

Codebreakers: Designing and Developing a Serious Game for the Teaching of Information Theory

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Abstract. This paper reports the conceptualization, design, and development of the first and second prototype of a serious game for the teaching of the basics of Information Theory. Using the steps for a needs and context analysis, the researchers, lecturer and game developers participated in a focused group discussion to conceptualize the context and content for the game. Based on the design concepts found through the literature review, the team chose to follow a design research approach to create the academic intervention. The team used known game attributes and design principles, as well as feedback from guided evaluations, to create the first two prototypes of the game Codebreakers which is currently being used at the University of Johannesburg. As described in the design research approach, the team used an iterative process to develop the prototypes, with the final goal being to reach a point where the academic intervention can be generalized to other contexts.

Keywords: Serious games · Engineering education · Self-determination theory

1 Background

As it is a final year module, Telecommunications can be very difficult for students to grasp the finer details of and in this context the academic staff sought to create a technology driven intervention to offer students an additional means of practicing their problem-solving skills. The specific intervention chosen was in the form of a serious game called Codebreakers. As the study was undertaken specifically to create an artifact to be used in the classroom, an educational design research approach (EDR), and more specifically a developmental studies approach [1] was chosen.

Behnke [2] explored the concept of applying the lens of self-determination theory to analyse the application of serious games and gamification interventions to the context of computer science education, and this same approach is followed in the

creation of the Codebreakers serious game. The application of games based interventions for the teaching of university level courses in the South African context is not without precedent as can be seen by previous work done by Leendertz, Fitchart and Booth [3].

With this concept in mind, an initial prototype of a game based intervention was created, and evaluated by the lecturer (as content specialist), a previous student, a post graduate student and a game developer. From this, a number of insights were gained, and fed into the creation of a second prototype, this time as a full game. This full prototype was again evaluated and then field trialed in the 1st semester of 2017 in the module with 91 students. This paper reports on the process of conducting the initial needs analysis and development of the first and second prototypes. It should be noted that this project is in the second phase of EDR and as described in [1, 4], this means that the intervention should be fit for purpose in the specific context it is being applied to, but may not be ready for generalization to other contexts just yet.

2 Literature Review

2.1 Serious Games

Alvarez & Djaouti proposed the following formal definition for serious games:

“Computer application, for which the original intention is to combine with consistency, both serious (Serious) aspects such as non-exhaustive and non-exclusive, teaching, learning, communication, or the information, with playful interaction from the video game (Game).” [5]

The above definition is used for the purpose of this article, but it is important to note as pointed out by Ulicsak that there is currently no universally accepted formal definition for serious games in the current literature [6]. It is sufficient however to view serious games as full games that are not purposefully developed only for their entertainment value. This concept does highlight the fact that developers of serious games need to focus on both the traditional fun aspects of games, as well as to ensure that the serious content they have to convey is brought forth clearly. It is for this reason then that Derryberry proposes that serious games development is a *“team sport”* involving members from the game design community, subject matter experts and students of the material that is representative of the serious aspect of the game being developed [7].

A distinction is made at this point between Serious Games and Gamification of university courses. The differences between the two used for the purpose of this article are put forth by Deterding, Dixon, Khaled and Nacke [8] with the main difference between the two concepts being that a serious game is a *“whole”* game, whereas a gamified system is one that only uses some game elements in its design. Game elements in this context can mean any aspects of a game that can be isolated and applied separately. With this in mind, the essential characteristics or dimensions of effective instructional games evaluated are the ones put forth by Garris, Ahlers and Driskell as: (i) Fantasy, (ii) Rules/Goals, (iii) Sensory Stimuli, (iv) Challenge, (v) Mystery and (vi) Control [9].

