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ABSTRACT

In this article, we present the design outline of a context-aware interactive system for smart learning in the STEM curriculum (science, technology, engineering, and mathematics). It is based on a gameful design approach and enables "playful coached learning" (PCL): a learning process enriched by gamification but also close to the learner's activities and emotional setting.

After a brief introduction on related work, we describe the technological setup, the integration of projected visual feedback and the use of object and motion recognition to interpret the learner's actions. This enables rapid feedback which is particularly important for correct habit formation. In a second step, we discuss gamification methods and analyze which are best suited for the PCL system. Emotion recognition, a major element of the final PCL design not yet implemented, is briefly outlined.

Author Keywords

Context-aware learning; playful coached learning; gameful design; smart learning; gamification; STEM

ACM Classification Keywords

H.1.2 User/Machine Systems: Human factors, Software Psychology; H.5.1 Multimedia Information Systems: Artificial, augmented, and virtual realities; H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous; I.2.1 Computing methodologies: games; K.3.1 Computer Uses in Education: Computer assisted instruction.

INTRODUCTION

Playful approaches in learning are not new but lie at the core of pedagogy. Learning and play have always been interwoven, and with methods like edutainment and serious games, education has tried to find good integrative solutions.

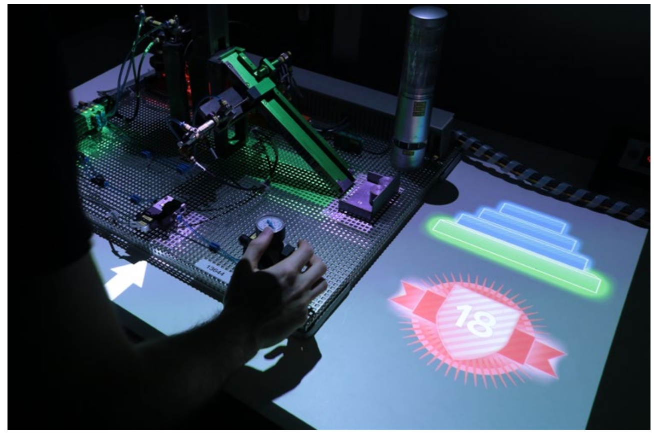

Figure 1. The playful coached learning (PCL) system projects instructions, feedback and gamification elements directly into the learner's workspace.

However, on the technology side, the domain is conservative and much of the potential generated by HCI does not find its way into mainstream education.

At the same time, most students embrace the digital world; they love to build machines or robots, especially if these can be connected to their smartphones. This is even truer in the STEM curriculum (science, technology, engineering, and mathematics) where technology often is both the means and the end. However, in exercises or lab scenarios there will often be a student-teacher ratio of at least 10 to 1. This makes it hard for teachers to distribute their support adequately. Students would love to get more feedback, and most of them would appreciate more time with hands-on exercises. Especially when looking at informal learning, it is clear that STEM involves a strong practical-skills element, for example in the large genre of "How-to" YouTube videos.

On this background, we see a need for a context-aware system that supports both educators and students. We present the design of a system for playful coached learning (PCL), which combines playful design with an automated solution for tutored learning. This potentially opens up smart education to a wider group of people and tasks. Thus, PCL can improve the quality of both academic and job-related education in the STEM fields.

After a brief introduction on related work, we describe the technical setup of the system. In a second step, we present a selection of gamification methods well suited for PCL.

RELATED WORK

In this section, we focus on gamification and the use of motion recognition system to support gameful designs.

Gamification is an umbrella term for "the use of video game elements to improve user experience and user engagement in non-game services and applications" [7]. However, gamification also is a new term for an established process. Gamified systems have been called "edutainment" in the nineties, and later "serious or applied games". Especially in the context of education, gamification already has a long tradition. A meta-analysis of serious games [21] provides a good overview of definitions, comparison criteria for serious games in education and an overview of 39 studies.

After its long-term application, there are several established techniques of gamification. A common example are points and badges. Points are the simplest form of quantifying a user's success and error rate: right answers or correct actions earn points. For wrong answers, the score may be reduced. Badges are a less granular form of rewarding users – they can be awarded if certain thresholds of points are reached, or for the completion of specific tasks like the 100th post or 10,000 accumulated flying miles.

