An educational neuroscience approach in the design of digital educational games

Panagiota Chalki, Angeliki Tsiara, Tassos A. Mikropoulos
pahalki@gmail.com, atsiara@cc.uoi.gr, amikrop@uoi.gr
Department of Primary Education, University of Ioannina, Greece

Abstract

A number of models, methodologies and conceptual frameworks have been proposed on how to design digital educational games aiming at better learning outcomes, while offering a fun experience. Our study combines two different methods, namely Delphi study and electroencephalograms (EEG), in order to provide an integrated digital educational game design model. Firstly, a Delphi survey was conducted in order academic experts in the field of digital educational games give their opinion and propose guidelines for designing digital educational games. Secondly, EEG recordings were used to examine how the game element of feedback for earned and lost points would be best incorporated in the game and how these elements affect players' experience. The results from the Delphi survey showed that the most important features to be included in the games are constructive elements, learning environments suitable for authentic learning, as well as elements which promote fun. Moreover, the experts highlighted that learning objectives should be included in activities in a way that the learners will not realize the actual learning process, but feel that they participate in everyday life experiences and examples. Bloom's taxonomy was also proposed as a way to match the learning elements with the game elements. EEG data combined with empirical data from questionnaires showed that players prefer to have audio feedback when gaining or loosing points during the gameplay rather than visual feedback or no feedback at all and contributed to the development of our digital educational game design guidelines.

Keywords: digital educational game, game design, educational neuroscience, EEG

Introduction

Digital games hold inherently features and elements, such as high interactivity, feedback, and personalized instruction that increase player's motivation (Prensky, 2001; Shaffer et al., 2005). Any element that makes up a game and contributes in the game experience is considered to be a game element (Bedwell et al., 2012; Deterding et al., 2011). Studies argue that elements such as challenge, curiosity, control, and fantasy form the core of a game (Malone & Lepper, 1987). Other studies extend this list by adding elements such as role playing, conflicts, rules, goals, and game constraints (Gredler, 1996). Adams (2009) categorized the game elements based on the issues of game definition i.e., challenging goals (challenges, goals), play (interactive activities, feedback, competition, collaboration), rules (core mechanics, levels, balance, luck, risk), and pretended reality (game world, characters, game aesthetics, story). Deterding et al. (2011) categorized game elements by game design levels i.e., interface patterns (e.g., badges, leader board, levels), game mechanics (e.g., time constrains, limited resources, turns), game heuristics (e.g., constant play, clear goals, game stiles), game models (e.g., challenges, fantasy, curiosity), and game design methods (e.g., testing, play centric design, participatory design). As it is noticed, authors mention almost the same game elements but they categorize them differently, based on the main dimension that they take into account.

The element that is an integral part of any game, as well as of learning, is feedback. Feedback allows teachers to gauge the learner's current understanding and make instructional decisions. Moreover, feedback allows students to evaluate their own learning. In games, immediate feedback engages players (Csikszentmihalyi, 1990) and allows them to make decisions about strategies and next steps

(Adams, 2009). Feedback can be provided through visual and audio elements and can be implemented in a variety of ways. As Sillaots (2015) mentions, feedback can be given through numeric values like points and levels, or symbolic values as progress bars and badges, or even through text and audio messages that are related with the gameplay. Simões et al. (2013) argue that immediate feedback, especially when it is paired with repeated chances to apply that feedback, can be an effective learning tool. In order to maintain the essential characteristic of fun, game elements should be selected and incorporated appropriately into the game.

Principles for the design of digital educational games

Many studies have been carried out in the context of the design of digital educational games. Guidelines, models, conceptual frameworks and methodologies have been created in order to specify the principles of digital educational game design. The biggest challenge in game design refers on how instructional design will be applied to game design, how learning activities will be designed and hid inside the game, what learning and game elements should be used and how they will be integrated into the gameplay, in order to have positive learning outcomes (Annetta, 2010; Arnab et al., 2012b; Arnab et al., 2014; Carvalho et al., 2015; Akill & Cagiltay, 2006; Amory, 2007; Buchinger & Hounsell, 2018; Capdevila, Marne, & Labat, 2011; de Freitas & Oliver, 2005; de Lope et al., 2017; Echeverria et al., 2011; El Mawas, 2014; Gunter, Kenny & Vick, 2007; Huynh-Kim-Bang, Labat & Wisdom, 2011; Kelle, Klemke & Specht, 2011; Kiili, 2005; Kordaki, 2015; Lim et al., 2013; Lindley, 2003; Marne et al., 2012; McMahon, 2009; Moreno et al., 2008; Moya et al., 2016; Plass & Homer, 2009; Salen & Zimmerman, 2004; Sanchez, 2011; Sicart, 2008; Staalduinen & de Freitas, 2011; Westera et al., 2008; Wouters et al., 2011; Yusoff et al., 2009).

A critical review of the above studies showed that the guidelines proposed for educational game design are based on general pedagogical approaches and not on specific instructional strategies closely related with the gameplay. There are not clear guidelines that show the connection between the game elements and the learning objectives of the game. Moreover, there are no guidelines on how to integrate the learning elements into the gameplay. In addition, there is no clear classification for the learning and game elements that can be used in a game. Likewise, specific guidelines for designing a game are not clearly proposed.

Regarding the methodologies that have been used in the studies that have been mentioned above, the evaluation of the proposed guidelines, models, frameworks, and methodologies was made by students (in most cases higher education students) who were given some information about the theoretical background of digital educational games. After that, they were asked to evaluate and/or design a game based on given guidelines, models, frameworks, etc. It is crucial to mention that these students did not have any relevant background in game design.

Constructive game elements and EEG

Neurophysiological techniques, such as electroencephalography and electroencephalograms (EEG), are now widely used in the field of research for the design and use of digital games as they provide an objective, non-invasive and real-time way to evaluate player's experience in a digital game. EEG are produced spontaneously, without conscious choice, and most importantly, along with the player's experience in the digital environment. This minimizes the likelihood of players to use their critical thinking to describe an experience of their participation in an experiment, as is usually the case with subjective methods such as interviews and questionnaires.

There are many empirical studies in the field of gaming where EEG activity informs us on cognitive and emotional processes underlying the gaming process. Changes in EEG activity during gaming is examined in the context of different research questions (Ninaus et al., 2014). EEG studies investigated players' experience during gameplay and presented the related neural effects of player's interaction from cognitive or affective aspect (Mondéjar et al., 2016; Sella, Reiner & Pratt, 2014; Sivanathan et al., 2014). Other studies assessed various stimulus modalities and gaming events by studying beta and gamma EEG activity (McMahan, Parberry & Parsons, 2015), or evaluated the theta activity that followed wins and losses (Christie & Tata, 2009; Yazmir & Reiner, 2017). Some researchers conducted real-time measurements in order to adapt game features to player's skills level or psychological state (Berta et al., 2013; Fairclough et al., 2013; Abujelala et al., 2016; Bakaoukas, Coada & Liarokapis, 2016; Balducci, Grana & Cucchiara, 2017). Some others, examined whether neurophysiological methods, such as EEG, can be used for the evaluation of cognitive/neural aspects as attention, flow, workload, engagement, immersion, executive functioning, and skill acquisition (Allison & Polich, 2008; Nacke & Lindley, 2008; Baumeister et al., 2010; Berta et al., 2013; Burns & Fairclough, 2015; McMahan, Parberry & Parsons, 2015; Mondéjar et al., 2015; Abujelala et al., 2016; Hou, Dong & Yang, 2017; Mathewson et al., 2012). Moreover, studies have presented cognitive or social aspects from game experience like advance of prosocial behavior or aggressive behavior due to extensive exposure to violent scenes in videogames (Bailey, West & Anderson, 2010; Chandra et al., 2016). Finally, there are studies which used neurophysiological measures to evaluate design choices for digital games (Ellick et al., 2013; Mekler et al., 2013; Ninaus et al., 2015; Nagle et al., 2014).

