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Successful implementation of user-centered game based learning in higher education: An example from civil engineering

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Abstract

Goal: The use of an online game for learning in higher education aims to make complex theoretical knowledge more approachable. Permanent repetition will lead to a more in-depth learning.
Objective: To gain insight into whether and to what extent, online games have the potential to contribute to student learning in higher education.
Experimental setting: The online game was used for the first time during a lecture on Structural Concrete at Master's level, involving 121 seventh semester students.
Methods: Pre-test/post-test experimental control group design with questionnaires and an independent online evaluation.
Results: The minimum learning result of playing the game was equal to that achieved with traditional methods. A factor called "joy" was introduced, according to [Nielsen, J. (2002): User empowerment and the fun factor. In *Jakob Nielsen's Alertbox*, July 7, 2002. Available from http://www.useit.com/alertbox/20020707.html.], which was amazingly *high*.
Conclusion: The experimental findings support the efficacy of game playing. Students enjoyed this kind of e-learning.

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"A good game should be easy to learn, but difficult to master"

Nolan Bushnell, the founder of Atari, Inc.

1. Introduction

Many projects have investigated the use of Internet and multimedia in Higher Education. Visualizations and animations are especially appropriate in engineering education (Ebner & Holzinger, 2003). Animations are generally more effective than comparable graphics in situations other than conveying complex systems, e.g., for real time re-orientation in time and space (Tversky, Morrison, & Betrancourt, 2002). For example, research supports the hypothesis that animation facilitates learning when it presents fine-grained actions that static graphics do not present (Thompson & Riding, 1990). However, animations are often too complex or too fast to be accurately perceived; continuous events are also often conceived as sequences of individual steps. Careful use of interactivity can overcome these disadvantages (Schnotz & Grzondziel, 1999). Learning is an active process on the part of the learner and knowledge, as well as understanding, can only be constructed by the learners themselves (Clark, 1994; Gagne, 1965; Holzinger, 2002a, 2002b; Wees, 1971). However, memorable educational experiences should not only be enriching and transformational but also enjoyable (Shneiderman, 1998). Lastly, an important factor is the motivation of the students (Bloom, 1976; Holzinger, 1997; Holzinger, Pichler, Almer, & Maurer, 2001; Logan & Gordon, 1981).

The project iVISiCE (interactive Visualization in Civil Engineering) was founded (Ebner & Holzinger, 2002) to assist students of Civil Engineering during their learning process by using visualizations and animations.

The students considered interactivity extremely important (Holzinger & Ebner, 2003; Kettenanurak, Ramamurthy, & Haseman, 2001; Kozma, 1991). Consequently the next phase of the project was to develop Interactive Learning Objects (ILO's), which require that the students independently operate this kind of visualization interactively using a didactically optimum method. The didactical concept chosen accords with the instructional design of Gagne (Gagne, 1965; Gagne & Briggs, 1979; Holzinger, 2002a, 2002b). The interaction design has been realized in close accordance to Preece, Sharp, and Rogers (2002) and Shneiderman (1998). Soon the idea of building a Game Based Learning (GBL) module emerged.

2. Background theory

2.1. Game based learning

Despite the widespread recognition of the advantages attached to the use of games in elementary and secondary education, we found little evidence of their use in higher education.

Game Based Learning (GBL) is similar to Problem Based Learning (PBL), wherein specific problem scenarios are placed within a *play* framework (Barrows & Tamblyn, 1980). Previous experience in the field of Medicine highlighted the usefulness of this approach (Baroffio, Giacobino, Vermeulen, & Vu, 1997; Carlile, Barnet, Sefton, & Uther, 1998; Morrison, 2004; Schmidt, 1983). Subsequently, PBL can provide a Student Centered e-Learning (SCeL) approach (Motschnig-Pitrik & Holzinger, 2002).

Also, games include many characteristics of problem solving, i.e. an unknown outcome, multiple paths to a goal, construction of a problem context, collaboration in the case of multiple players etc., and they add the elements of *competition* and *chance*. However, online games provide the additional possibility of building teams of players who are geographically scattered. The benefits of learning through games are numerous (Mann et al., 2002), and games are often closer to simulating real life experiences than more traditional educational media. This allows the students to immerse themselves in a realistic simulated setting without the fear of real life consequences, which – although not the necessity it is in Medicine – is also very useful in Civil Engineering.

2.2. What makes a computer application fun to operate?

Fantasy can be very important in creating intrinsically motivating environments. However, these must be carefully chosen to appeal to the target audience. Usually, user interfaces are designed for tools and not games but much of the motivation for using a system depends on the user's motivation to achieve an external goal.

In cases where the external goal fails to provide the necessary motivation, particularly where the subject of the exercise is routine and boring, a game-like interface can be useful in making the activity enjoyable. For any activity to be challenging, it needs to have a goal with an uncertain outcome. The end-users need a performance feedback in order to judge how well they are achieving their goals.

Malone (1980) summarized three essential characteristics for computer games to answer the question of what makes a computer application enjoyable to operate: challenge, fantasy and curiosity. Whereas, challenge and curiosity are important aspects in the iVISiCE Internal Force Master (IFM) game (see Section 2.3), fantasy is only relevant in adventure games, in Civil Engineering education it could possibly be contra productive.