However, both examples relate to extrinsic motivational factors, so their effects wear off rather quickly. If the points and badges have no additional value, inside the application or outside, users will get bored of acquiring them [15]. Furthermore, it has been established that there are specific player types, e.g. in the famous model by Bartle [3]. However, collecting rewards only suits one type: the achiever. Amongst others there are players who preferably want to interact with other players and develop in-game relations (social players), others who want to discover every last inch of a virtual world (explorers) or players who just immerse themselves in the game, play a role and escape the real-life problems (immersion players) [22]. In the section "gamification methods", we explore which forms are best suited for the PCL solution.

There are very helpful examples of gamification outside of the domain of education. Especially after the success of the Microsoft Kinect depth sensor, gamification quickly spread to areas where human body motions are of great importance: the most obvious application is in health and sports. Gamified solutions in this area, where controlling movements is essential, are often called "games for health" or "exergames" [4].

With a design study on "industrial playgrounds" in 2012 [10], gamification also extended into the area of production environments. In this domain, the combination of projection and motion recognition [8] allowed to create an augmented and gamified industry workplace (Figure 2). Several studies show that the system can be of help for both impaired and unimpaired workers [11,12]. Recent work evaluates the suitability of different gamification designs [13], including the pyramid method discussed later in this work.

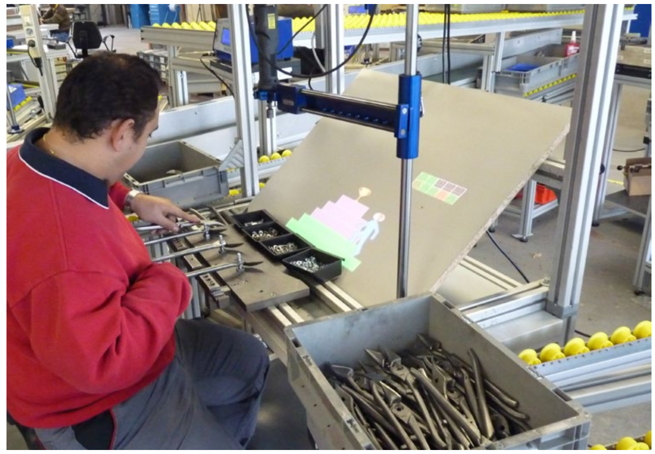

Figure 2. The augmentation and gamification of production workplaces created the technological expertise required to gamify learning processes in the STEM fields.

The combination of motion recognition, projection and gamification in the area of health and production were the pre-requisite for a new development: context-aware learning environments start to spread to the educational domain. While gamification in general is well established in education, both the use motion recognition to analyze learned behavior in real-time and the use of projection to give immediate user-specific situated feedback are new.

SYSTEM DESIGN

On a technological level (Figure 3), PCL is a context-aware system which uses motion recognition to identify the learner's actions (e.g. molding a wire to a circuit board) and object recognition to control the results (e.g. checking if the solder joint is at the right position).

Figure 3. The design of the PCL system is based on three components: user, tools & actions, and artifact / workpiece.

The depth sensor allows creating a 3D representation of the working area and the users, especially hands, arms, and face. The PCL system recognizes and interprets the learner's actions and triggers the gamified presentation of hints and instructions, typically by in-situ projection, tangibles, and audio.

System Components

In the following table, the system's design is shortly described based on the three most important components:

Component	Tracked Elements	Tracking Aims
User / Student	*Final version:* - facial expressions - eye gaze - posture / body cues *Design and lab phase:* - brain activity - skin conductance	- fatigue - stress - distraction - motivation - emotional state (approximation)
Artifacts / Work pieces / Tangibles	- movements of hands - state of objects in 3D - object surface profiles	- task progress - task performance
Tools / Actions	- movements of hands - tremor	- predict errors - allow stealth mode

Table 1. Table captions should be placed below the table. We recommend table lines be 1 point, 25% black.

A system that aims to become a "coach" needs to learn a lot about the **User**. The user's emotions are tracked by facial expression analysis, eye gaze analysis and an interpretation of body posture and body cues like gestures. In the design / lab phase, we will additionally track brain activity and galvanic skin conductance to come closer to the "ground truth". Of course, such intrusive forms of physiological measurement are not part of the final system. Such measures are ethically challenging; they are discussed in the section "Future Work: Emotion Recognition".