The above brief review shows that there is a lack on how to choose learning and game elements during the game design as well as how to integrate them into the gameplay. What is more, the empirical studies that have been carried out use participants who are not experts in digital educational game design. The review also shows that there is a lack in studies that use EEG data to evaluate different design options of a single game element and the way to integrate it into the game in order to have the best game experience.

Thus, the goal of this study was to determine which learning and game elements should be used in a game and how to integrate them into the gameplay, as well as to evaluate the element of feedback by using neurophysiological measures.

Research axes

The present study, combined two different methodologies in order to propose an optimal way to integrate feedback in digital educational games.

Firstly, guidelines for the design of digital educational games were proposed by using the Delphi method. The goal of the Delphi study was to acquire guidelines by academic experts regarding the most important learning elements and game elements of a game as well as the connection between them, and on how to integrate learning activities into the gameplay.

Secondly, we used the technique of EEG together with empirical data of a players' experience questionnaire, in order to corroborate the Delphi's results on how the element of feedback for earned or lost points is best integrated into the game.

The research axes of the present study were to investigate:

- the most important game elements to be used in a digital educational game.
- the way the most important learning elements have to be used in a digital educational game.
- the way the learning elements have to be connected with the game elements in the gameplay.
- the type of feedback for earned or lost points players prefer.
- the way player's experience and performance in an educational game are affected by the element of feedback of points.
- which brain regions are involved in player's interaction with the element of feedback of points.
- whether EEG data contribute to the development of guidelines about how to integrate game elements into the game.

The Delphi method

Research process

Two Delphi surveys were conducted in this study with the aim to reveal critical guidelines for the design of digital educational games. Both surveys took place online. The questionnaires were created in Google forms. The first Delphi survey included three rounds and the second one two rounds. The duration given to the participants in order to submit their answers was two weeks per each round. Consensus was equaled with 70% agreement among the respondents.

Participants

Sixty-eight (68) academic experts in the field of Digital Educational Game Design were invited to take part in the surveys. Eleven (11) academic experts participated and completed all rounds in total. The participants were between 41 and 60 years old, professors in Universities from different countries of the world, with a scientific background in education and computer science and with more than five years of experience in the field of Digital Educational Games with several publications.

Data collection and analysis

In the first round of the first Delphi survey, a questionnaire of six open-ended questions was sent to the participants. The participants were asked about the learning and game elements that should be included in the games, how the learning activities should be integrated into the gameplay, which steps/stages should the game design consist of and challenges they are facing during the game design. The participants were asked to give at least six opinions for each question. A content analysis technique was used after the data collection. Similar opinions were grouped together in order to be used for the questionnaire of the second round.

The questionnaire of the second round consisted of 46 closed-ended questions/statements, which were created based on the participants' answers from the first round. The participants rated each question/statement by using a 9-point Likert scale (1=no importance, 2= very low importance, 3=low importance, 4=some importance, 5= neutral, 6=moderate importance, 7=high importance, 8= very high importance, 9=extremely high importance). Quantitative techniques were used to analyze the answers in terms of the participants' agreement.

A third round was followed with a questionnaire of one open-ended question. The participants were asked to describe an exemplary snapshot of an educational digital game for any age or subject of their preference, which combined learning and game elements. A content analysis technique was used for the answers of this round.

After the analysis of the first Delphi survey, it was decided to carry out a second Delphi survey in order to investigate if a categorization of the learning and game elements could be managed. In addition, it was conducted to explore more opinions about how to integrate learning activities into the gameplay (as it was presented as the main challenge in the game design in the first Delphi survey).

The first round's questions were the following:

1. Which game characteristics do you consider as the key factors for the gaming dimension of digital educational games?
2. Could the game characteristics you have reported be categorized into groups? If yes, please put the game characteristics in groups and name them.
3. Which learning characteristics do you consider as the key factors for the learning dimension of digital educational games?
4. Could the learning characteristics you have reported be categorized into groups? If yes, please put the learning characteristics in groups and name them.

After a qualitative analysis of the participants' answers, a second questionnaire of 35 closed-ended questions/statements was created. The participants rated each question/statement by using a 5-point Likert scale (5=strongly agree, 4=agree, 3=neutral, 2=disagree, 1=strongly disagree). Quantitative techniques were used to analyze the answers in terms of the participants' agreement. Consensus was reached in this round among the participants.

Exploring players' experience using EEG data

Stimuli

We have developed a 2D educational action game in which players had to use the left mouse button to select objects depicting items that an earthquake survival kit should contain and avoid to hit items that are not useful to have them in a survival kit (Figure 1).

The useful items as well as the non-useful items were presented repeatedly in the game, moving downwards, starting from the top of the screen. The game was quite simple. It consisted of a background image, the useful and non-useful objects, the time bar in which the time appeared as number in seconds and the total score. The time and the total score were displayed at the top right corner of the screen (Figure 2). In order to select an item, the player should move the cursor over the item and click with the left mouse button. For each useful item the player gained 10 points and for each non-useful item the player lost 2 points. The game was developed with Construct2, a 2D game editor that is developed by Scirra Ltd.

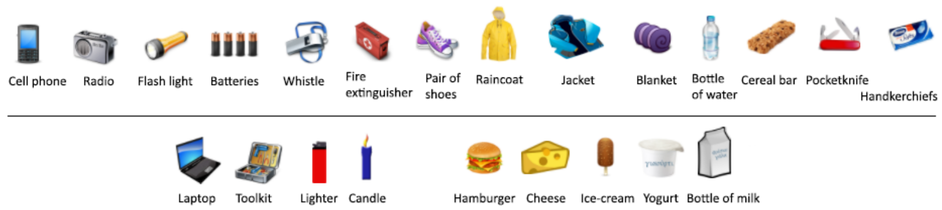

Figure 1. The useful (up) and non-useful (down) objects

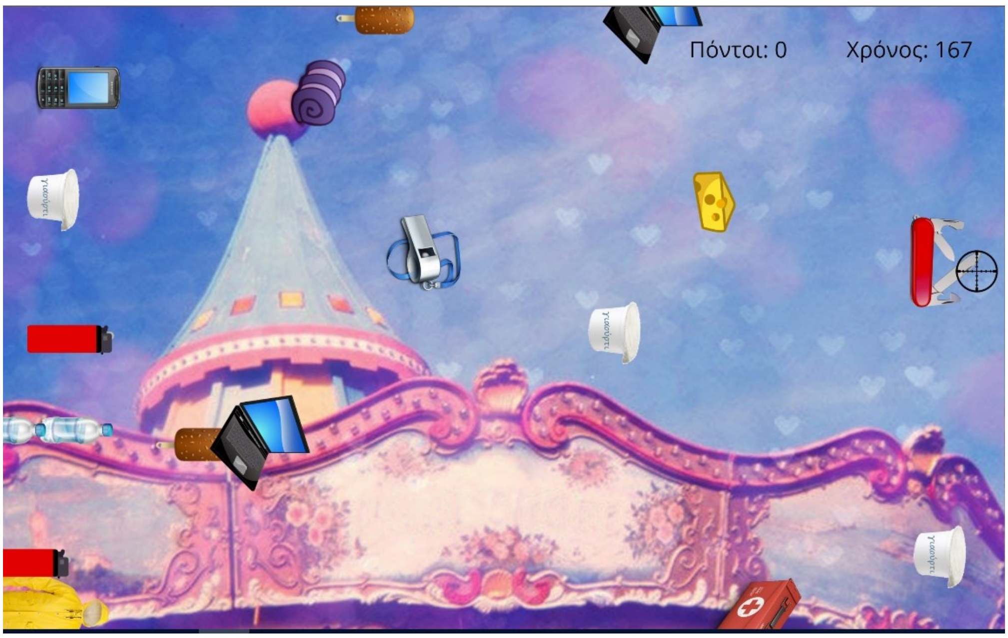

Figure 2. A snapshot from the game's interface. At the top right corner, the score and the time are displayed.

