The principles of the implementation of gaming technologies in a blended learning environment in a technical university

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Abstract
We formulated seven general principles for authors for the implementation of educational gaming technologies in an engineering university based on descriptions in the literature. The principles are ordered by their "importance" for the quality of the game model and systemic influence on the student. These principles provide conditions for mastering educational material by resolving problematic game situations. Conclusions are made about the effectiveness of the methodology based on the principles. It was found that the role of the emotional component in the educational process increases, the students' independent work is stimulated, the quality of teaching increases, and the teacher is freed from routine control operations.
Keywords
gamification, blended learning, engineering education, motivation, psychological comfort, student involvement

Принципы реализации игровых технологий в условиях смешанного обучения в техническом ВУЗе

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Аннотация

На основе обобщения описанных в литературе игровых приёмов в обучении мы сформулировали семь авторских принципов реализации учебных игровых технологий в техническом ВУЗе. В качестве примера их реализации приведена автоматизированная учебная установка (АУУ) для изучения устройства, программирования и отладки аппаратных и программных средств микроконтроллеров. Соответствие АУУ сформулированным принципам оценено количественно с помощью метода экспертных оценок (учебная технология – 43%, методика – 32%, резерв совершенствования – 25%). Соподчинение принципов между собой рассмотрено по критерию «важности» для качества игровой модели и по критерию системного влияния на обучаемого. Отмечено, что без целеполагания как осознанной цели участие субъекта в игре превращается в формальность. Также без обеспечения условий психологического комфорта, в первую очередь, без снижения уровня тревожности личности девальвируются последующие усилия по повышению мотивации к учёбе. Важное место мы отводим потребности в значимости – осознаваемому и нерефлексируемому учёту игроком-обучаемым неизбежности публичной оценки успехов и неудач и связанных с этим самооценки, мотивации (гордость или стыд) и, как следствие, – качества последующей самоподготовки. Эти три принципа определяют степень вовлечённости субъекта в игру. Дальнейшее усиление вовлечённости определяется, во-первых, эффективностью обратной связи как «эмоциональным подкреплением» очередного шага обучаемого по сценарию игры, а во-вторых, эффективностью внешнего управления как дозированной рациональной помощи в продвижении игрока. Вышеперечисленные принципы обеспечивают условия для освоения учебного материала посредством разрешения игровых проблемных ситуаций. Сделан вывод об эффективности методики, опирающейся на предлагаемые нами принципы: повышается роль эмоциональной составляющей в учебном процессе, активизируется самостоятельная работа обучаемых, повышается качество обучения, преподаватель освобождается от рутинных контролирующих операций.

Ключевые слова: игровые методы обучения, смешанное обучение, инженерное образование, мотивация, психологический комфорт, вовлечённость студентов в игру.

Introduction

Since 2020, the system of higher education across the world has found itself, along with traditional challenges, facing new ones generated by the COVID-19 pandemic (Andreev et al. 2020a). One of the most important tasks of education, which has always been and continues to be in the focus of attention of many researchers and educators, is how to preserve and develop motivation of students in the learning process as a means of self-education and self-control (Andreev et al. 2020c; Andreev et al. 2020d). Games are well-known for creating an atmosphere of psychologically comfortable conditions for students (Fotaris et al. 2016; Wiggins 2016). The game brings satisfaction not only with the result, but also with the process itself. Here the emotional sphere of the personality is involved due to the positively colored experience of novelty and success. The effect of the game is enhanced by the possibility of choosing goals, showing activity, and receiving immediate feedback to one's actions. The learning process with elements of a game (gamification) satisfies both the cognitive motives and needs, and social needs of success, status, and self-esteem of the individual. But when using gamification, participants in the educational process must always be careful not to cross the line beyond which the game turns from a means of achieving an end into just a means of entertainment and pastime (Andreev et al. 2020b). Empirical evidence of the positive impact of gamification on the academic performance of engineering students is presented by Díaz-Ramírez (2020). Urh et al. (2015) concluded that in e-learning in higher education, gamification makes it possible to achieve higher satisfaction and motivation, as well as greater involvement of students in the process of acquiring new knowledge, skills and abilities. At the same time, it is important to clearly define the goals, rules, techniques and mechanisms of gamification. Khaleel et al. (2020) also concluded that gamification had a positive influence by