2.2 Self-determination Theory

If the goal of a serious game is to allow students to explore some material in the context of a game, then students need to feel motivated to do so. In terms of motivation, there is a distinction made in the literature between intrinsic motivation (doing something for the satisfaction it brings) and extrinsic motivation (doing something to attain some external outcome) [10]. Self-determination Theory puts forth 3 main needs that people need to fulfill in order to feel self-motivated to do some task namely (i) Competence or gaining mastery over some challenge over time, (ii) Relatedness or social interaction with other people, and (iii) Autonomy or the ability to make choices and have control. In terms of game development, Behnke described how different game elements can be categorized into these 3 needs [2]. The educational context brings a unique benefit as the above needs can be addressed by the game to attempt to gain intrinsic motivation from students, but as there is also the extrinsic need to do better in the course (as represented by the course grade) so both motivations can be addressed.

3 Research Design and Methodology

3.1 Educational Design Research and Development Studies

Akker, Plomp and Nieveen define Educational Design Research (EDR) as follows:

“to design and develop an intervention (such as programs, teaching-learning strategies and materials, products and systems) as a solution to a complex educational problem as well as to advance our knowledge about the characteristics of these interventions and the processes to design and develop them, or alternatively to design and develop educational interventions (about for example, learning processes, learning environments and the like) with the purpose to develop or validate theories.” [1]

The core of the EDR process is therefore to not only generate research documentation to guide the creation of educational interventions, but rather to document the process of creation of these interventions. Within EDR, there are two distinct approaches that can be taken namely Validation studies (creating artifacts with the goal of validating a theory) and Development studies (the creation of educational intervention artifacts). For the purposes of this study the latter focus is of most relevance.

One of the characteristics of an EDR study is that there are a number of research cycles undertaken within a number of defined phases throughout the course of the study as can be seen in [1]. The flow of this specific study is described in Fig. 1.

As can be seen from Fig. 1, the study is split up into 3 phases namely (i) The preliminary research phase (Needs and context analysis), (ii) the design, development and test phase and (iii) the semi summative evaluation phase. Each of these phases are then made up of a number of research cycles. The steps indicated in Fig. 1 for the research cycle are defined by Plomp in [1]. The design and prototyping of the software artifact in this study is done through an Agile development methodology. In this article, the first three cycles of the study are explored.

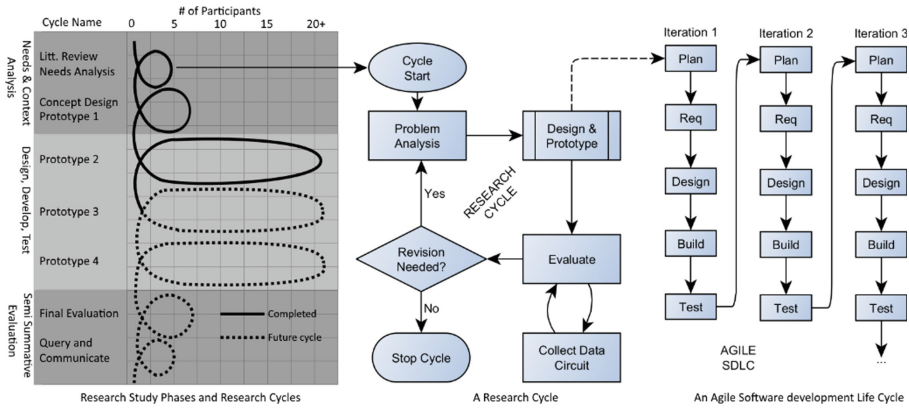


Fig. 1. The design research approach followed

3.2 Measuring Success

In EDR, as an iterative process is followed, it becomes difficult to define when the study has effectively “completed”. In order to overcome this problem, the concept of quality evaluation was put forward by Nieveen [11] such that the artifact is evaluated at the end of each cycle to measure how “fit for purpose” it is. The criteria that the artifact is measured against are: (i) Relevance (is it based on state of the art knowledge?), (ii) Consistency (Is it logically designed?), (iii) Practicality (Is it fit for purpose?) and (iv) Effectiveness (Does it result in the required outcome?).

These criteria are measured to different extents depending on the phase of the research being done as follows [1]: (i) Preliminary research phase (content relevance and consistency focus), (ii) Development phase (initially a consistency and practicality focus with a later shift to effectiveness) and (iii) Assessment phase (practicality and effectiveness focus). Tessmer presents evaluations that can be done in an EDR study, and ranks them by how formal and resistant to change each of the evaluations are in [12].

