Adaptivity in Educational Games: Including Player and Gameplay Characteristics

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Abstract

The use of educational games for teaching and training is nowadays well-known, although its effectiveness in terms of learning and motivation has not been firmly corroborated. A first reason for this is that research on instructional design research often does not reach the fields of game development and game design. Consequently, instructional design principles that have proven to be effective are often not incorporated in educational games. A second reason for the mixed results on the effectiveness of educational games can be found in the way instruction in such games is offered. To our knowledge, educational games rarely account for individual differences between players and research on adaptive educational games is rather sparse.

This paper focuses on adaptive approaches in educational games and discusses various player and gameplay characteristics that can be integrated in a framework that conceptualizes player-centered adaptivity in educational games.

Keywords: Educational games, Adaptive instruction, Game elements, Learner characteristics

1. Introduction

Adaptive systems can be described as taking into account learners' knowledge, goals or needs in order to behave differently for different (groups of) users (Vandewaetere & Clarebout, 2013). With respect to learning environments, adaptivity can range from very basic adjustments (like providing easier exercises to learners with low prior knowledge) to advanced and fine-grained adaptivity rules (taking jointly into account types of errors, time-on-task, need for help and knowledge). The majority of educational games today seems to implement a low-resolution form of adaptivity at the level of individual players, based on player profiles that are being obtained by stereotype modeling or modeling of learners into groups with fixed characteristics. For example, a player can be assigned to one of three difficulty levels based on a prior knowledge test. The problem with this discrete approach, however, is that classification is based on one single measurement at a certain moment and that players are assigned to groups or predefined player types.

In contrast to the discrete approach, a micro-adaptive approach is more dynamic, fine-grained and player-centered. In line with the discrete approach, the measurements of relevant player and gameplay characteristics can be non-obtrusive, but are used for more detailed run-time modeling (e.g. Kickmeier-Rust & Albert, 2010). For instance, when playing minigames (i.e., small games within the overall educational game such as word games), the attempts on single items or questions can be logged so that errors can be analyzed at run-time (e.g. for classifying errors into error types), the speed of answering and the behaviors of players can be logged and used for immediate reactions in the application. Also, when solving quests, player behavior can be analyzed in terms of need for support and gaming skills in order to adjust the environment in a next quest (e.g. easier access to help, fewer opponents, etc.).

In this paper, an overview is given of player and gameplay characteristics that can be taken into account when developing adaptive educational games. To conclude, a theoretical framework is presented that defines a fine-grained level of player-centered adaptivity in educational games.

2. Source of adaptation ("adapt to what?")

In order to define the characteristics that need to be taken into account in an adaptive educational game, one should first define the purpose of adaptivity, or the motivation for steering adaptivity (Lopes & Bidarra, 2011). Several purposes of adaptivity in an educational game can be mentioned: to improve (the efficiency of) learning (gains); to improve transfer of knowledge to situations outside the gaming context; to optimize challenge, fun, etc. for the learner; to optimize a learner's metacognitive skills such as self-regulation, planning and monitoring; to optimize learners' collaborative skills. Depending on the purpose of the game adaptivity models will contain different measurement and learner models. For example, if the focus of the game is on the improvement of learning (gains), the learner model will focus on measurements that represent the acquisition of knowledge, the transfer of knowledge to other in-game situations and the remediation of knowledge gaps. If however the purpose is to optimize challenge and fun, then adaptivity models will rather focus on the measurement of knowledge in order to provide an optimal balance and challenge between what the learner already knows and what the learner should acquire.

Typically the source of adaptation can be divided into player and gameplay characteristics. Combining relevant player and gameplay characteristics then result in game states, by which adaptive instruction in educational games can be offered.

3. Player characteristics

Player characteristics comprise characteristics that either can be measured before a player enters the game or while a player is engaged in gameplay.

3.1 Prior player characteristics

The first set of player characteristics can be called prior player characteristics and comprises the following characteristics:

(a) *Prior knowledge.* Prior knowledge can be measured by a quiz-like assessment, after which the player is directed to the most appropriate level of difficulty given his/her incoming knowledge.