2.2.1. Challenge

These characteristics must encompass a clear goal and provide performance feedback regarding the end-users' imminence to accomplishing their goal. The outcome of reaching the goal must be uncertain (not predictable). An adjustable difficulty level is helpful in this respect and must include scorekeeping.

2.2.2. Curiosity

Any activity designed to provoke the end-users curiosity must provide an optimal level of informational complexity (Piaget, 1951). This includes the use of randomizing to add variety without making the tools unreliable. Malone (1980) emphasizes that environments should be neither too complicated nor too simple with respect to the end-user's existing knowledge.

In any case, they must be novel and surprising while remaining comprehensible. In general, an optimally complex environment will be one where the end-user knows enough to be able to anticipate what will happen but where their expectations are sometimes wrong.

2.3. The concept of the online game: internal force master (IFM)

The concept of the online game Internal Force Master (IFM) is to provide a motivating computer game, wherein players need to identify the right solution in order to win. Even players not willing to learn may do so indirectly; by playing and remembering the correct solution – and we consider that the learning effect is much higher in an emotional and motivated situation, such as when playing a game (Brehm & Self, 1989; Holzinger & Maurer, 1999; Holzinger et al., 2001; Kettenanurak et al., 2001).

In order to test the efficiency of incidental learning methods and to measure the degrees of motivation, certain demands have been placed on the learning module:

- *Background:* The target group must be able to identify with the contents of the game. The learners must become annoyed when they are loosing – this leads to a higher degree of motivation;
- *High score and time limits:* A lose–win situation also seems to be necessary for high motivation. Difficult time limits should induce the learner to play again and again. Repeated playing leads to more in-depth learning, according to (Skinner, 1954);
- *Simplicity and clarity:* Controlling the game flow without the need to read endless instructions is a further step for motivating to play; this is directly connected with
- "ease of use", which includes the possibility of adjusting the game for different levels of expertise; a precondition of every successful game (Malone, 1982; Nielsen & Mack, 1994; Shneiderman, 1998).

2.4. Content of the game

The content of the game is based on the Theory of Structures. Before starting *any* project, each Civil Engineer must calculate the internal forces of the statically determined or undetermined system. Only after completing this calculation ist the design of, for example, a structural concrete (wood, steel, etc.) beam possible.

The correct calculation of the internal forces is *the* precondition for all further measures – consequently this is the basic and most important content of the whole study of Civil Engineering. In the same way that it is necessary for every pilot of an airplane to train with a flight simulator, the calculation of the internal forces is necessary for every student of Civil Engineering. This learning process appears to take a long time.

The calculations necessary for the practical work of a Civil Engineer can be done today by using computers. However, since the development of specific software it has been possible to solve very complex problems within a very short time. Consequently, today the job of an engineer is to make the right input and to *check and supervise* whether the output is correct. The principal task of a stress analyst is to secure the exact estimation of the solution and to provide the right graphics and lines of the internal forces.

It can be summarized that the purpose of our Internal Force Master was to help learners in the field of static determinate systems by training them to distinguish carefully the correct internal forces from wrong solutions *within an extremely short time*. Because of the ready availability and the encouraged use of computers, the students, of course, do not practice the calculation by themselves and they are allowed to analyze structures on the computer, which exceeds their level of learning.

2.5. What is the internal force master (IFM)?

Internal Force Master (IFM) can best be described as educational game software specifically designed and developed for the study of Civil Engineering. The aim was to build an online computer game, which provides a high level of fun *and* motivation.

The game was programmed and designed with Macromedia Flash. As we have already shown (Holzinger & Ebner, 2003), Flash is one of the primary tools for creating content for the World Wide Web. Using the programming language Action Script it has been possible to program end-user dependent interactive tools and a specially designed online game. One of the main advantages of Flash is the very compact file size – which is a precondition for usable online distribution. Furthermore, only one browser plug-in is necessary – the only method which is acceptable for a heterogeneous environment at a university. We preferred Flash because of the possibility to quickly develop usable visualizations of the engineering models.

The design of the game started in January 2003 with an extensive survey and study of the material (see Fig. 1). The development team consisted of a Civil Engineer (domain expert) with experience in e-learning and didactics; an expert on Human–Computer Interaction (HCI), who managed the User-Centered Development (UCD) approach (Holzinger, 2002a, 2002b; Holzinger, 2003) and the application of rapid prototyping (Holzinger, 2004); and Flash experts as well as students, whose responsibilities included drawing the examples.

Bearing in mind the didactical concept, the software has been separated into so-called *main screens*. These main screens consist of:

- *The start screen (Fig. 2):* A description of the content and the necessary tasks are shown on this screen. Further, a definition is given of the colors used and the directions are specified. At the

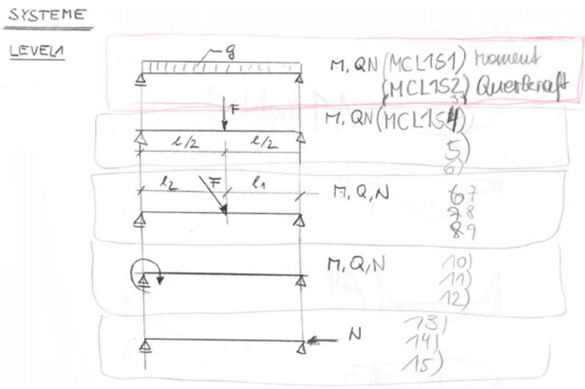

Fig. 1. One of the first sketches during the design.