4 Preliminary Research Phase

Phase 1 of the study involved the literature review (which is also part of each cycle in an ongoing body of work), as well as the needs and context analysis. The steps required for a needs and context analysis are put forth by McKillip as [13]: (i) identifying the audience and purpose for the analysis, (ii) describing the target population and service environment, (iii) identifying the needs, (iv) assessing the needs and (v) communicating and collating the results. This section describes the outcome of the initial needs analysis done at the start of the study.

4.1 Needs Analysis

Identifying the audience and purpose for the analysis. As stated previously, the audience for this specific game would be final year engineering students. As information theory is not an elective module, and one in which students occasionally struggle due to the fact that a number of the theories are difficult to put into practice immediately due to its more mathematical nature, it was decided that it would be an ideal test bed for the creation of a serious game. Students at this level are expected to have a high level of skill when it comes to applying more abstract ideas to problem solving and be very familiar with digital technology (even if they are not fundamentally “gamers”), so the audience seemed like a good candidate for this style of intervention.

Describing the target population and service environment. As stated previously, students in this population already have a high level of familiarity with digital technology and as such no problems were foreseen in getting students to understand the game or how to play it. With this in mind, the knowledge, skills, values and attitudes that are required of the students to successfully gain the knowledge were reflected upon by the research team.

As the final goal of the research team is to validate the use of serious games in the greater context of the university, there is a certain level of sensitivity required to the problem of access and platform independence. As not all students will have access to a computer at home and library workstations may not be appropriate for the installing of games. As such, HTML5 compliant game engines were explored from the start of the project as they allow for the greatest level of access, and when responsive design principles are followed will give a similar experience across mobile, tablet or desktop environments. Access would not be limited to specific times or locations to students so that they have the ability to choose when, where and how often they wish to play. All that would be required is some way to gain internet connectivity to access the game.

Identifying the needs. The main need of the students in this specific module was to have some way of practicing solving problems once the problem-solving techniques are understood. In terms of which specific problems would be addressed, the following sections of the syllabus were proposed as being good candidates: (i) Probability theory and Boolean algebra, (ii) Error-Correcting Block codes (Hamming code), (iii) Source coding (Shannon-Fano and Huffman algorithms), (iv) Markov chains and (v) Channel capacity.

Assessing the needs. Once the areas to be addressed were evaluated by the team, they were prioritized and used as input into the initial conceptual design to validate whether the concepts in the syllabus could be effectively translated into game mechanics. This was done in collaboration with a student who had completed the course, and their knowledge and skill levels was used as a gauge. For the initial conceptual design, Hamming codes (as a specific block code) was used to evaluate whether a full game system would be worth developing (see Sect. 4.2).

Communicating and collating the results. With the above initial analysis completed, the researchers put together conceptually which areas they would like to address

specifically with the serious game intervention, and specifically how they would approach the problems of addressing the students' knowledge and skills needs. This was done specifically by creating the conceptual design, discussing the overall strategy with a leader in the engineering education focus group in the department as well as with fellow lecturers as to how the process would be followed. After very positive feedback all around, the go-ahead was given to create the initial conceptual prototype.

4.2 Conceptual Prototype

As the subject matter lent itself well to encoding and decoding of information, the idea of covert operations, spies and codebreaking came to the fore as an appropriate concept for a game. The conceptual prototype was created in Gamemaker: Studio with pixel art sourced either online from open source projects or created by the research team. Using the film "Casablanca" [14] as inspiration, a conceptual prototype was built where the player controls Ilsa, and attempts to rescue Rick from a Nazi jail cell using Hamming code to unlock the jail cell doors as can be seen in Fig. 2.



Fig. 2. Codebreakers, featuring Ilsa, Rick and Hamming code

Although showing that the proposed mechanics for the game would work, feedback received was that the overall storyline should not be used. The reason for this is that although Casablanca has been part of the western consciousness for a very long time, this context would not translate well into the South African context. Additionally, although used as the stereotypical "bad guys", the Nazi symbolism ran the risk of making students feel uncomfortable.