(b) *Learning style/cognitive style/cognitions.* Although the issue of learning styles is a hot topic in educational research, empirical data on the effectiveness of learning styles-based adaptivity is nonexistent. In addition, we must bear in mind that learning styles can be highly dependent on the domain that is being learned (e.g., language learning vs. math) and that the measurement of learning styles is currently based on self-report data, which can be prone to measurement error. An alternative way to look at learning styles was presented by Rowe, Shores, Mott & Lester (2010) who referred to learning preferences, instead of learning styles. Rowe and colleagues suggested that learning preferences such as background knowledge and interests are strongly related to style of gameplay (i.e. typical activities performed in the game, such as using certain kinds of objects or reading content). Specifically for an educational math game, learning preferences/styles and learners' cognitions comprise characteristics such as self-efficacy for math, perceptions towards math, math anxiety, impulsivity, game-play experience, overall perceived usability of games or gaming, need for feedback and supportive materials for learning. Learning preferences thus largely determine the actual gameplay behavior. For example, a player's perceptions towards games in general as a tool to improve learning will influence motivation, willingness to engage and gameplay behavior. In turn, this will influence learning outcomes and the overall game effectiveness. It is thus important to consider players' overall conceptions and beliefs towards games and to the domain in which the game is situated. Applied to an educational math game, it can be suggested that players' attitudes towards math (e.g., math anxiety), their learning or gameplay goals, their prior experiences with math learning and their specific cognitions about games as a method to assist math learning will mediate the effectiveness of a math game.

(c) *Gaming skills.* Not only are prior gaming experiences and current game beliefs likely to determine the gameplay behavior, a player's gaming skills can largely influence effective gameplay behavior. Gaming skills comprise (1) metacognitive skills such as spatial skills and problem-solving skills (e.g., moving blocks in puzzle games) and effective help-seeking behavior (knowing when to search for additional help, e.g., through additional practice in mini games) and (2) gameplay skills such as reaction speed, mouse and keyboard accuracy. Overall gaming skills can largely influence the gameplay and learning outcomes. Insufficiently developed gameplay skills can result in the system's underestimation of a learner's actual knowledge level or skill since not all errors from the perspective of the game give evidence about the learners' skills. For example: if a learner is not able to complete a puzzle game because he or she is not able to jump quickly enough on moving blocks, then this is an indication of lack of speed and accuracy, rather than a lack of domain knowledge and domain-related skills.

(d) *Personality.* Previous research has demonstrated the relevance of including personality traits in the learner model, such as openness, conscientiousness and extraversion (Major, Turner, & Fletcher, 2006). The reason for this is that a learner's motivation to learn and his/her training proficiency is also influenced by personality (Barrick, & Mount, 1991). It can be hypothesized that certain personality traits will also affect a player's behavior in educational games. For example, Teng (2008) hypothesized that players with a high level of openness, conscientiousness and extraversion would be eager to learn and quickly master things. Moreover, such players derive pleasure from playing games, are satisfied with having imposed effects on the game environment, have high self-efficacy in dealing with complexity and thus have strong motivation to engage in gaming (Klimmt & Hartmann, 2006). The study of Teng (2008) corroborated the findings that players who score high on openness, conscientiousness and extraversion have advantages in interpersonal competition, which seems to be a defining characteristic of many (online) games nowadays.