Fig. 2. The start screen.

Fig. 3. The info screen.

end, there is the possibility for the player to choose an identifying name (nickname), which will appear in the high score lists after the game, and to choose the difficulty level.

- *The info(rmation) screen (Fig. 3):* This screen provides an overview of the online game. The learning goals are described and also the necessary previous knowledge. The concept of this kind of meta-information is the same as we used during the development of our Interactive Learning Objects (ILO) and is a result of extensive usability studies including methods such as thinking aloud, cognitive walkthrough and video analysis (Ebner & Holzinger, 2003). The concept of the screens are also shown and their connection to each other.
- *The main screen (Fig. 4):* This screen is the "game" screen, here the game takes place. On the top of the screen a static determinate system is presented and directly underneath three possible solutions. Within the available time (represented by a decreasing red bar) the learners must click on the correct solution – to reach the next example, question or problem. This is repeated throughout the game.

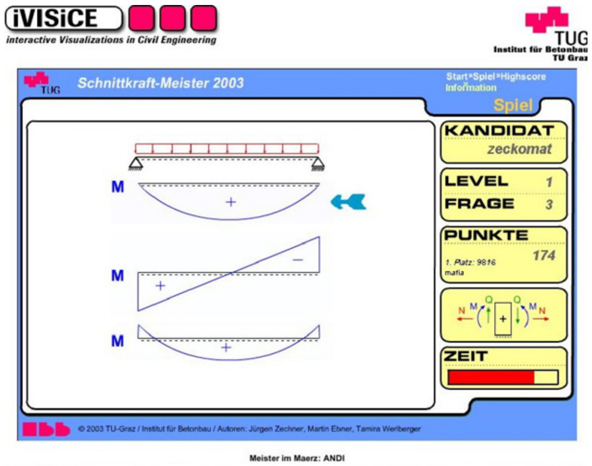

Fig. 4. The main screen.

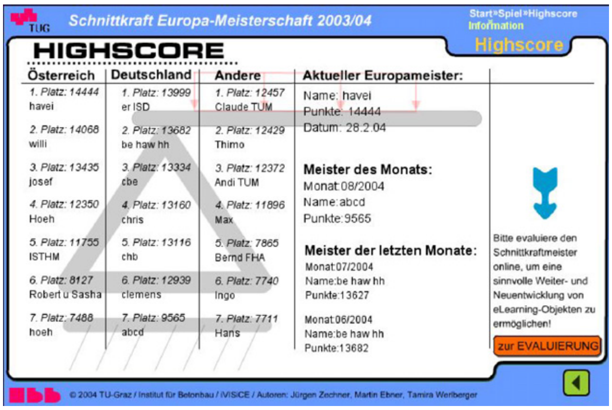

Fig. 5. The high score list.

- The game is separated into 6 levels, which differ in the degree of difficulty of the examples and in the available time for solving them. The examples change with every new game and the possible solutions are randomized. This is required to counteract the decreasing motivation effect. By developing a large number of examples and possible solutions, the danger of a player attuning to the first level too rapidly is avoided.
- *High score list (Fig. 5):* After each game the high score lists are presented. If the players' points are high enough their nickname is registered together with their result. The lists are separated into a *best of the month* and a *current high score* list.

The development of the game took place from January 2003 to October 2003. In accordance with Nielsen (Nielsen, 1993, 1994; Nielsen & Levy, 1994; Nielsen & Mack, 1994), usability principles were used to help adopt the game for the target group in the best possible way.

One of the crucial factors during the design and development of the game was the User Centered Design aspect, which was extended to a User Centered Development. During the early design phase, we were able to locate the end-users' problems (Holzinger, 2004). Nielsen and Molich (1990) found that the optimum number of participants in such usability oriented development cycles were three to five per user class and that a larger number showed diminishing returns (Nielsen & Molich, 1990).

During our development, five students of Civil Engineering played the game for the first time at the institute and participated in extensive usability tests. For example, students remarked that the clicking area was too small; other students expressed that they did not know how many points they had obtained for the actual level and how many levels were implemented, etc.

In summer 2003, an online test phase was established, including a larger number of students, to check the performance and to identify any remaining bugs of the software.

New static systems were also implemented to enhance the variation of each level. For example, one of the last feedbacks received, mentioned that there was no possibility of getting into the high score list during a short online presence and that this was very frustrating for the students.

The findings of all these usability methods have been taken into account for the re-design of the end product, which began in November 2003.

3. Research

3.1. Questions and hypotheses

Some of our Questions included:

Q1: Does this game lead to similar/equal learning results as the traditional methods? Are there any disadvantages for the learners who used this game?
Q2: Does playing this game on a voluntary basis feel similar to incidental learning?
Q3: Is there a difference in the *enjoyability factor* between the online population and the participants in the lecture?
Q4: Is good usability a precondition for the acceptance of the game?
Q5: Does the game lead to increasing motivation to play again?