Three different structures of the same game were developed by incorporating a different type of feedback for the points that were earned or lost. The stimulus under study was the type of the feedback.

- **GS 1:** game with visual feedback
- **GS 2:** game with auditory feedback
- **GS 3:** game with no feedback.

The visual stimuli were displayed as numbers with a duration of approximately 1.5sec. The positive number "10" was displayed for the useful items and the negative number "-2" for the non-useful items. For the earned points the number was displayed with green color (RGB: 0, 255, 0), font size 24, size 200x150 and a zoom effect, while for the lost points the number was displayed with red color (RGB 255, 0, 0), font size 24, size 200x150, also with a zoom effect. The auditory stimuli were two different stereo sounds each having a length of 1.25sec (44100Hz, 55db).

Participants

The sample consisted of 60 male volunteers with a mean age of 25.23 (SD=8.04). Although the participants were informed by the researchers prior to expressing their interest in participating in the present research, about their preparation and data collection process, only 41 of them followed the instructions and finally participated in the experiment. The basic reason for excluding the participants were the lack of sleep and the use of hair-styling products. The participants were only men in order to avoid possible gender differences in brain activity. All participants had normal vision, were right–handed native Greek speakers, without certain diagnosed learning difficulties or mental disease. None of the participants received any medication or substances that affected the operation of the nervous system and they had not consumed caffeine or alcohol in the last 24 hours before the experiment. The alpha rhythm of all the participants was checked and found to be normal (8–12Hz, 10Hz peak). The participants were randomly assigned only to one of the three game structures described in the previous section to avoid effects of one task on other.

After the experimental procedure the participants were asked to fill in a questionnaire. From the questionnaire data, we noted that from the 41 participants that played the game, three were left-handed and seven of them reported to have a learning disability or a problem with their vision, so their data were excluded. The final sample consisted of 31 participants. All participants underwent a familiarization period with the computer and the equipment. The experimental room was calm, and light and temperature were continuously regulated.

Experimental procedure

The EEG data were recorded during the gaming session. Each player played the game for one session that lasted 180sec. During the game play, the objects displaying the useful and non-useful items were randomly generated with a random frequency based on the formula CREATION_INTERVAL + random (-0.5, 0.5), where CREATION_INTERVAL was set to 1.5sec. The objects were moving downwards with a speed of 100px/sec.

The Emotiv EPOC+ EEG headset was used to record the EEG data. Emotiv includes 14 channels (plus CMS/DRL references, P3/P4 locations) according to the International 10–20 system, each based on saline sensors. The sampling rate of the 14-channel EEG is 128 Hz. The available channels (based on the International 10–20 system) are depicted in Figure 3. The electrode impedance was decreased by using saline liquid until the level required by the software was reached and was checked along the experiment.

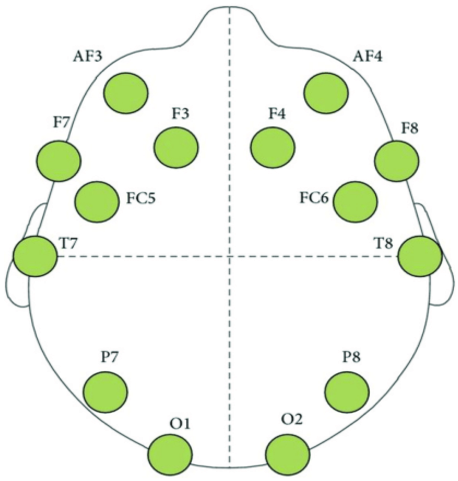

Figure 3. Locations of the 14 EEG sensors

After the EEG recording, each participant completed a questionnaire. Apart from the personal data such as gender, age, etc. the participants had to answer questions about their gaming experience (see Appendix A), the time they spend in gaming weekly as well as their preference about the type of feedback used for earned and lost points. The questions were selected from the Game Experience Questionnaire (GEQ) – Core Module on a Likert scale (IJsselsteijn, de Kort & Poels, 2013). In addition to the EEG signals and questionnaire responses, we also kept the players' scores.

Data analysis

The EEG results were initially evaluated by observing the EEG signals that were recorded through the sensors of the Emotiv EPOC+ headset (Figure 3). The electrical brain activity patterns were interpreted by comparison between participants and different game structures i.e., for different feedback modalities for the points. Data were interpreted by visual analysis of the graphical representation of EEG signals. Then, the EEG raw data were preprocessed and the analysis was conducted with the EEGLAB toolbox (MATLAB). Through EEGLAB the acquired EEG signals were firstly visually inspected and segments with artifacts were removed. Each individual signal was imported in EEGLAB and was subdivided for further analysis at shorter intervals called epochs whose size was determined empirically and based on experimental characteristics (e.g., the presentation of each stimulus lasted for about 1.5sec) at 2sec. The DC level of the epochs was also removed and the epochs were band-pass filtered in the frequency band of 1-30Hz. A 50Hz notch filter was employed. Eye movement artifacts were corrected by using an independent component analysis.

After preprocessing all the signals, for each feedback modality, one merged dataset was created. The merged dataset included the epoched signals of all participants separately for each feedback modality, meaning that we finally had three datasets to analyze. Spectral analysis was performed for each feedback modality. The data were banded into theta (4–8 Hz), alpha (8–12 Hz), beta (13–29 Hz), and gamma (30-32Hz) frequency bands. The EEG oscillations during gaming was compared with the EEG activity during the resting period (baseline) recorded before playing the game as these spectrum bands have been linked in the literature for studying the cognitive and emotional responses of players.

Different components of the game experience were measured by the questionnaire. It included several game-related subjective measurements dimensions such as positive affect, negative affect, competence, challenge, sensory and imaginative immersion and flow. Each question item consisted of a statement on a 5-point scale ranging from 0 (Extremely) to 4 (Not at all). The participants' responses to the questionnaires on their experience of the game analyzed and compared with the neurophysiological results.

Results

Delphi survey

Referring to the results of the first Delphi survey, the learning elements that were considered by the participants as the most important for digital educational games are shown in Table 1. The participants also mentioned that the learning elements have to be always selected according to the learning objectives of the game.

As far as the game elements were concerned, the results that came of the survey are summarized in Table 2. It was also mentioned that the game elements would be chosen based on the entertainment and fun goals of the game.