(e) *Goal setting.* Not only are certain personality traits related to engagement, competition and pleasure, they might also explain which goals that a learner or player sets (Matthews, Derryberry, & Siegle, 2000). For example, highly conscientious players are more likely to set goals like "avoid failing"; highly extravert players are more likely to set goals like "having fun", while players scoring high on agreeableness (i.e., amiable, cooperative, flexible, trusting) will set goals that are related to "succeeding by myself" (Conati, 2002). In turn, the type of goals that are set influence a player's emotional states (e.g., joy, arousal, engagement), motivation and gameplay behavior. The type of goals that are set by learners also provide information to provide player-centered adaptivity. According to achievement goal theory (Elliott, 1999; Elliott & McGregor, 2001), 2x2 types of goals can be distinguished: mastery goals and performance goals, each in terms of approach or avoidance. This results in four approaches (Finney, Pieper, & Barron, 2004): performance-approach (e.g., *It is important for me to do better than other students*), performance-avoidance (e.g., *My goal in this class is to avoid performing poorly*), mastery-approach (e.g., *I want to learn as much as possible from this class*), and mastery-avoidance (e.g., *I worry that I may not learn all that I possibly could in this class)*. Depending on the goals a player has set, adaptivity in terms of support (e.g., action agent), content (e.g., more support), environment (e.g., longer minigames) can be offered. A more recent operationalization of achievement goal theory (Elliot, Murayama, & Pekrun, 2011) distinguishes 3x2 goal constructs. The first dimension defines competence in three ways: absolute (task), intrapersonal (self) and interpersonal (other); the second dimension defines how competence may be valenced: either positive (approaching success) or negative (avoiding failure). Consequently, there are six goal constructs: (1) task-approach, e.g., "do the task correctly"; (2) task-avoidance, e.g., "avoid doing the task incorrectly"; (3) self-approach, e.g., "do better than before"; (4) self-avoidance, e.g., "avoid doing worse than before"; (5) other-approach, e.g., "do better than others" and (6) other-avoidance, e.g., "avoid doing worse than others". If an educational game is played in an online, collaborative, competitive environment where the scores of other players can be consulted, then it makes sense to use this model of goal orientation, which basically subdivides the performance dimension of the 2x2 model (comprising the 2 constructs performance-approach and performance-avoidance) into 4 more specific goal constructs (self-approach, self-avoidance, other-approach, other-avoidance).

(f) *Motivation.* Motivation-related research in educational games found a three-component structure of motivation in which the components also correlate positively (Bartle, 1996; Yee, 2006). First, there is the achievement component, comprising the notions of advancement (i.e., the desire to gain power, to progress rapidly, to gather all tokens); mechanics (i.e., being interested in the underlying game rules in order to improve character performance); and competition (i.e., the desire to challenge and compete with others). A second component is the social component, which consists of socializing (i.e., having an interest in helping and chatting with other players); relationship (i.e., the desire to form long-term relationships with others); and teamwork (i.e., deriving satisfaction from begin a part of group effort). This component is only relevant in online, multiplayer games. The last component is the immersion component, focusing on discovery (i.e., finding and knowing things that most other player do not know about); role-playing (creating a persona with a background story and interacting with other); customization (i.e., having interest in customizing the appearance of a character) and escapism (i.e., using the environment to avoid thinking about real life problems). A second motivational framework and their according measurements focus on self-determination as predictor for motivation (Deci & Ryan, 2000; Ryan & Deci, 2000). In self-determination theory, motivation is a combination of interest/enjoyment (intrinsic motivation), perceived competence, effort, value/usefulness, felt pressure and tension and perceived choice. A third framework that can be used in game research has been developed by Rigby and Ryan (2007) and focuses on the player's experience. The framework is an adaptation of the self-determination theory for the context of (video) games (Ryan, Rigby, & Przybylski, 2006) and focuses on the gameplay experiences with competence, autonomy, relatedness, presence/immersion and intuitive controls.

Because all frameworks focus on the measurement of motivation during or after gameplay, the associated questionnaires cannot be used to create a baseline measurement of motivation. Alternatives to such a baseline measurement that can be integrated in a player model are the goals that a player has set, combined with a player's cognitions about overall gameplay and educational games. Research then can investigate whether there is a correlation between the prior goals and cognitions of a player and the motivation during and after gameplay. If a reliable estimation of in-play and post-play motivation can be made based on prior measurements of goals and beliefs, this estimation can serve as input for defining the motivational baseline of a player, and hence, for determining the kind of adaptation that can be offered during gameplay.