On the basis of our questions we formed hypotheses, which we carefully proved by using the game Internal Force Master (IFM):

H1: Playing this game leads to at least equivalent learning results as the traditional method – there is no disadvantage for the learners who used this game.
H2: Playing this game on a voluntary basis feels like incidental learning.
H3: The online participants and those attending the lecture experience a difference in the *enjoyability factor*.
H4: Ease of use is a precondition for acceptance of the game.
H5: The game environment and the high score lead to increasing motivation – the learner plays the game again.

All these hypotheses are independent of the end-user profile, this means that there is no difference between an Internet expert and a novice.

3.2. Experimental design, setting and demographics

The game was tested during the Structural Concrete course at the University of Technology of Graz from November 2003 to January 2004. Parallel to the students of Civil Engineering, the game was made accessible to the public. Especially universities in Austria, Germany and Switzerland (the German speaking countries) were invited to participate. We designated this community the *online population*.

In the end there were three groups:

- students who attended the lectures/courses and *played* the game on a voluntary basis ("playing students");
- students who attend to the lectures/courses and did not play the game ("non playing students");
- online participants who only played the game ("online population").

As method, we used the pre-test/post-test experimental control group design with questionnaires for the participants of the lecture. As shown in Fig. 6, the students ($N = 47$) had to complete the pre-test during the first hour of the lecture.

They had to draw five internal forces of static determinate systems, which were also the content of the game (Fig. 7). After the first test the game was presented to the students and lecturers and it was emphasized that the tool can be used for free and on a voluntary basis via the Internet. Two months later, at the end of the lecture(s), the post-test took place (Fig. 8). The principles and tasks were the same as in the pre-test but there were some additional questions concerning the research. $N = 60$ students took part in the post-test.

Parallel to the pre-test/post-test experimental control group, there was the possibility of playing the game and evaluating it online, independent of the participants of the lecture(s). To date, 108 evaluations from the research period have been received.

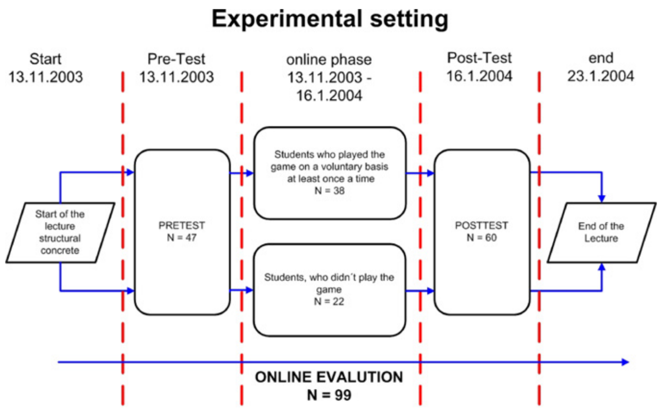

Fig. 6. The experimental setting; please notice that the students took part on a voluntary basis.

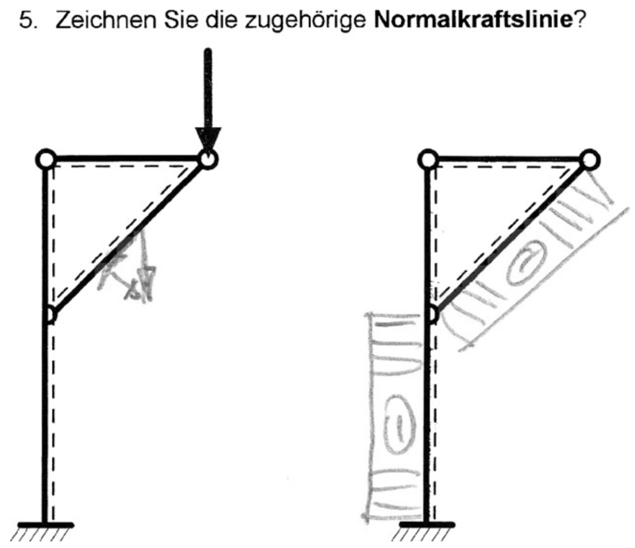

Fig. 7. Example: this problem was stated within the pre-test.

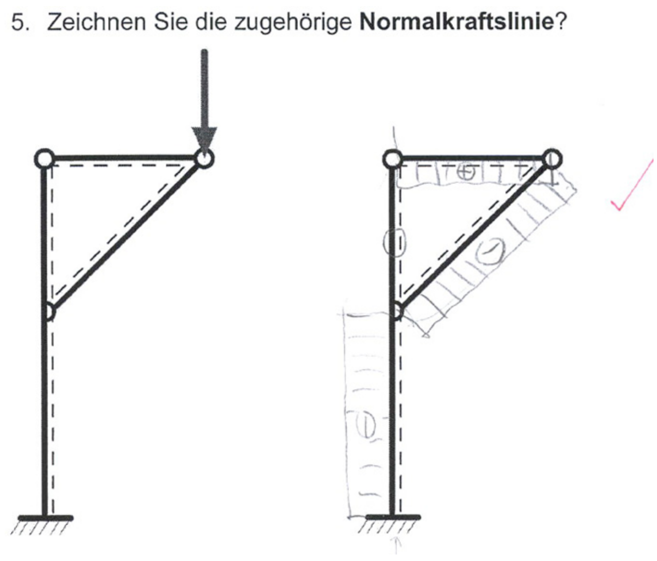

Fig. 8. Example: this problem was stated within the post-test.