Table 1. Most important learning elements for digital educational games

Learning elements
Actions/tasks, challenging activities, competition, problem solving, because the student gets more motivated and engaged
Appropriate, constructive feedback, because the student needs it in order to learn from his/her actions
Experimentations, because the student should have opportunities to form hypotheses and test them through experimentation, being an active way of learning
Exploration, discovery, because the student gets more engaged and motivated when he/she takes part in active learning
Role-playing, because the student gets more empathy, critical and social skills.
Simulations, because they transfer real-life phenomena that are difficult to otherwise explore, but crucial in constructing meaning and understanding
Discussions, social interactions, collaboration activities, because the student can learn by interacting with others
Assessment, because the student needs to self-monitor his/her performance and gets motivated when he/she progresses
Detection of learners' previous knowledge
Scaffolding activities

Table 2. Most important game elements for digital educational games

Game elements
Rules of the gameplay: rules provide a constraining and support strategy necessary for learning and playing
Cut scenes: they can easily situate the student within the game narrative and the tasks that he/she is called to undertake; they can offer information that are relevant to the game's learning objectives
Scoring mechanism (e.g. action points), visible progress and levels: gathering action points or unlocking a new level can be very motivational for the student. Furthermore, designing various levels offers the student variety and enables a better organization of the game's learning activities.
Collecting and interacting with objects: exploring a digital environment in order to discover interactive objects that offer opportunities for experimentation can support active learning. Collecting objects can also be motivational.
Challenges: motivational well-designed challenges that are in accordance with the game's learning objectives are at the core of an educational game
Appropriate, constructive feedback: the student needs it in order to learn from his/her actions
Multiplayer capabilities: social interactions may foster learning
Simulations: they can bridge the gap between the real world and the game's world
Movement in the digital environment, sensation of exploration, realism: students usually like to be situated within a digital environment that consists of various spaces, which they can explore. In addition, this 'spatial metaphor' might help the game designer to better organize the challenges that he/she will embed in the game.
Adaptation to the learner's needs (learning style, misconceptions)

Table 3. How to integrate learning activities into the gameplay

Ways of integration
By converting learning activities into challenges that the student has to resolve
By meaningfully integrating those challenges in the context of the game with relevant game elements into an engaging and fun narrative
By authentic learning approaches
By incorporating real world problem-solving activities in a way that the learner would not be consciously aware of the learning objectives of the game until he or she is already highly engaged
By taking into consideration the specific high level educational and entertainment requirements

Table 4. Stages/steps for the design of digital educational games according to the participants

Stages/steps
Take into account modern pedagogical approaches, e.g., constructivism, multiple intelligence theory, social theories of learning
Take into account basic game-based learning principles
Define the learning objectives and sub- objectives
Connect the learning objectives and sub- objectives with the acts of the game
Define the scoring mechanism as well as the game's levels
Define the possible actions that the player can take within the digital environment and the corresponding feedback that he/she can get
Design the scaffolds that the player will be offered
Evaluate the game with experts (teachers and usability experts)
Evaluate the game by using real students
Redesign the game after evaluation

Table 5. Challenges during the game design

Challenges
To transfer the basic aspects of modern pedagogical approaches into educational game-design principles
To create appropriate challenges in accordance with the specific learning objectives
To create an interesting, persuasive narrative
To create appropriate challenges that are motivational and not explicitly didactic
To incorporate feedback by using the appropriate game elements
To have different professionals (e.g., graphic designers, game designers, programmers, educators) cooperating in order to design and develop the game

After having given the answers about the learning and game elements that are considered as the most important to use in digital educational games, the participants were asked about how to integrate the learning activities into the gameplay. In Table 3 are shown the results of the survey regarding the way that learning activities should be integrated into the gameplay.

In Table 4 are summarized the participants' answers about the stages/steps for the design of digital educational games.

Regarding the challenges during the game design, the main challenges participants are facing are summarized in Table 5.

Referring to the results of the second Delphi survey, the key factors for the gaming dimension of the digital educational games, according to the participants, are as shown in Table 6.

As mentioned above, the participants were asked about the key factors for the game dimension. After this question, they were asked if they could categorize the game characteristics. Regarding the game characteristics categorization, those, which were proposed, are depicted in Table 7.

Table 6. Key factors for the gaming dimension of the digital educational games

Key factors
Story/narrative
Challenging tasks within the game
Authentic/relevant tasks within the game
Constant, relevant and unobtrusive feedback
Flow
Levels
Clear progress and goal indicators
Suitability of the theme for the target audience
Balanced game tasks in terms of learning and playing (i.e., effective, efficient and enjoyable)
Reality(R)', 'Meaning(M)' and 'Play(P) should be balanced in three dilemmas R-M; R-P; M-P and one trilemma R-M-P
Compatibility of the game mechanics and goal structures

Table 7. Game characteristics categorization

Categorization
Gaming experience should be engaging, challenging, motivating, enjoyable
Feedback: progress, goal indicators
Feedback could include feedthrough (during the process) in order the player to complete a current task, feedforward (hints/tips) in order the player to complete a future task, feedback (after) related to a completed task
Narratives can be either endogenous or exogenous, linear or non-linear, fiction or non-fiction

Table 8. Key factors for the Learning dimension of digital educational games

Key factors
Learning objectives
Subject matter content
Pedagogical/didactical approach for sequencing
Reflection
Application of knowledge or skills
Experimentation/experiential characteristics
Exploration
Instructive feedback (customized / personalized)
Feedback focused on 'learning progress' (i.e., progress towards mastery on the learning objectives)
Feedback used for support and scaffolding
The learning characteristics need to follow the specific learning goal, for which the game will be designed (i.e., skills, knowledge, understanding, awareness, behavioral change)
Learning gains should be transferable to real world tasks/settings
The learning design should not just impose an additional cognitive/mental effort that obstructs learning

The key factors for the learning dimension of digital educational games according to the participants of the survey are presented in Table 8.

Finally, after the question about the learning dimension, the participants were asked if they could categorize the learning characteristics. Regarding the learning characteristics categorization, the participants answered that learning characteristics can be mapped to categories with existing taxonomies (such as Bloom and others).

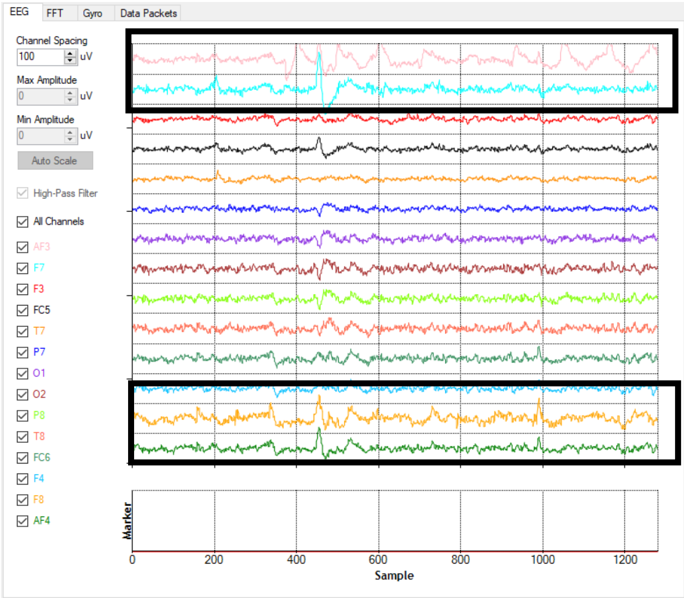

Figure 4. An example of EEG data recorded during the experiment with visual feedback. AF3, F7, F8, AF4 which correspond to the frontal area show higher activity than the rest electrodes

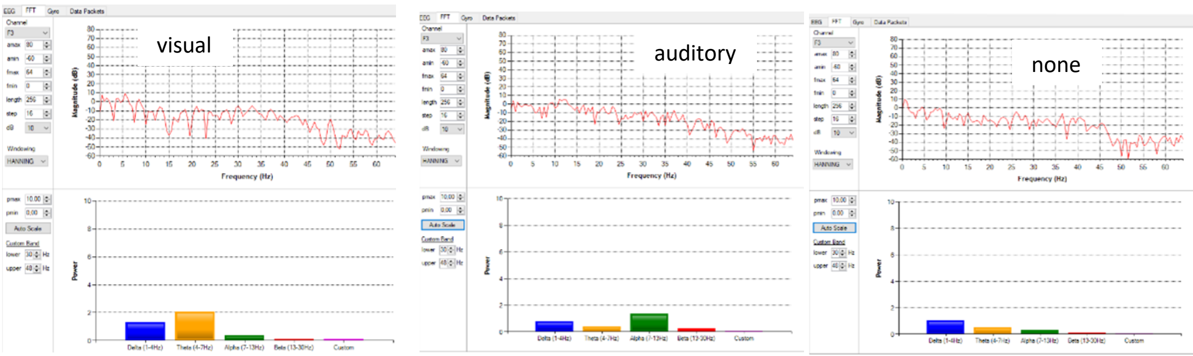

Figure 5. Visual inspection of the spectrum of three participants, each one had played a different game structure

EEG data

By observing the EEG signals through the Emotiv Testbench software (Figure 4), we noticed that the frontal electrode locations showed high activity for the most of the participants for the two of the three game structures, specifically for the game structure with the visual (GS1) and the auditory feedback (GS2).