The measurements regarding **Artifacts and Work Pieces** to determine task progress and performance are less critical, as educators regularly obtain such measures in the standard teaching processes. A potential advantage of PCL is that the user can be guided without the pressure of an exam or even the presence of any human of superior hierarchy. Tangible objects in the work area can serve as projection areas where users can view tutorials or look at instructions on demand, without the need to ask around and potentially embarrass themselves.

Finally, the component **Tools and Actions** is partially redundant with the other components. However, its important aim is to predict what the user will be doing. Late error detection is a major source of frustration and requires complex diagnosis. The system will feature a **"stealth mode"** that intervenes when errors are about to be made and, In addition, the stealth mode reduces stress (a barrier to learning) as well as the perceived risk, the "what if I mess it all up?" feeling that blocks creativity and self-learning. This is required for early error detection and the "stealth mode", where the system just observes the actions without giving any feedback unless a costly error would occur, e.g. when soldering makes an error permanent. Depending on the user's level of guidance, the system will offer potential solutions. Analyzing tremor and manner of movement in this component supplements the facial analysis; it might even allow assessing the user's skillfulness: tentative or clumsy versus confident and fluid movements.

System Feedback and Scaffolding

The system's setup enables rapid feedback. This is particularly important for correct habit formation. Unless the human instructor is watching at the moment an error is made, it will be considerably later until it will be discovered: either the instructor comes round and punts out the mistake, or the error is revealed when future steps become problematic. Either way the bad technique will have had a level of learning that is hard to undo.

This "erroneous behavior" is similar to the way that if you take a wrong turning and realize it, the next time you often make the same mistake as you have learned the incorrect route. This has already been found to be important in mathematics teaching: the computer algebra system *WebFrog* merely told students if their steps were incorrect, i.e. they did not correspond to the original formula [19]. Later versions offered further advice, but even the most basic system performed better, as measured by post session learning, than a teacher going round the class for the same period of use. Immediate automatic feedback on its own was more effective than delayed but rich human feedback on its own. It is even harder to unlearn wrong habits for physical actions, especially once these have become muscle memory.

Effectively the **Tools and Actions** guidance is a form of **scaffolding**, which – as described 40 years ago – allows the student to "solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts" [20]. This approach has become a central feature in constructive learning theory. In HCI literature, the classic Training Wheels interface [5] is an example of this principle, where users were constrained in menu choices, avoiding dangerous or confusing expert options, while still being able to see the complete menus.

However, a critical aspect of a scaffold is that it should eventually not be needed. This is why PCL needs the **stealth mode** that only offers really critical aid. This handing over stage, is perhaps most difficult. It could be a simple on/off, or offer more staged withdrawal. For example, a powerful way to teach reading skills is through reading together. In this a parent reads with their child, both saying the words simultaneously. Over time as the child is able to read the simpler words, the parent tries to lag slightly, so the child says the words first, but if challenged by a difficult word, the adult naturally speaks the word filling in the gap. Over time, the adult is needed less and less.

Note how this differs from listening to the child reading and only intervening if the child puzzles over hard words and fails. The reading together method allows far more complex books to be tackled and does not interrupt the enjoyment, allowing the child to learn higher-order reading comprehension skills.

For PCL, similar methods can be employed – for example, the aids could be gradually delayed until not needed. The emotion recognition (discussed in the final section) is particularly important here, as this could naturally adjust this small timing delay in response to levels of sensed stress.

After discussing the system setup and its feedback potentials with respect to guidance, in the next section we take a look at gamification methods suitable for PCL.

GAMIFICATION METHODS FOR PCL

In our understanding, for a successful application in a learning environment, gamification needs to employ mechanisms that address several player types and have a long-term motivational pull [18]. Does that mean we are "Beyond Points, Badges and Leaderboards", as the subtitle of the book *Actionable Gamification* [6] suggests? Should we not apply these methods in the PCL system? No – they are useful strategies that engage learners right from in the first moments of a gamified application [16]. A comparison of common gamification methods shows that points and badges are among the most accepted [14].