We must point out that *all* of these investigations took place *within a real-life setting*, including all its disadvantages; subsequently we were not able to gather data similar to a laboratory setting. All participants took part in the experiment on a voluntary basis. Although this lack of control necessarily weakens our ability to generalize from the data, the chosen method has the strength of ecological validity. The difference between the number of participants in the pre- and post-test is also well founded on the real-life setting. Both populations are a randomly variety and strongly according to the whole student personnel.

The voluntary aspect of these experiments was one of its strengths. If the students would have been forced to take part, the results would probably have been less successful.

4. Findings

4.1. Statistical methods

We used Mann–Whitney tests, Chi-Quadrat and Wilcoxon tests, as well as the correlation coefficient according to Spearman for measuring statistical correlations (Christensen, 2001).

5. Results

H1. Playing this game leads to at least equivalent learning results as with the traditional way – there is no disadvantage for the learners who used this game.

The students of the lecture had been tested with the aid of the pre-test/post-test method. They had to draw five internal forces of static determinate systems.

The solution to such a problem is unique and so the test result was defined by counting the correct solutions. 0 meant that all examples were wrong and 5 that all examples were correct (see Fig. 9).

In Table 1, all the results of the tests have been listed.

The main conclusion is that there has been an obvious increase of the "correct solution" factor. Before the lecture the students had drawn, on average, three correct internal forces. At the end of the three months the average had increased to 4.

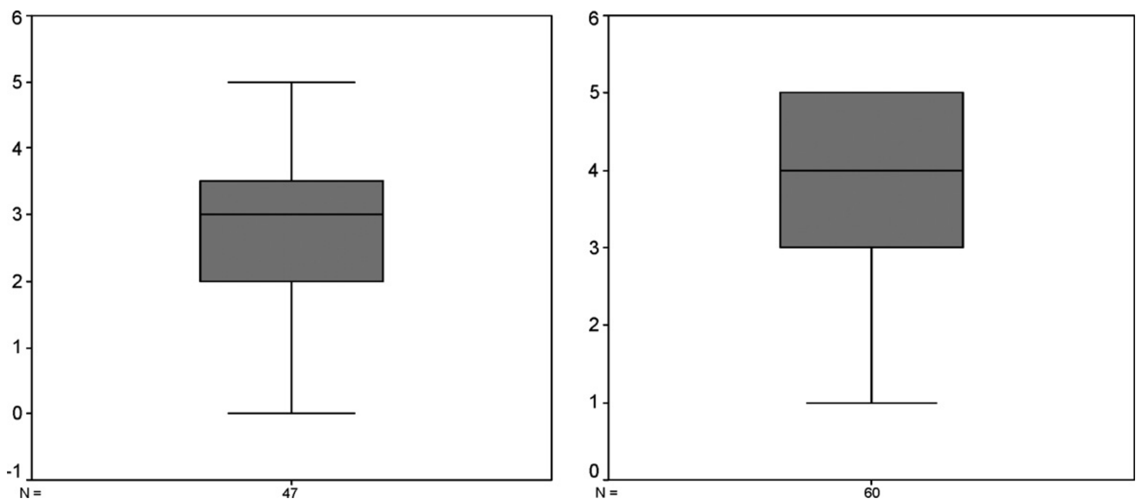

Fig. 9. Result of the pre-test and post-test.

Table 1
Result of the pre-test and post-test

Test	N	Mean	Standard deviation	Median
Pre-test	47	2.72	1.425	3
Post-test	60	3.95	1.08	4
Post-test, playing students	38	4.03	1.026	4
Post-test, non playing students	22	3.82	1.18	4

Further, the group who completed the post-test was split into two groups: Those who played the game during their learning process ("playing students") and those who never played it ("non-playing students"). The result shows that there is no difference between the two groups, which shows that the "playing students" group had the same learning result as the group who learned by the traditional method.

H2. Playing this game on a voluntary basis feels like incidental learning.

This questionnaire deals with incidental learning. On a scale from 1 to 5 the players had to answer whether they feel *provoked* about their drop out and will play once more or not. The result is listed in Table 2. 1 means "yes, I fully agree" and 5 "no, I do not agree."

The mean of 2.12 shows that the majority of the players cannot believe that they are losing. It should be further mentioned that nearly all (98%) played the game once more.

Collected comments of the evaluation showed further hints for incidental learning. Some players commented: "After I chose the wrong solution, the correct answer should be shown by the game, because I want to learn it" (7 statements), "Some comments as to why this solution is the wrong one would be useful" (5 statements) and "a game mode without time limits for beginners could be helpful" (3 statements).

H3. The online participants and those attending the lecture experience a difference in the enjoyability factor.

The next question concerned the so-called *enjoyability factor* (Knuth & Cunningham, 1993; Malone, 1980; Raskin, 2000).

NB: We called this factor preliminarily "fun factor", but *enjoyablility* factor seems to be more appropriate.

First the players had to point out whether they enjoyed playing the game (1) or not (5).

It is interesting that both groups (online group and the participants of the lecture) like playing, which can be seen in Table 3.