From FFT tab of EMOTIV Testbench (Figure 5) we noticed that the auditory feedback showed an increased theta signal, while the visual feedback showed an increase in alpha activity. Also, for visual feedback the beta band showed an increase compared with the auditory feedback. For the game structure with no feedback, the activity was decreased for all both theta and alpha bands.

The colored lines in Figure 6 represent the channel spectral density and the associated topographical maps of the activity of each data channels. The leftmost scalp map shows the scalp distribution of the power at 6Hz, which in these data is concentrated on right frontal and left parietal electrode locations. The other topographical maps indicate the distribution of power at 10Hz, 22Hz and 31Hz, showing almost the same spectrum distribution. These frequencies have been chosen as they are the median of the theta (4–8 Hz), alpha (8–12 Hz), beta (13–29 Hz), and gamma (30-32Hz) frequency bands respectively. For the auditory feedback modality, the spectrum has almost the same distribution (Figure 7). Apart from the right frontal and left parietal electrode locations, the activity was also high in the left frontal electrode location, namely F7. For the non-feedback modality (Figure 8) although the spectrum had almost the same distribution as in the visual modality, the spectrum had less activity in all electrode locations.

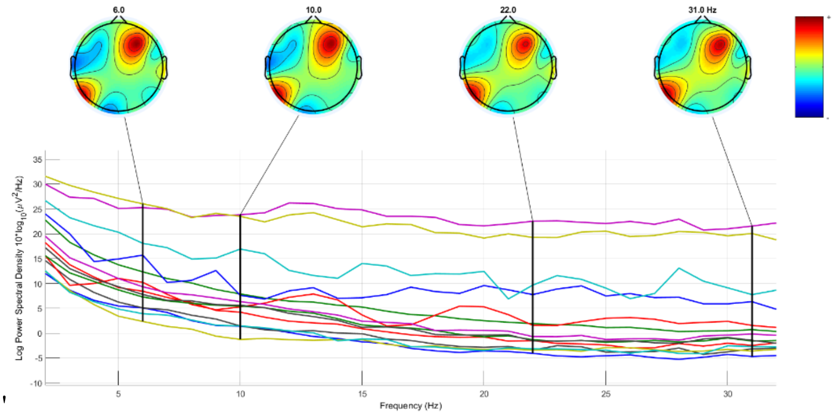

Figure 6. Channel spectral power analysis and associated topographical maps for visual feedback game structure

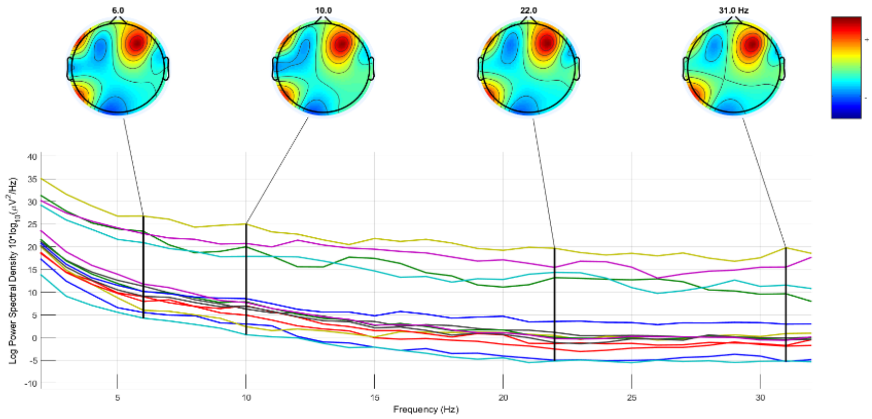

Figure 7. Channel spectral power analysis and associated topographical maps for auditory feedback game structure

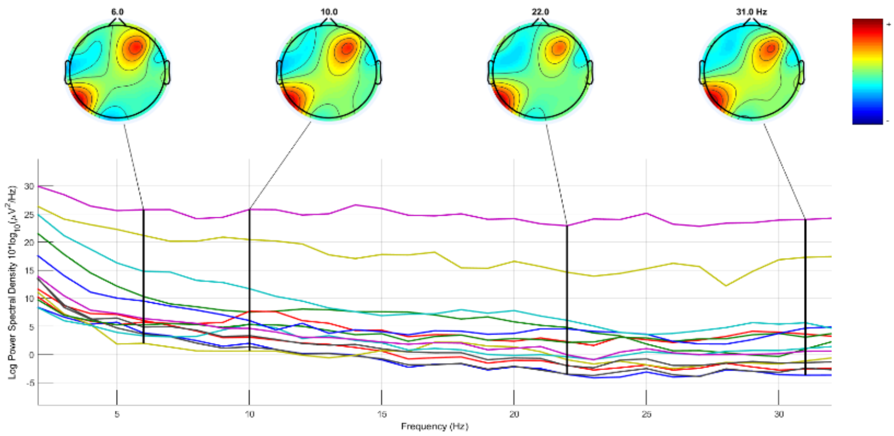

Figure 8. Channel spectral power analysis and associated topographical maps for none feedback game structure

Game experience questionnaire

Based on the participants' answers in the questionnaire given after the gaming session, we noticed that most of the players had a moderate experience in playing digital games. Forty-five percent (45%) of the participants played digital games less than one hour per week, 29% about five hours, 13% played about 1-2 hours per week and 13% answered that played more than five hours. For their preference about the modality of the feedback, 55% preferred having auditory feedback for points, 39% visual feedback and 4% preferred to have both visual and auditory feedback.

The participants' responses to the questions regarding their gaming experience (Table 1) were separated based on the game structure the players played. For each component (extremely, fairly, moderately, slightly, not at all) the percentage average value was calculated. The percentage values (Figure 9) corresponding to the questions that evaluate the feeling of positive affect (Q1, Q2, Q3) showed a preference in the auditory feedback. For questions evaluating the feeling of negative affect (Q4, Q5) the results showed that none of the game structures differed significantly for the emotion of the negative feeling. Question six that evaluated the flow that the players experienced during the gameplay, showed that visual and auditory feedback had increased flow comparing to the no feedback structure. Flow is a little bit higher though for auditory compared to visual feedback. The emotion of sensory and imaginative immersion evaluated through question seven was increased for visual and auditory feedback comparing to the no feedback structure. The same results occurred for the feeling of challenge based on questions Q8, Q10, Q11. Finally, answers corresponding to the question nine evaluating the feeling of competence, showed that the players experienced that feeling mostly in visual feedback.