In the PCL design presented here, we incorporated a small choice of gamification methods, which are suited to fulfil the demands of several player types and address both intrinsic and extrinsic motivational strategies [9]. We have identified the following methods as well suited:

Points

As mentioned before, points are a simple and straightforward method of rewarding users for correct steps, and measuring success – a high user score indicates a good performance during the game. The downside of points is their potentially abstract nature. However, in a learning environment, users are used to points – e.g. in exams or even on a larger scale when gathering "credits" during academic studies, like the famous "ECTS" (European Credit Transfer and Accumulation System).

For some learners, the point system could result in stress, e.g. when they compare their scores to others. However, especially for these students PCL can be designed to reduce stress. For example, it enables a learner to repeat a difficult task several times without human observers; only the best score can be added as a "record".

Levels

A player's level typically correlates directly with the "experience points" (XP) scored. At certain amounts of accumulated XP, the level, or rank, is increased. This concept is employed in nearly all role playing games where higher levels often allow to visit new areas, to use new skills or items. Due to the ubiquitous nature, the concept of levels is highly familiar to almost all younger learners.

Within PCL, the system can easily be employed: in STEM (and in other fields where manual work is important), the very core of acquiring skills is practising them. In correspondence, the nature of levels is that they are achieved by continuously accumulating points over time, rather than achieving goals within a certain time limit. In PCL, levelling is based on gained points and thus on minutes spent practising; this takes the competition out of this part of the gamification system.

Badges

In opposition to points and levels, badges can also be awarded for "real" performance, i.e. achieving a specified result (e.g. molding all wires on a circuit board) within a given time (e.g. in less than 5 minutes). However, badges can also be awarded if important major continuous achievements are reached, e.g. 10 hours of practicing time. This flexibility makes badges an excellent instrument for motivation in the PCL system. They can even be graded for both variants:

- performance: bronze level for completing a board in under 5 minutes, silver level for completing it in less than 4.5 minutes etc.
- continuous: bronze level for 5 hours of practicing time, silver level for 10 hours etc.

Leaderboards

Leader boards lists the scores of players engaging in the same type of application context, for example all students in one class in descending order. Such transparency would of course be stressful for less successful learners. Laundry workers at Disneyland called leaderboards comparing their speed an "electronic whip" [2].

In PCL, only the top 10%-20% of learners will be shown on the leaderboard. This keeps the amount of frustration in the lower-ranking players at a minimum level.

Also, variations of the leaderboard can be used to help those earlier in the learning journey, or who do not respond to more public displays. One option is to have complete "ladders" showing everyone, but pseudonomised, that is with persistent game handles. AlSugair designed such a system called *AnswerPro* [1]: a learning motivation framework that recognizes psychological and social needs of students, building on self-determination theory [17]. It allowed students to assess themselves relative to peers. Simpler alternatives may just say where the student ranks among peers without any explicit form of listing (e.g. "congratulations, you are now in the top 50% of students").

Pyramid

The pyramid method is adapted from gamification approaches developed for industrial production and discussed in the "Related Works" section. It is a performance-oriented method of gamification and can be activated by the learner.

The basic idea is that each step of the pyramid represents an activity in a linear process. Each step starts in dark green and over a given time period changes its color over yellow to orange and finally red (Figure 4). The times can be either the previous means (so the user is competing against himself or herself) or training times pre-determined by the instructors.

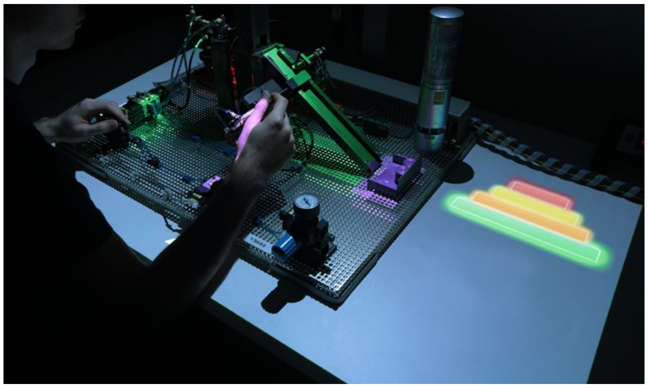

Figure 4. The pyramid method in the PCL prototype. In this case a four-step process was completed. The visualization clearly shows that the speed decreased continuously.