The following Chi-Quadrat-test turned out a significant correlation ($p = 0.033$) between both groups. Altogether our theory has been confirmed, that the players like to play the game.

Table 2
Results of the question: "An early drop out dares me to play once more"

Test	N	Mean	Standard deviation	Median
All (evaluation)	141	2.12	1.15	2

Table 3
Results of the question: "Playing the game is fun"

Test	*N*	Mean	Standard deviation	Median
Online evaluation	103	1.48	0.756	1
Post-test	38	2.39	1.264	2

Table 4
Results of the question: "I have no problem playing the game"

Test	*N*	Mean	Standard deviation	Median
All (evaluation)	141	2.27	1.52	2

Table 5
Results of the question: "I think that the implementation of the high score was absolutely necessary"

Test	*N*	Mean	Standard deviation	Median
All (evaluation)	141	1.92	1.19	1

H4. Ease of use is a precondition for acceptance of the game.

The students had to answer a further question concerning the ease of use. On a scale of 1–5, 1 meant the usability of the game was good and 5 meant that it was not.

The Mean of 2.27 (Table 4) was surprisingly good because there was no help function on how to play and no hints on how to navigate through the game.

This result confirms also all assumptions that good usability leads to an intuitive correct handling.

H5. The game environment and the high score lead to increasing motivation – the learner plays the game again.

The last question concerned the problem of motivation. During the programming of the game it was been mentioned that a high score is absolutely necessary for a game. Now we wanted to know if the players also thought so – does the availability of such a list lead to more frequent playing? On a scale of 1–5, 1 meant that the implementation of the high score is necessary, 5 that it is not.

The result of Table 5 pointed out that the high score list is definitely necessary. Moreover, the tracking of the players showed that some players played the game repeatedly. This is a definite sign that this person will achieve a higher score in the lists.

6. Discussion

6.1. Learning result

In H1 it has been shown that playing the game leads – at least – to an equal learning result as with the traditional method.

Further, H3 pointed out that the fun factor for playing is higher than expected. The combination of these two hypotheses means that there is a positive effect caused by Game Based Learning because the learners enjoyed playing the game during their learning process and achieve at least an equal result.

6.2. Motivation

A high level of motivation is often a prerequisite for success. There is a high probability that learning will not be successful if there is a lack of motivation. Therefore we needed some tactics to motivate the students to play the game repeatedly. First the game environment and the design should help to keep the students playing. Further, of course, the content of the game and also the implementation of the high score lists should be motivating factors.

In H5 it could be shown that almost every learner played the game again. The motivation of the players was high enough for another run.

6.3. Incidental learning

In the traditional method of classroom learning, intentional learning dominates. With the aid of the game incidental learning is possible because the primary intent of the players is to accomplish the game rather than to learn. According to Lankard (1995, available online: http://www.ericfacility.net/ericdigests/ed385778.html) incidental learning occurs when it is unexpected – a byproduct of other activities, such as, for example, playing a game.

Although the students played the game on a voluntary basis – and their primary intent was of course *not* to learn – after playing the game once, a learning process occurred.

In H2 it could be shown that the players discovered their mistakes and felt motivated to play again. Incidental learning is also characterized by discovering something while in the process of doing something else: *serendipity*.

Further the collected comments of the users have shown that, after the students failed, they thought about the correct solution and wanted to learn why the selected answer was wrong. Their statements pointed out an ongoing learning process on the part of the players.

6.4. Usability

In H4 the usability of the game was tested (Holzinger, 2005). "As simple as possible" – was demanded of the end-user group because things which can be used without reading complex instructions first are used more enthusiastically than others. The paradigm was that *no help tools* should be necessary to explain how to play the game correctly. Every student of Civil Engineering has to be able to play the game intuitively.

According to Nielsen (1994), the ease of use must be judged a first priority, because difficult technology defeats the goal. The success of games including: Tetris, Moorhuhn, Yeti (some examples from a long list) is in their simplicity of use. Everyone must be able to play without reading any instructions – or running through preparatory installation routines.

Furthermore, curiosity is the learning motivation, independent of any goal seeking (Malone, 1980). Computer games can evoke a learner's curiosity by providing environments that have an optimal level of informational complexity (Piaget, 1951).