3.1 Runtime player characteristics

Next to the prior player characteristics, that have been discussed in the previous section, also runtime player characteristics can be taken into account when defining the adaptivity model. Such runtime player characteristics can change during and because of gameplay. For example, before a player enters a game, he/she can have a very low degree of motivation, which the adaptivity algorithm can take into account by providing an adjusted game-environment. However, a player's motivation can change because of positive interaction with the game (i.e., the player shows more engagement, fun, interest). If the adaptivity algorithm is then not able to change the game state from low-motivated to high-motivated, then there is the risk that the player's motivation decreases because the game environment is not adjusted anymore to the changed motivational state of the player. The following paragraphs list the possible runtime player characteristics than can be taken into account.

(a) *Motivation.* The problem with motivation-based run-time adaptivity is that motivation needs to be measured in an unobtrusive way to be practical in non-experimental settings. Reliable measurement of in-game motivation requires multiple questions on a regular basis and thus interrupts the gameplay process, which might lead to frustration, boredom, or gaming behavior by the learner. To avoid obtrusive measurement, motivational states can be inferred based on in-game behaviors, reaction times, use of support, etc. However, to date and to our knowledge, probabilistic models for measuring motivation at run-time on the basis of player behavior have not been empirically validated yet.

(b) *Gameplay skills.* A second characteristic that can be taken into account for developing run-time adaptivity is the increase in gameplay skills. As a player proceeds through the game, he/she acquires better skills with respect to mouse/keyboard coordination, is able to react faster or more accurate, knows better where to find help, etc. If prior gameplay skills were incorporated in the adaptivity algorithm, then this algorithm should also take into account a likely increase in these skills.

(c) *Knowledge and goal setting.* As with gameplay skills, a player's knowledge of the domain (e.g., math) and of the game environment can increase during gameplay. More specific potential areas for the development of domain knowledge include problem-solving skills, knowledge, or rules. With respect to knowledge of the game-environment a player may learn the pitfalls, particular rules in the environment, how to avoid failing, how to become better in achieving goals, etc. This increasing domain- and game-related knowledge is also likely to affect goal-setting behavior. As a player gains more expertise in the domain and in the game, he/she will adjust the initial goals that were set, refine goals or even change goals from performance to mastery-oriented goals.

4. Gameplay characteristics

The previous sections discussed learner or player characteristics and distinguished between characteristics that can be measured either prior to the gameplay or during the gameplay. Next to the learner or player characteristics, a second group of characteristics that provide input for adaptivity models in educational games are the gameplay characteristics, and focus on the process of gameplay and learning. This group includes learning process characteristics and learner behavior, such as reaction times, tool use, need for help, collaboration with others, number of attempts. This group of characteristics is strongly linked with the domain model (e.g., math, language, physics), in which domain structure, knowledge components or item categories are represented in such a way that there is a logical sequence, an order or structure in the learning materials. To demonstrate this presumed link between the domain model and gameplay characteristics, for instance, supportive information can be offered in the game that contains a rule to be learned, which may or may not be used by learners. Or, difficult items may require more cognitive processing and may thus lead to longer reaction times without this being an indication of inappropriate gameplay.

For example, a rule can be set which specifies that a minigame should be completed within 2 minutes, or that an item in a minigame should be answered within 45 seconds. If this is not the case, then an opponent wins the minigame and gets all the points. If a player does not answer the items correctly or does not answer them in time and hence loses the minigame, then an action agent or a question can appear, prompting the player to solve some remediation items or to provide support (e.g., game skills support or domain support). Another issue to take into account is the "gaming the system behavior" (Baker et al., 2008). If, based on analyses of a player's behavior, the probability of such behavior is high (e.g., if a player continuously clicks without moving the cursor), then specific messages can be offered to the player in order to penalize or to discourage such behavior.

5. Game states and a framework for player-centered adaptivity

Instead of creating simple rules that associate a system's reaction with a certain measurement of a player or gameplay characteristic, it is possible to create game states. Game states are inferred by using the logged values of relevant variables (as discussed in the previous sections) and modeling them into an overall game state. More specifically, game states of players can be developed by a combination of player and gameplay characteristics. In order to infer game states, a probability model can be developed, in which several characteristics (nodes) and links between those characteristics (links) are drawn. Each link can be given a certain weight, depending on the initial game states, on prior player characteristics, on the goals of the educational game, etc.

