot be currently processed, and on the other hand the client must be aware of this error conditions and resend the request after a certain amount of time.

It is desirable to have a tool to monitor the client-server communication during the experiment. This allows adapting the settings to deal with any technical issue that may prevent correct data collection. Ideally, this tool gives real time feedback on the communication and summary statistics. In our case, we had a service that showed how many students were playing and its identifiers, allowing us to visually confirm that the number of students playing were the same as the number of users that server was receiving traces for.

To help to interpret part of the collected data, it can be helpful to write notes about observations made during the experience, associated to concrete student identifiers.

For example, we observed that most high school girls carefully read screen texts, while most boys don't. Something that we confirmed after analyzing traces with the time-stamps to know the time expend in those screens that include instructions for the game.

5 Final Remarks

Probably the most important recommendation, according to our experience, is to follow a careful process to design and execute the experiment. All the aspects are important - from the design of the game to the wording of the questionnaires. To achieve success attention must be placed on all the details. Also it is important to be prepared for unexpected situations and to have a backup plan for carrying out the experiment.

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