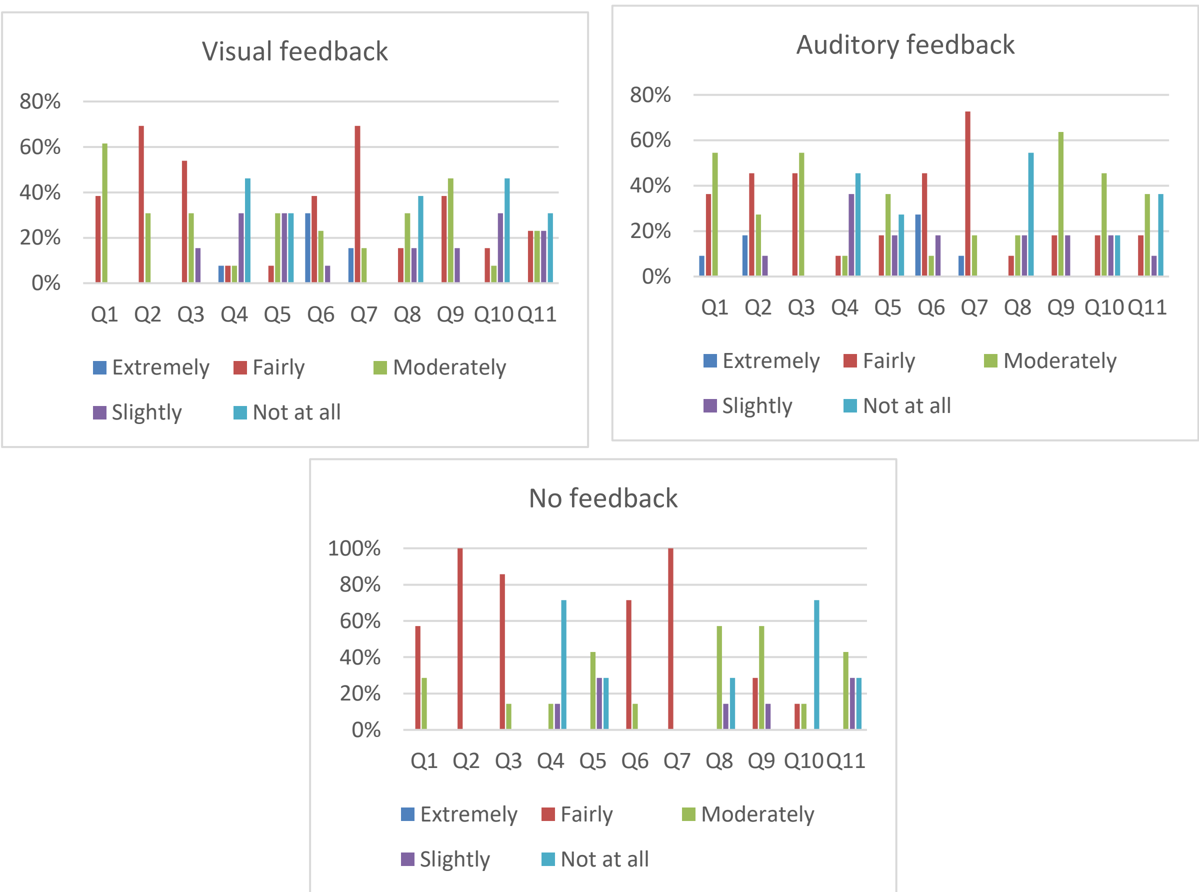

Figure 9. Percentage average of each component per question and per game structure

Discussion and conclusions

Our aim was to examine which learning and game elements should be used in a game and how they should be integrated into the game. The learning and game elements that have been proposed by the experts as the most important elements for the game design were those that promote constructivism, authentic learning environments, personalized learning and fun. The learning and game elements should be used in the game by creating learning activities which not clearly reveal their learning objectives, but incorporate them into symbolic representations of everyday life experiences that provide fun and motivate the users for high interaction during the gameplay. The results showed that the most critical step for the game design is to describe and connect the learning objectives with the context of the game by creating an instructional design, which combines the most suitable learning elements and their integration into the gameplay.

The experts suggested to use existing taxonomies such as Bloom taxonomy, in order to integrate the learning elements into the gameplay. Based on that, the learning elements could be assigned to Bloom taxonomy levels and the same could be done for the game elements. Thus, the integration of the learning elements into the gameplay could be based on these assignments to Bloom levels. However, for this to be done, a common taxonomy that involves both learning and game elements should be created. In the current study, a first attempt was made to explore the potentials of learning and game elements categorization.

Our aim was also to examine whether EEG could give guidelines about how to integrate game elements, and especially feedback, into the game. In order to evaluate the effect of different feedback modalities for earned and lost points in a digital educational game, we have recorded EEG data from 31 participants with the Emotiv EPOC+. We also used a questionnaire to examine whether players' subjective answers corresponded to the EEG data.

From the EEG data we concluded that theta and alpha bands for visual and auditory feedback stimuli were increased as compared to non-feedback game structure. The spectral data showed that the increase focused at the right frontal and left parietal areas. Theta activity at the frontal area of the brain is related with situations of information analysis (Ninaus et al., 2014). The increase might reflect the processing of the visual feedback (GS1, GS2) as players mentioned that they were sometimes distracted by the visual feedback. Alpha band was decreased for the game with visual feedback compared to the auditory feedback. As alpha oscillations increase with focus or concentration and is positively correlated with flow (Ninaus et al., 2014), we argue that participants preferred the auditory feedback compared to the visual. Beta activity deals with active attention while discriminates among gaming conditions (Berta et al., 2013). In the game structure with the auditory feedback, beta band was increased compared with the visual as well as the non-feedback game structure, so it seems that players were more focused during the gameplay. Gamma was increased in both visual and auditory game structures. Gamma activity in frontal areas represent the state of arousal and is connected to cognitive processes like decision-making and information processing (Ray & Cole, 1985).

The results from the participants' answers to the questionnaire matched the results from EEG data, as they showed that the feeling of positive affect was higher for auditory feedback compared to visual and non-feedback game structures, while flow is a little bit higher for auditory than visual feedback. Sensory and imaginative immersion based on the questionnaire for visual and auditory feedback was found increased, which agrees with gamma activity that was increased in both visual and auditory game structures. Based on both questionnaire and EEG data, the results showed that the players preferred the auditory feedback. Although the visual feedback offered a positive emotion, it rather distracted players during the gameplay as they had an additional visual stimulus to process. Thus, we conclude that neurophysiological data such as EEG signal provide information on players' preferences about the element of feedback for earned and lost points.

One limitation of this study is the small sample per feedback modality. Another limitation could be the fourteen out of nineteen electrode locations used because of the system's design. The five electrode locations that are not covered with Emotiv headset are located at the central line of the scalp namely Fz, Cz, Pz and also electrodes C3, C4.

As a proposal for future studies, more research is needed in order to create new taxonomies for learning and game elements to be integrated into the gameplay. In addition, empirical studies could be carried out in order to apply the proposed way described above, by using Bloom taxonomy, aiming to combine the learning and game elements into the gameplay. Regarding the contribution of educational neurosciences, more research should be done on game elements, in order to investigate players' experience and provide guidelines for the design of educational games and specifically to inform about the most effective way to integrate game elements into the game. Finally, studies with women participants should also be conducted in order to examine possible gender differences.

Acknowledgments. This research is implemented through the Operational Program "Human Resources Development, Education and Lifelong Learning" and is co-financed by the European Union (European Social Fund) and Greek national funds.

References

Abujelala, M., Abellanoza, C., Sharma, A., & Makedon, F. (2016). Brain-EE: Brain enjoyment evaluation using commercial EEG headband. In M. Abujelala & S. Gieser (Eds) *Proceedings of the 9th ACM International Conference on Pervasive Technologies Related to Assistive Environments.* (pp. 1-5). NY: ACM Press.

Adams, E. (2009). *Fundamentals of Game Design*. Berkeley, CA, USA: New Riders.

Akilli, G. K., & Cagiltay, K. (2006). An Instructional Design/Development Model for the Creation of Game-Like Learning Environments: The FIDGE Model. In M. Pivec (ed.), *Affective and Emotional Aspects of Human-Computer Interaction – Game-Based and Innovative Learning Approaches* (pp. 93-112). Amsterdam: IOS Press.