5 Development Phase

Following the feedback received on the conceptual prototype put forward, a second prototype game was developed, this time as a full game design. The attributes of the game are described using the seven attributes of games described by Derryberry [7]. The first full field trial of the system was conducted during the first semester of 2017.

Final results will be published in a subsequent paper. The game was developed in JavaScript using the Phaser.io game engine. Artwork used was either purchased from the itch.io asset store, or created by the team specifically for this version of the game.

5.1 Backstory and Storyline

The game, maintaining the name “Codebreakers”, has the player exploring a castle and then being trapped in a prison cell by the villainous, Dr. H, Master of Codes. They need to travel the world and break all the codes before they will be set free.

Game mechanics and rules of the game As can be seen in Fig. 3, the primary game interaction is based on a retro JRPG style of gameplay where players are free to move throughout the over world of the castle (1) and enter the dungeon to select mini games (2). Puzzles are randomly chosen from a selection of appropriately difficult versions of each of the problems being attempted. The remaining sections marked in Fig. 3 are:



Fig. 3. Full game overview showing different worlds and puzzles

- In the Hamming Hills (3), players manipulate levers to open doors to escape a prison. The lever state required is based on the Hamming code problem stated.
- In the Shannon Shire (4), players move through a maze that has bombs blocking their path. When touched, bombs are disarmed by indicating the probability of a specific state change on the supplied Markov diagram.
- In Fano Forest (5), players navigate through a forest by following signs that are marked with the source encoded value represented by the probabilities at the bottom of the screen (using standard source encoding).
- In Huffman holes (6), similar to (5) students use the Huffman (or greedy) algorithm to create the source encoding which shows the correct path through caves.

Every time a player enters one of the above sections, their start time is logged and if successfully completed the end time is logged. Unsuccessful attempts are logged by indicating a *null* as the completion time.

5.2 Immersive Graphical Environment

The game is designed with a retro JRPG look that was chosen due to the current popularity of games of this nature, access to artwork assets, artwork skills available in the development team and the accessibility of the style. Feedback for this was very positive, and subsequent iterations will continue in this direction.

5.3 Interactivity

The game allows players to move freely through the game world and if they feel they don't want to complete a specific puzzle they are free to leave back to the selection screen and choose either a different one of the same nature, or one of the other game worlds. This level of autonomy is added to ensure players don't get overly frustrated and to increase the level of flow.

5.4 Challenge or Competition

For all of the above-mentioned puzzles, the relative ranking of students is based on the time it takes for them to traverse through each of the worlds. Scores are shown on a leaderboard to allow students to compete but each world has its own leaderboard meaning that students aren't forced to complete all worlds in order to compete.

5.5 Risks and Consequences

Students are free to participate as they choose as there is no penalty for only partially playing or even for not playing at all. Additionally, the game lowers the consequence of failure, as although the player can fail to complete a puzzle, there is no cost associated with this and they are free to try again. The level of immediate feedback and re-usability is one of the best characteristics of the serious game style intervention.

6 Results

6.1 Research Activities Overview

It is important to note that in keeping with the concepts of game design students were given a choice as to whether they would participate or not. Table 1 shows the number of participants and analysis techniques used. For the current field test, the research team of 4 members are the content expert, game design expert, programming expert and student are participating with the current class of 91 students to trial the suitability of the game in the first set of outcomes for the module. As of the writing of this paper more than 300 game world attempts have been recorded during the field trial.

Table 1. Research activities

Phase	Cycle	Circuit	Strategy						Participants		#
			WT	ME	OT	DS	ER	FT	Users	Experts	
Needs and content analysis	Literature review	1	×				×		0	2	2
	Conceptual design	2				×	×		0	2	2
	Conceptual Prototype	3			×	×	×		0	2	2
		4		×		×	×		2	3	5
Design and development	2nd prototype	5				×			2	4	6
		6				×	×		0	4	4
		7		×	×	×	×		0	4	4
		8 ^a	×					×	88	4	92

Where WT = Walk Through, ME = Micro Evaluation, TO = Try Out, DS = Design Session, ER = Expert Review, FT = Field Trail, ^aCurrently in progress.