As each step of the pyramid is colored separately, the completed pyramid represents a completed task (e.g. the circuit board) with a color mix, which immediately gives an impression of both the overall performance and the "weak spots" which require additional practice.

Extra Life

Next to adapted established forms of playful design and the pyramid approach, PCL will also include a more experimental performance-oriented method: the concept of extra lives. In Jump and Run games or platformers, a common method is to assign the player an initial amount of lives at the start of the game. When the character in the game dies, a life is lost but the player can still continue playing at the same point. Only when all lives are lost, the game is over and starts from the beginning. Some actions, like completing a level without dying, can earn additional lives.

In the PCL system, we will offer an extra life mode, which can be activated by the learner. If this mode is active and the system needs to "step in" to prevent the learner from making a mistake, a life is lost. However, this mistake is not counted in the final score, as long as there are lives left. For error-free sessions, the user gains additional lives.

The appeal of this concept is that if a learner has a bad day, or is temporarily distracted, he or she is not instantly put off by just one mistake. This will raise the acceptance of both the coached learning and the stealth mode. Furthermore, it can lead to a more concentrated effort, to collect more extra lives with flawless performances, to compensate for a loss.

Real-world connection

As pointed out, learning already has a strong real-world connection: we learn not for school, but for life. However, many students appreciate additional incentives. The transparency achieved by applying the gameful design to the learning process allows combining "in-game" concepts with real-world concepts easily. An example is rewarding the first place of the leader board or every person who achieved level 10 with a gift like a book token.

FUTURE WORK: EMOTION RECOGNITION

PCL envisions reaching the competence of a dedicated teacher (with enough time for the students). Thus, it is not enough to add gamification elements. It does not suffice to know the learning history and it does not even suffice to be aware of a student's actions. A good coach must also consider a student's emotions. While context-aware guidance and playful design help to raise overall mood and motivation, this remains a one-way street unless the PCL system can interpret emotional cues.

We are aware that the required level of observation is problematic. For this reason, we integrated ethical experts in the design team. Also, we aim to store all emotional data only temporarily in a "black box", with the contents being automatically erased after each session (as recommended by Korn in 2014 [11]). Nevertheless, we believe that in educational settings, only non-invasive techniques such as facial expression will be accepted for obtaining emotional cues. Even for this feature, the emotion analysis will need to be black-boxed; that is, emotion records will be neither externally accessible during a learning session nor saved afterward. However, during the ongoing research and design phase of the PCL system, we use biosignals like galvanic skin response (GSR) or encephalography (EEG) as additional data sources [7].

While the aim is that the emotional cues from these invasive data sources and the non-invasive facial expression analysis will converge, we are well aware that reliable emotion recognition is highly dependent on advances in the field of affective computing. In this area, PCL will require the most development effort to create a pleasing user experience.

CONCLUSION

In this article, we presented the outline for the design of a context-aware interactive system based on a gameful design approach. The intended result is "playful coached learning" (PCL): a learning process enriched by gamification but also close to the learner's activities and emotional setting.

In many ways, PCL is intended to be an automatic coach. If a system becomes aware of the user's real-world interactions, this strongly contributes to the user's sense of interaction and exchange. We described the system's technical design, focusing on the feedback and scaffolding techniques. We discussed how real-time feedback can prevent learning erroneous behavior.

We presented in detail the gamification methods we selected for use in PCL: points, levels, badges, leaderboards, the pyramid, extra-life and pointed out the importance of a real-world connection. As these interventions are designed for transparent and simple feedback, they are much closer to the physical activity and generate less distraction.

However, while context-aware guidance, scaffolding and playful design help to raise overall mood and motivation, this remains a one-way street unless a system can interpret emotional cues – this has only been sketched and remains a task for future work.

We think a system that directly assists users in practical learning tasks will help increase the overall quality of education. Additionally, it will reduce the stress for trainers and educators who must teach large groups with limited time resources. A PCL learning experience that incorporates the emotional cues of the student will help to raise motivation and contribute to practice and skill acquisition.

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