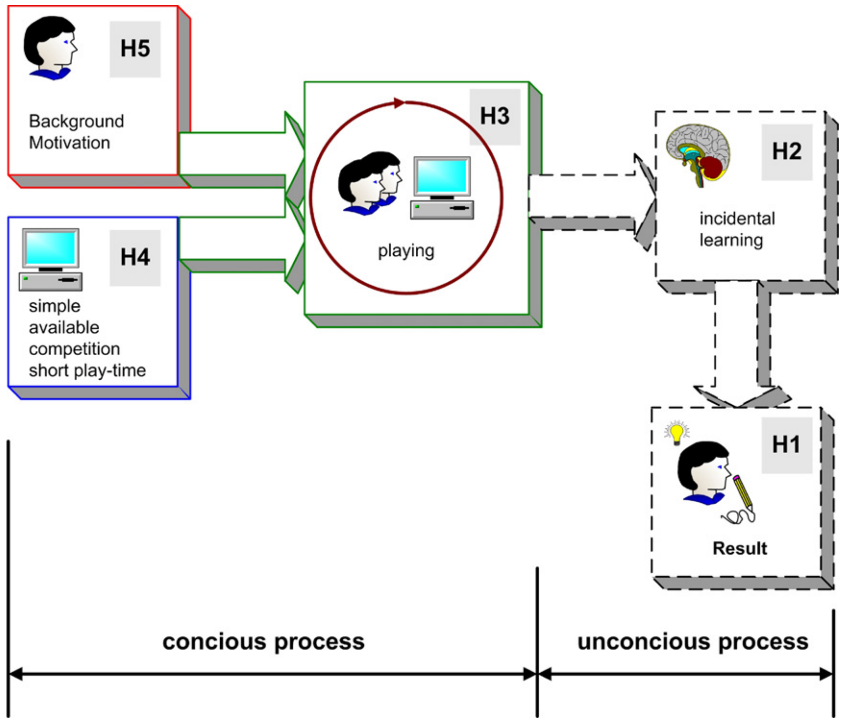

Fig. 10. Conclusion. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In other words, the user-centered design at the beginning of the project helped to design a game that was neither too complicated nor to simple, with respect to the learners existing knowledge.

7. Conclusion

We can definitely state that at the beginning of the lectures the students liked learning with the Interactive Learning Objects but after a short time a surprising effect was noticed: Learning, whether with or without a multimedia tool, is hard and subsequently motivation decreased.

It was therefore necessary to create something, which combined the following attributes: motivating the students and providing software, which is enjoyable and does *not* feel like learning. This idea was the incentive for the development of the Internal Force Master (IFM) which is an educational game for the study of Civil Engineering at Master's level. In Fig. 10 the results of our research are summarized. Each research question aims to be a part of the whole process – the specific role is displayed and explained.

8. Conscious–unconscious

First, it has been shown that the players have to be motivated to play the game. This fact includes the necessity of the game being useful to the target group (background). The results confirmed these assumptions. The next box (blue) presents the necessary characteristics of the game – it must be simple, availability must be independent of time and place, playable within a short time and with the appearance of a competition. As a result of these facts, we showed that students played the game for a considerable time – and that they like to play, as hypotheses 3 showed. The use of the internet-based tool led to incidental learning as hypothesis 2 expressed. The important result which came out of this work is stated in hypothesis 1 – the learning result of the playing group is *at least* equivalent to the group who learned using the traditional method. Due to this fact, we point out, that gambling can be a new, modern and also useful method in the education of Civil Engineers at masters' level of a university.

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References

Baroffio, A., Giacobino, J., Vermeulen, B., & Vu, N. (1997). The new preclinical medical curriculum at the university of Geneva: processes of selecting basic medical concepts and problems for the PBL learning units. In S. Ajja, V. Cpm, R. Jj, & V. Afw (Eds.), *Advances in medical education* (pp. 498–500). Dordrecht: Kluwer Academic Publishers.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: an approach to medical education (Springer series on medical education)*. New York: Springer.

Bloom, B. S. (1976). *Human characteristics and school learning*. New York: McGraw-Hill.

Brehm, J. W., & Self, E. A. (1989). The intensity of motivation. *Annual Review of Psychology, 40*, 109–131.

Carlile, S., Barnet, S., Sefton, A., & Uther, J. (1998). Medical problem based learning supported by intranet technology: a natural student centred approach. *International Journal of Medical Informatics, 50*(1–3), 225–233.

Christensen, L. B. (2001). *Experimental methodology*. Boston, London, Toronto, etc.: Allyn and Bacon.

Clark, R. E. (1994). Media will never influence learning. *Educational Technology, Research and Development, 42*(2), 21–29.

Ebner, M., & Holzinger, A. (2002). e-Learning in civil engineering: the experience applied to a lecture course in structural concrete. *Scientific Journal of Applied Information Technology, 1*(1), 1–9.

Ebner, M., & Holzinger, A. (2003). Instructional use of engineering visualization: interaction-design in e-learning for civil engineering. In J. Jacko & C. Stephanidis (Eds.), *Human–computer interaction, theory and practice* (Vol. 1, pp. 926–930). Mahwah, NJ: Lawrence Erlbaum.

Gagne, R. M. (1965). *The conditions of learning*. New York: Holt, Rinehart and Winston.

Gagne, R. M., & Briggs, L. J. (1979). *Principles of instructional design*. New York: Holt, Rinehart and Winston.

Holzinger, A. (1997). Computer-aided mathematics instruction with mathematica 3.0. *Mathematica in Education and Research, 6*(4), 37–40.

Holzinger, A. (2002a). Multimedia basics. In *Learning. Cognitive fundamentals of multimedial information systems* (Vol. 2). New Delhi: Laxmi. Available from www.basiswissen-multimedia.at.

Holzinger, A. (2002b). User-centered interface design for disabled and elderly people: first experiences with designing a patient communication system (PACOSY). In K. Miesenberger, J. Klaus, & W. Zagler (Eds.), *Lecture notes in computer science* (Vol. 2398, pp. 34–41). Berlin, etc.: Springer.

Holzinger, A. (2003). Experiences with user centered development (UCD) for the front end of the virtual medical campus Graz. In J. A. Jacko & C. Stephanidis (Eds.), *Human–computer interaction, theory and practice* (pp. 123–127). Mahwah, NJ: Lawrence Erlbaum.