Figure 1 provides a theoretical framework for an adaptivity model in which player and gameplay characteristics are incorporated.

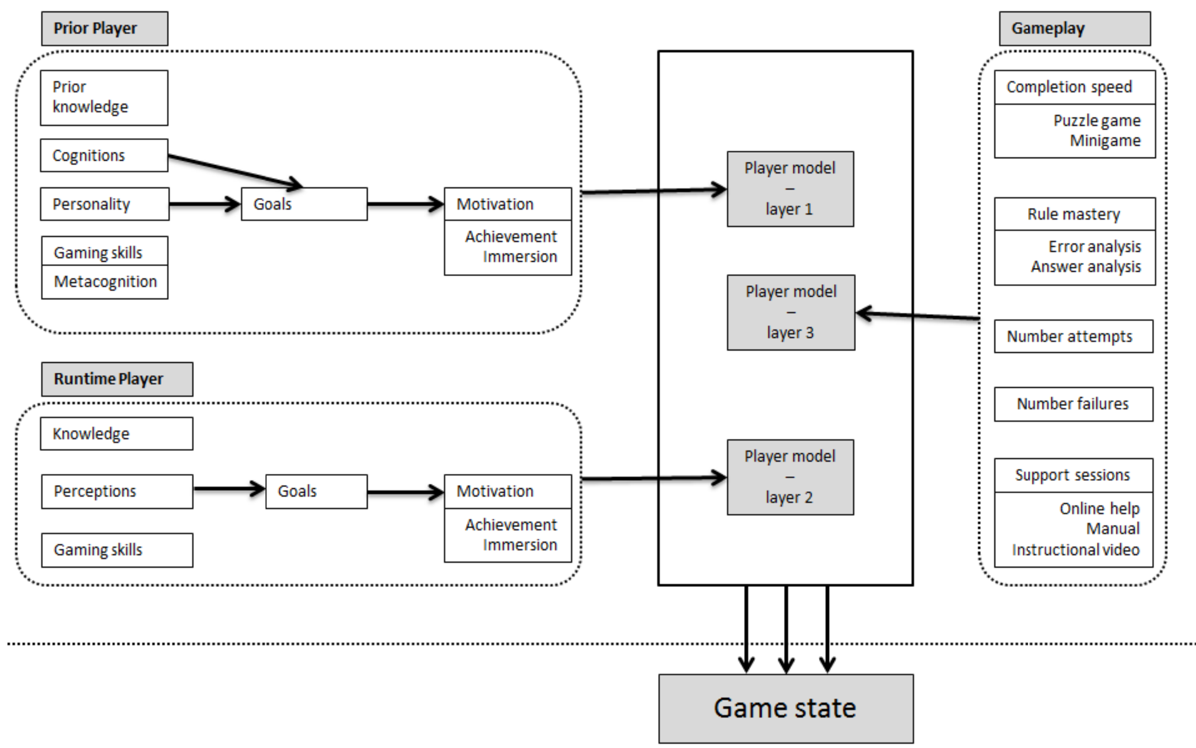

Figure 1. A multi-layered player-centered adaptivity model

Each group of characteristics (prior player, runtime player and gameplay) form a separate layer within the player model. Not all layers or characteristics need to be included in the player model in order to create a game state. What is included in the player model in order to infer a game state is up to the instructional designer, game designer, teacher, goals of the game.

The group of prior player characteristics comprises a player's prior knowledge of the domain, cognitions and beliefs about the game(play), personality characteristics and gaming skills. Also, a player's goals (like mastery or performance goals) can be inferred and form the input for defining the motivation of players. This first group of player characteristics form the first layer of the player model.

A second layer consists of runtime player characteristics or characteristics that are measured during gameplay. In this layer a player's (increasing) knowledge can be taken into account, with perceptions of the game (like perceived usefulness and ease of use) and gaming skills (like ability to run fast through the game, mouse and keyboard skills) as well. Part or all of these runtime player characteristics can be entered in the second layer of the player model.