Allison, B. Z., & Polich, J. (2008). *Workload assessment of computer gaming using a single-stimulus event-related potential paradigm.* Biological Psychology, 77(3), 277–283.

Amory, A. (2007). Game object model version II: a theoretical framework for educational game development. *Educational Technology Research and Development*, 55(1), 51-77.

Annetta, L. A. (2010). The "I's" have it: A framework for serious educational game design. *Review of General Psychology*, 14(2), 105.

Arnab, S., Lim, Th., Carvalho, M., Bellotti, F., de Freitas, S., Louchart, S., Suttie, N., Berta, R., & De Gloria, A. (2014). Mapping learning and game mechanics for serious games analysis. *British Journal of Educational Technology,* 46(2), 391-411.

Bailey, K., West, R., & Anderson, C.A. (2010). A negative association between video game experience and proactive cognitive control. *Psychophysiology*, 47 1, 34-42.

Bakaoukas, A.G., Coada, F., & Liarokapis, F. (2015). Examining brain activity while playing computer games. *Journal on Multimodal User Interfaces*, 10, 13-29.

Balducci, F., Grana, C., & Cucchiara, R. (2016). Affective level design for a role-playing videogame evaluated by a brain–computer interface and machine learning methods. *The Visual Computer*, 33, 413-427.

Baumeister, J., Reinecke, K., Cordes, M., Lerch, C., & Michael, W. (2010). Brain activity in goal-directed movements in a real compared to a virtual environment using the Nintendo Wii. *Neuroscience Letters*, 481(1), 47-50.

Bedwell, W. L., Pavlas, D., Heyne, K., Lazzara, E. H., & Salas, E. (2012). Toward a taxonomy linking game attributes to learning: An empirical study. *Simulation & Gaming*, 43(6), 729–760.

Bellotti, F., Berta, R., De Gloria, A., D' Ursi, A., & V. Fiore, V. (2012). A serious game model for cultural heritage. *ACM Journal on Computing and Cultural Heritage*, 5(4), 1-27.

Berta, R., Bellotti, F., Gloria, A.D., Pranantha, D., & Schatten, C. (2013). Electroencephalogram and physiological signal analysis for assessing flow in games. *IEEE Transactions on Computational Intelligence and AI in Games*, 5, 164-175.

Björk, S., & Holopainen, J. (2004). *Patterns in Game Design*. Boston, MA: Charles River Media.

Buchinger. D., & da Silva Hounsell, M. (2018). Guidelines for designing and using collaborative-competitive serious games. *Computers & Education*, 118, 133–149.

Burns, A., & Tulip, J. R. (2017). Detecting flow in games using facial expressions. *Proceedings of IEEE Conference on Computational Intelligence and Games (CIG)* (pp. 45-52). NY: IEEE.

Capdevila Ibáñez, B., Marne, B., & Labat, J.M. (2011). Conceptual and technical frameworks for serious games. *Proceedings of the 5th European Conference on Games Based Learning* (pp. 81-87). Academic Publishing Limited, Reading, UK.

Carvalho, B., Bellotti, F., Berta, R., De Gloria, A., Sedano, I., Hauge, J., Hu, J., & Rauterberg, M. (2015). An activity theory-based model for serious games analysis and conceptual design. *Computers & Education*, 87, 166-181.

Chandra, S., Sharma, G., Salam, A. A., Jha, D., & Mittal, A. P. (2016). Playing action video games a key to cognitive enhancement. *Procedia Computer Science*, 84, 115–122.

Christie, G.J., & Tata, M.S. (2009). Right frontal cortex generates reward-related theta-band oscillatory activity. *NeuroImage*, 48, 415-422.

Csikszentmihalyi, M. (1990). *Flow: The Psychology of Optimal Experience.* New York: Harper & Row.

de Freitas, S., & Jarvis, S. (2006). *A Framework for Developing Serious Games to meet Learner Needs*. Retrieved 17 September 2018,from https://pdfs.semanticscholar.org/55ac/334ce13377cc031350f85b8de2567f3d735f.pdf?_ga=2.20427896.1556093815.1579613675-1924017177.1579613675

de Lope., R., López Arcos, J. R., Medina-Medina. N., Paderewski. P., & Gutiérrez-Vela, F. L. (2017). Design methodology for educational games based on graphical notations: Designing Urano. *Entertainment Computing*, 18, 1–14.

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: Defining "Gamification". In A. Lugmayr, H. Franssila, C. Safran & I. Hammouda (Eds.), *Proceedings of the 15th International Academic MindTrek Conference on Envisioning Future Media Environments- MindTrek '11* (pp. 9). NY: ACM Press.

Echeverría, A., García-Campo. C., Nussbaum. M., Gil. F., Villalta. M., Améstica. M., & Echeverría. S. (2011). A framework for the design and integration of collaborative classroom games. *Computers & Education*, 57, 1127–1136.

El Mawas, N. (2014). An architecture for co-designing participatory and knowledge-intensive serious games: ARGILE. In G. Fox & W. W. Smari (Eds.), *Proceedings of the International Conference on Collaboration Technologies and Systems* (pp. 387-394. Minneapolis, USA: IEEE.

Ellick, W., Mirza-Babaei, P., Wood, S. L., Smith, D., & Nacke, L. E. (2013). Assessing user preference of video game controller button settings. In W. E. Mackay (Ed.), *CHI Extended Abstracts on Human Factors in Computing Systems* (pp. 1107-1112). NY: ACM.

Fairclough, S.H., Gilleade, K.M., Ewing, K.C., & Roberts, J. (2013*).* Capturing user engagement via psychophysiology: measures and mechanisms for biocybernetic adaptation. *International Journal of Autonomous and Adaptive Communications Systems*, 6, 63-79.

Gredler, M. E. (1996). Educational games and simulations: A technology in search of a (research) paradigm. *Technology*, 39, 521-540.

Gunter, G. A., Kenny, R. F., & Vick, E. H. (2007). Taking educational games seriously: using the RETAIN model to design endogenous fantasy into standalone educational games. *Educational Technology, Research and Development*, 56(5/6), 511–537.

Hou, G., Dong, H., & Yang, Y. (2017). Developing a Virtual Reality Game User Experience Test Method Based on EEG Signals. In B. Vitoriano, G. H. Parlier & D. de Werra. (Eds.), *Proceedings of the 5th International Conference on Enterprise Systems* (pp. 227-231). Portugal: SciTePress.

Huynh-Kim-Bang, B., Labat, L.-M. & Wisdom, J. (2011). Design patterns in serious games: A blue print for combining fun and learning. *International Journal of Technology Enhanced Learning*, 3(6), 555-569.

IJsselsteijn, W. A., de Kort, Y. A. W., & Poels, K. (2013). *The Game Experience Questionnaire*. Eindhoven: Technische Universiteit Eindhoven.

Kelle, S., Klemke, R., & Specht, M. (2011). Design patterns for learning games. *International Journal of Technology Enhanced Learning*, 3(6), 555-569.

Kiili, K. (2005). Digital game-based learning: Towards an experiential gaming model. *The Internet and Higher Education*, 8, 13–24.

Kordaki, M. (2015). A 7-step modeling methodology for the design of educational constructivist computer card games: results from an empirical study. *Recent Patents on Computer Science,* 9(2), 114-123.

Lim, T., Louchart, S., Suttie, N., Ritchie, J.M., Aylett, R.S., Stanescu, I.A., Roceanu, I., Martínez-Ortiz, I., & Moreno-Ger, P. (2013). Strategies for effective digital games development and implementation. In Y. Baek & N. Whitton (Eds.), *Cases on digital game-based learning: methods, models, and strategies* (pp. 168–198). Hershey, PA: Information Science Reference.