7 Conclusion

The required outcome of the first two research cycles was to conceptualize, design and develop a game for final year students doing a Telecommunications module giving students an additional tool to practice the skills they have learned in the coursework. From the needs analysis the researchers, designers and developers were able to conceptualize a full game world as well as a series of mini games using the module's syllabus. Students shared that their experience of the game was very positive, and will be given an opportunity to help design the following iteration. The theme from the game grew from the source material, and will continue to do so. Following iterations will focus on expanding the current narrative, adding in additional mini games to cover the full syllabus and integrating the back end of the game system to the university's learning management system. A literature review was done to ensure a high level of quality and sufficiently place the work in the proper context, and this process will continue with future iterations to ensure game is as suitable as possible. During the first semester of 2017 students in the module were playing the game both inside and outside of the classroom. The lecturers, researchers and designers are continually collecting quantitative and qualitative data to evaluate the usability of the mini games conceptualized for the game through the course of the field trial, and will continue to collect feedback from all stakeholders to guide the creation of future iterations through questionnaires, contact sessions and workshops.

As this is a EDR process that is being followed, the initial prototypes of the game will be very context specific, but the goal of the research team is to continue to thoughtfully reflect on this, and identify areas that can be generalized to other contexts.

References

1. van den Akker, J.J.H., Plomp, T., Nieveen, N.M.: Educational Design Research. SLO, Enschede (2013)
2. Behnke, K.A.: Gamification in Introductory Computer Science, in ATLAS Institute, University of Colorado Boulder (2015)
3. Leendertz, V., Lizanne, F., Martin, B.: Survive with Vuvu in the Vaal: conceptualizing, designing and developing a Serious Game for first year statistics students at the Vaal Triangle Campus, in EdMedia 2015, Montreal, Quebec, Canada. pp. 328–338 (2015)
4. McKenney, S., van der Akker, J.J.H.: Computer-based support for curriculum designers: a case of developmental research. *Educ. Technol. Res. Dev.* **53**(2), 41–66 (2005)
5. Alvarez, J., Djaouti, D.: An introduction to Serious game definitions and concepts. In: *Proceedings of the Serious Games & Simulation for Risks Management Workshop 2011*, Paris. pp. 11–15 (2011)
6. Ulicsak, M.: Games in Education: Serious Games, a Futurelab literature review. Futurelab, United Kingdom (2010)
7. Derryberry, A.: Serious games: online games for learning. Adobe, San Jose (2007)
8. Deterding, S., et al.: Gamification: Toward a Definition. In: *CHI 2011*, Vancouver, BC, Canada, pp. 1–4 (2011)
9. Garris, R., Ahlers, R., Driskell, J.E.: Games, motivation, and learning: a research and practice model. *Simul. Gaming* **33**(4), 441–467 (2002)
10. Ryan, R., Deci, E.: Self-determination theory and the facilitation of intrinsic motivation. *Soc. Dev. Well-Being Am. Psychol.* **55**(1), 68–78 (2000)
11. Nieveen, N.: Prototyping to reach product quality. In: van den Akker, J., Branch, R.M., Gustafson, K., Nieveen, N., Plomp, T. (eds.) *Design Approaches and Tools in Education and Training*, pp. 125–137. Springer, Dordrecht (1999). doi:[10.1007/978-94-011-4255-7_10](https://doi.org/10.1007/978-94-011-4255-7_10)
12. Tessmer, M.: *Planning and conducting formative evaluations*. Kogan Page, London (1993)
13. McKillip, J.: Need Analysis, in *Handbook of Applied Social Research Methods*. SAGE, Thousand Oaks (1998)
14. Curtiz, M.: *Casablanca*, 102 min. Warner Bros, United States (1942)

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