The third and last level of the player model is formed by the gameplay characteristics or the features that define the interaction between game and player. For example, the speed of completing exercises or quests in the game can provide input on both domain knowledge and gaming skills; gaming skills can also be identified by the number of attempts a player needs to complete a quest or by the number of failures that is made. Also, in a game where multiple exercises are offered to players, answering options can be included that, if selected by the player, reflect errors in the player's domain knowledge and reasoning. Hence, error analyses can help to identify the gaps in a player's domain knowledge, if any. Finally, as many games also offer help in the form of online chat, an in-game manual or instructional videos, the use of these help function can also be used as input to form a more complete view of a player's need for help and support during gameplay.

All three levels of the player model (prior player, runtime player and gameplay characteristics) comprise observations made before and during gameplay. The observations that are deemed to be relevant as defined by game designers and instructors can be used separately or jointly to form game states. For example, a player can be attributed with a gamestate of "gaming behavior", indicating that a player is misusing the system's features in order to complete a quest or exercise faster or more easily (Baker et al., 2008). This misuse, often accompanied by low motivation and presence of performance goals, can be shown during gameplay by continuously asking for hints or taking the easiest way to complete quests. Gaming behavior could thus be identified by looking up whether a player has a low motivation, shows performance goals, has specific perceptions about the gameplay (e.g., obligatory learning rather than experiencing fun), shows a high finishing speed but with a high number of failures.

Table 1 summarizes three examples of game states. It is the final gamestate that will serve as input for the target of adaptation, of what should be adapted.

Table 1. Example of three game states from which adaptive instruction in educational games can be offered

Gamestate	Measurements
Gaming behavior	2*(low motivation) + presence of performance goals + suboptimal perceptions + high finishing speed + high number of failures
Competitive	2*(performance goals) + 2*(gaming skills) + high finishing speed[a]
Not-engaged	Negative cognitions + negative goals + low motivation + high finishing speed

[a] *If feasible, a distinction can be made between completion speed (i.e., time for finishing the game with result = "win") and finishing speed (i.e., time for finishing the game without taking into account the result).*

6. Game states as input for adaptive instruction

Once a gamestate has been defined, instructional and game designers must decide the target(s) of adaptation. This has also been labeled as the recipient(s) of adaptivity (Lopes & Bidarra, 2011) because the targets or recipients are elements in the game environment that can be adjusted based on the inferred game state for an individual player or a group of players. Targets or recipients of adaptivity include:

(a) *Gameplay mechanics* (e.g., adjusting the speed of opponents, make tokens more easily accessible);

(b) *Game scenarios and quests* (e.g., simplify quests, provide more elaborated feedback if the player's goal is to maximize learning; provide tips and tricks through an action agent if the player's goal is to avoid failure);

(c) *Game worlds and objects*(e.g., adjust the difficulty level of mini games; add more non player characters (NPCs) such as a supportive NPC for beginning learners or players or a challenging NPC for advanced learners or players; adjusting game scenarios based on a player's learning style);