Lindley, C. A. (2003). *Game taxonomies: A high level framework for game analysis and design*. Retrieved January 27, 2020 from https://www.gamasutra.com/view/feature/131205/game_taxonomies_a_high_level_.php.

Malone, T.W., & Lepper, M.R. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning. In R.E. Snow & M.J Farr (Eds), *Aptitude, learning, and instruction volume 3: Conative and affective process analyses* (pp. 223-253). Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

Marne, B., Wisdom, J., Huynh-Kim-Bang, B., & Labat, J. M. (2012). The six facets of serious game design: a methodology enhanced by our design pattern library. In A. Ravenscroft, S. Lindstaedt, C. Delgado Kloos, D. Hernández-Leo (Eds.), *21st Century Learning for 21st Century Skills* (pp. 208-221). Berlin Heidelberg: Springer.

Mathewson, K.E., Basak, C., Maclin, E.L., Low, K.A., Boot, W.R., Kramer, A.F., Fabiani, M., & Gratton, G. (2012). Different slopes for different folks: alpha and delta EEG power predict subsequent video game learning rate and improvements in cognitive control tasks*. Psychophysiology*, (49) 12, 1558-70.

McMahan, T., Parberry, I., & Parsons, T. D. (2015). Evaluating player task engagement and arousal using electroencephalography. *Procedia Manufacturing*, 3, 2303–2310.

McMahon, M. T. J. (2009). The DODDEL Model: A Flexible Document-Oriented Model for the design of Serious Games. In T. Connolly, M. Stansfield & L. Boyle (Eds.), *Games-Based Learning Advancements for Multi-Sensory Human Computer Interfaces: Techniques and Effective Approaches* (pp. 98-118).Hershey, NY: Information Science Reference.

Mekler, E., Brühlmann, F., Opwis, K., & Tuch, A. (2013a). Disassembling gamification: The effects of points and meaning on user motivation and performance. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI EA'13)*, 1137-1142.

Mondéjar T. et al. (2015) Can Videogames Improve Executive Functioning? A Research Based on Computational Neurosciences. In: Bravo J., Hervás R., Villarreal V. (Eds.), *Ambient Intelligence for Health*. AmIHEALTH 2015. Lecture Notes in Computer Science, vol 9456. Springer, Cham

Moreno-Ger, P., Martínez-Ortiz, I., Sierra, J. L., & Fernández-Manjón, B. (2008*).* A content-centric development process model. *Computer*, 41(3), 24–30.

Moya, S., Tost, D., Grau, S., von Barnekow, A., & Felix, E. (2016). *SKETCH'NDO: A framework for the creation of task-based serious games. Journal of Visual Languages and Computing*, 34-35, 1–10.

Nacke, L.E., & Lindley, C.A. (2008). Flow and immersion in first-person shooters: measuring the player's gameplay experience. *Proceedings of the Conference on Future Play: Research, Play, Share* (pp 81-88). Future Play.

Nagle, A., Wolf, P., Riener, R., & Novak, D. (2014). The use of player-centered positive reinforcement to schedule in-game rewards increases enjoyment and performance in a serious game. *International Journal of Serious Games*, 1(4), 35-47.

Ninaus, M., Kober, S.E., Friedrich, E.V.C., Dunwell, I., de Freitas, S., Arnab, S., Ott, M., Kravcik, M., Lim, T., Louchart, S., Bellotti, F., Hannemann, A., Thin, A.G., Berta, R., Wood, G., & Neuper, C. (2014). Neurophysiological methods for monitoring brain activity in serious games and virtual environments: a review. *International Journal of Technology Enhanced Learning*, 6 (1), 78-103.

Ninaus, M., Pereira, G., Stefitz, R., Prada, R., Paiva, A., Neuper, C., & Wood, G. (2015). Game elements improve performance in a working memory training task. *International Journal of Serious Games*, 2(1). https://doi.org/10.17083/ijsg.v2i1.60.

Plass, J.L., Homer, B.D. (2009). Educational Game Design Pattern Candidates. *Journal of Research in Science Teaching*, 44, 133-153.

Prensky, M. (2001). *Digital Game-Based Learning*. New York, NY: McGraw-Hill.

Ray, W.J., & Cole, H.W. (1985). EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. *Science*, 228 (4700), 750-752.

Salen, K., & Zimmerman, E. (2004). *Rules of play: Game design fundamentals*. MIT press.

Sanchez, E. (2011). *Key criteria for Game Design. A Framework. MEET Project*. European Commission.

Sella, I., Reiner, M., & Pratt, H. (2014). Natural stimuli from three coherent modalities enhance behavioral responses and electrophysiological cortical activity in humans. *International Journal of Psychophysiology*, 93(1), 45-55.

Shaffer, D. W., Squire, K. A., Halverson, R., & Gee, J. P. (2005). Video games and the future of learning. *Phi Delta Kappan*, 87(2), 105-111.

Sicart, M. (2008). Defining Game Mechanics. *Game Studies*, 8(2). http://gamestudies.org/0802/articles/sicart.

Sillaots, M. (2015). *Game Elements*. Retrieved 15 October 2019 from http://htk.tlu.ee/icampus/mod/file/download.php?file_guid=220182.

Simões, J., Redondo, R. D., & Vilas, A. F. (2013). A social gamification framework for a K-6 learning platform*. Computers in Human Behavior*, 29(2), 345–353.

Sivanathan, A., Lim, T., Louchart, S., & Ritchie, J.M. (2014). Temporal multimodal data synchronisation for the analysis of a game driving task using EEG*. Entertainment Computing*, 5, 323-334.

Staalduinen, J. P. v. & de Freitas, S. (2011). A game-based learning framework: Linking game design and learning outcomes*.* In M. S. Khyne (ed.) *Learning to Play: Exploring the Future of Education with Video Games* (pp. 29-54). New York: Peter Lang.

Westera, W., Nadolskl, R. J., Hummel, H. G. K., & Woperels, I. G. J. H. (2008). Serious games for higher education: a framework for reducing design complexity*. Journal of Computer Assisted Learning*, 24, 420-432.

Wouters, P., Oostendorp, H. V., Boonekamp, R., & Spek, E. V. D. (2011). The role of Game Discourse Analysis and curiosity in creating engaging and effective serious games by implementing a back story and foreshadowing. *Interacting with Computers*, 23(4), 329-336.

Yazmir, B., & Reiner, M. (2017). I act, therefore I err: EEG correlates of success and failure in a virtual throwing game. *International Journal of Psychophysiology*, 122, 32-41.

Yusoff A., Crowder R., Gilbert L., Wills G. (2009). A conceptual framework for serious games. In I. Aedo, N. S. Chen, K. D. Sampson & L. Zaitseva (Eds.), *Proceedings of 9th IEEE International Conference on Advanced Learning Technologies* (pp. 21-23). Southampton, UK: University of Southampton.

Appendix A. Game Experience Questionnaire

Questions
I thought it was fun (positive affect)
I enjoyed it (positive affect)
I felt good (positive affect)
I thought about other things (negative affect)
I found it tiresome (negative affect)
I was fully occupied with the game (flow)
It felt like a rich experience (sensory and imaginative immersion)
I thought it was hard (challenge)
I was good at it (competence)
I felt time pressure (challenge)
I had to put a lot of effort into it (challenge)

To cite this article: Chalki, P., Tsiara, A., & Mikropoulos, T. A. (2019). An educational neuroscience approach in the design of digital educational games. *Themes in eLearning*, 12, 17-34.

URL: http://earthlab.uoi.gr/tel