Holzinger, A. (2004). Application of rapid prototyping to the user interface development for a virtual medical campus. *IEEE Software, 21*(1), 92–99.

Holzinger, A. (2005). Usability engineering for software developers. *Communications of the ACM, 48*(1), 71–74.

Holzinger, A., Ebner, M. (2003). Interaction and usability of simulations and animations: a case study of the Flash technology. In *Proceedings of: Interact 2003* (pp. 777–780). Zurich.

Holzinger, A., Maurer, H. (1999). Incidental learning, motivation and the tamagotchi effect: VR-Friends, chances for new ways of learning with computers. In *Proceedings of: computer assisted learning, CAL 99* (p. 70). London.

Holzinger, A., Pichler, A., Almer, W., Maurer, H. (2001). TRIANGLE: a multi-media test-bed for examining incidental learning, motivation and the tamagotchi-effect within a game-show like computer based learning module. In *Proceedings of: educational multimedia, hypermedia and telecommunication 2001* (pp. 766–771). Tampere, Finland.

Kettenanurak, V., Ramamurthy, K., & Haseman, W. (2001). User attitude as a mediator of learning performance improvement in an interactive multimedia environment: an empirical investigation of the degree of interactivity and learning styles. *International Journal of Human–Computer Studies, 54*(4), 541–583.

Knuth, R. A., & Cunningham, D. J. (1993). Tools for constructivism. In T. M. Duffy, J. Lowyck, & D. H. Jonassen (Eds.), *Designing environments for constructive learning* (pp. 163–188). Berlin: Springer.

Kozma, R. (1991). Learning with media. *Review of Educational Research, 61*, 179–201.

Logan, F. A., & Gordon, W. C. (1981). *Fundamentals of learning and motivation* (3rd ed.). Dubuque, IA: Brown.

Malone, T. W. (1980). What makes things fun to learn? Heuristics for designing instructional computer games. In *Proceedings of: 3rd ACM SIGSMALL symposium and the first SIGPC symposium on small systems* (pp. 162–169).

Malone, T. W. (1982). Heuristics for designing enjoyable user interfaces: lessons from computer games. In *Proceedings of: conference on human factors in computing systems* (pp. 63–68). Gaithersburg, MD.

Mann, B. D., Eidelson, B. M., Fukuchi, S. G., Nissman, S. A., Robertson, S., & Jardines, L. (2002). The development of an interactive game-based tool for learning surgical management algorithms via computer. *The American Journal of Surgery, 183*(3), 305–308.

Morrison, J. (2004). Where now for problem based learning? *The Lancet, 363*(9403), 174.

Motschnig-Pitrik, R., & Holzinger, A. (2002). Student-centered teaching meets new media: concept and case study. *IEEE Journal of Educational Technology and Society, 5*(4), 160–172.

Nielsen, J. (1993). *Usability engineering*. San Francisco: Morgan Kaufmann.

Nielsen, J. (1994). Enhancing the explanatory power of usability heuristics. In *Proceedings of: SIGCHI conference on human factors in computing systems: celebrating interdependence* (pp. 152–158). Boston, MA.

Nielsen, J., & Levy, J. (1994). Measuring usability: preference vs. performance. *Communications of the ACM, 37*(4), 66–75.

Nielsen, J., & Mack, R. L. (1994). *Usability inspection methods*. New York: Wiley.

Nielsen, J., Molich, R. (1990). Heuristic evaluation of user interfaces. In *Proceedings of: CHI 90* (pp. 249–256). Seattle, WA.

Nielsen, J. (2002). User empowerment and the fun factor. In *Jakob Nielsen's Alertbox*, July 7, 2002. Available from http://www.useit.com/alertbox/20020707.html.

Piaget, J. (1951). *Play, dreams, and imitation in childhood*. New York: Norton.

Preece, J., Sharp, H., & Rogers, Y. (2002). *Interaction design: beyond human–computer interaction*. New York: Wiley.

Raskin, J. (2000). *The humane interface: new directions for designing interactive systems*. Boston, MA: Addison-Wesley-Longman.

Schmidt, H. G. (1983). Problem-based learning: rationale and description. *Medical Education, 17*(1), 11–16.
Schnotz, W., & Grzondziel, H. (1999). Individual and co-operative learning with interactive animated pictures. *European Journal of Psychology of Education, 14*, 245–265.
Shneiderman, B. (1998). Relate-create-donate: a teaching/learning philosophy for the cyber-generation. *Computers and Education, 31*(1), 25–39.
Skinner, B. F. (1954). The science of learning and the art of teaching. *Harvard Educational Review, 24*(2), 86–97.
Thompson, S. V., & Riding, R. J. (1990). The effect of animated diagrams on the understanding of a mathematical demonstration in 11- to 14-year-old pupils. *British Journal of Educational Psychology, 60*, 93–98.
Tversky, B., Morrison, J. B., & Betrancourt, M. (2002). Animation: can it facilitate? *International Journal of Human-Computer Studies, 57*(4), 247–262.
Wees, W. R. (1971). *Nobody can teach anybody anything*. Toronto: Doubleday.