(d) *(Action) feedback.* Because of the possibilities of technology and the premises of game design, feedback in digital games is invariably immediate (Prensky, 2001, p. 121; Rigby & Ryan, 2011, p. 20), although it may also be complemented with delayed feedback (Rigby & Ryan, 2011, pp. 23-25). Also, feedback in games may be more consistent than feedback in classroom environments. A second salient characteristic of feedback in games is that it has an affective orientation. This applies both to *positive feedback* (feedback after "correct" actions or responses) and to *negative feedback* (feedback after "incorrect" actions or responses). In games, positive feedback is often excessive and has been called *juicy feedback*, i.e. "*tons of cascading action and response for minimal user input [… which makes] the player feel powerful and in control of the world, and it coaches them through the rules of the game by constantly letting them know on a per-interaction basis how* *they are doing*" (game designer Kyle Gabler cited in Juul, 2010, p. 45). Such positive feedback serves to reinforce learning and to reward for achievement (Becker, 2007). Further, also negative feedback in games takes into account the learner's affective state. Here, the notion of *failure state* is worth considering. Failure states are phases in the game in which the player fails, followed by some message from the system that indicates the failure in a compelling way (Swink, 2010). Game designers often spend significant effort on the design of failure states, as they expect players to fail repeatedly and thus to spend a lot of time in such states – and have fun. For game designers, it is important that players find these states a) interesting, so that they understand why they failed, and b) compelling, so that frustration is lowered (Purushotma, Thorne, & Wheatley, 2008; Swink, 2010). In other words, failure states are designed to help "learning from mistakes" (Prensky, 2001, p. 159), but in an enjoyable way. A third element that deserves mentioning is the representation of feedback. In most games, feedback comes via action (Prensky, 2001, p. 159). Feedback may also involve narrative elements, as it presents "*an opportunity to wrap a story around the situation*", and its function is to make the experience more immersive (Aldrich, 2005, p. 25). Fourth, in high-end multimedia & simulation games, game-based feedback can come in various forms and combinations: as text, graphics, sound, or as video, through visual meters and head-up displays, or it can be tactile. In short, and on a more practical level, for learners who already master a specific problem, more simple feedback (FT, correct/wrong feedback) might suffice, whereas learners who still have not yet fully acquired a specific problem need to be given more detailed/elaborate feedback. In addition to providing the most appropriate type of cognitive feedback, adaptivity algorithms in educational games might also consider giving affective feedback to learners who might lack motivation. Affective feedback focuses on stimulating, encouraging, motivating the learner. This can be done by an agent/avatar that pops up in the learning environment and says things like "Well done" or "You did very well, you've reached you goal!". However, we need to take into account the findings of research which has consistently shown that praise, punishment and extrinsic rewards have been the least effective for enhancing achievement, and have also undermined intrinsic motivation. One fairly recent empirical study on micro-adaptive interventions in an educational game reported that appropriate and meaningful feedback was superior to "neutral" (non-individualized but meaningful) feedback and "inappropriate" (non-individualized and unsuited) feedback both in terms of the learning and gaming measures taken (Kickmeier-Rust, Marte, Linek, Lalonde, & Albert, 2008). The researchers concluded that adaptive feedback not only facilitated learning but also learners' attitudes and their sense of immersion. However, the sample size of the study seems quite small, and moreover, it is not clear how attitudes or immersion were measured, which raises methodological issues.

7. Conclusion

In this paper, two dimensions of adaptive instructions have been discussed: sources of adaptivity and targets of adaptivity. The sources include player and gameplay characteristics and serve as input for creating game states. Based on a player's game state, it can be defined what elements in the gaming environment will be adjusted (i.e., targets or recipients of adaptivity). Although source and target of adaptive instruction can be considered as crucial components in adaptive instruction, the framework for adaptive instruction, as described in Vandewaetere and Clarebout (2013), includes also the time of adaptation (i.e., static or dynamic); method of adaptation (i.e., learner-controlled; system controlled; shared control) and context of adaptation (i.e., device, time, place). It should thus be noted that the topics covered in this paper only represent a small, although significant part of the broader framework of adaptive instruction.

With the theoretical framework presented in this paper, researchers on educational games now have a tool that can be used to draw new research lines such as(a) the creation of game states based on measurements of player and gameplay characteristics; (b) the experimental validation of the game states; and (c) the effectiveness of adaptive educational games. Future research in educational technology can compare the effectiveness of different methods to create gamestates and how many characteristics that need to be entered in order to provide reliable gamestates that can serve as input for adaptation. This all needs to be evaluated in the light of costs and benefits on several levels: the development and implementation of such adaptive gameplay by game developers; the ease of use for tutors or school teachers; and the relevance for providing high-level personalized gameplay. After all, we should bear in mind that gameplay, and its accompanying flow is very personal (Csikszentmihalyi , 19979; Inal & Cagiltay, 2007).

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