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increasing the degree of student involvement in the study of curriculum disciplines. A conceptual model for inclusion game elements into e-courses of higher education is proposed by Zaric et al. (2017). This is an extension of the Felder-Silverman Learning Style Model (Felder and Silverman 1988).

The training of university teachers for the active use of gamification in the educational process is discussed by Vanduhe et al. (2020). A considerable number of works are devoted to the study of contribution of gamification to the progress of students in engineering fields of study, taking into account the specifics of the education system in individual countries (Panis et al. 2020; Henning et al. 2017; Oliver 2017). Campillo-Ferrer et al. (2020), and Varannai et al. (2017) considered the possibility of the effective use of the popular online platform Kahoot as a creative and effective tool to support gamification through its integration into the educational process of a higher educational institution. It was proposed to use gamification more actively, based on the use of attractive digital platforms. The problems associated with the introduction of mobile applications of gamification into the educational process, as well as possible ways of more effective use of such technologies, were investigated by Al Amri & Almaiah (2020). Theories of motivation in relation to gamification are analyzed by Gilyazova and Zamoshchanskii (2020). It is concluded that the internal motivation of the game participant plays a key role in gamification. A huge positive effect from the integration of gamification into the didactic context in higher engineering education is demonstrated by the results of the study by Söbke (2019).

Vinichenko et al. (2019) noted that there are obstacles to the gamification of the educational process. These are the complexity of gamification and a high risk of not achieving the desired result. In this regard, the authors of that study recommend a selective gamification of individual processes, with a focus on educational and research activities.

The research review shows that gamification and the use of elements of game learning technologies have a positive impact on the academic performance of students in engineering fields. However, there is a significant risk: it is important to ensure that the game does not turn into a means of entertainment and pastime, for which it is necessary to maintain the internal motivation of the participants in the game.

It should be noted that modern pedagogical technologies, including gamification of the educational process, are based on fundamental results obtained by various scientists over many years of research. For example, many modern pedagogical technologies are based on the Galperin theory of stage-by-stage formation of mental actions and concepts (Galperin 1966; Galperin 2017) The theory of stage-by-stage formation of mental actions goes back to the earlier views of Vygotsky on development of the higher mental functions (Vygotsky 1983). Theory of the stage-by-stage formation of mental actions and concepts is analyzed and studied by Talyzina (1993). Skinner made a significant contribution to the development of learning methods based on the techniques of behavior modification developed in behaviorism (see, for example, Skinner 1953). It is worth mentioning the significant contribution to development of the behavioral theories of learning by such scientists as Thorndike (Jones and Robinson 2012) and Watson (Malone 2017). It should be noted that modern pedagogical technologies are very extensive and diverse (see, for example, Jang and Chen 2010; Yalçın and Yayla 2016; Deci and Ryan 2008; Tejedor et al. 2018; Abeysekera and Dawson 2015; Goedhart et al. 2019).

The purpose of this research was to develop principles for the implementation of educational game technologies for the formation of psychologically comfortable conditions for the educational activity of students in higher technical educational institutions. In addition, it examined the development of principles for implementation of educational gaming technologies at a technical university, establishing their relationships themselves and assessing their compliance between the technological environment and elements of gaming technologies.

Materials, approaches and methods

The research used observation, questioning, testing, pedagogical experiment, data processing methods and modeling to provide a comprehensive study of the role of gaming technologies in higher education.

A system approach was applied, which allowed consideration of a single complex of interconnected and interacting elements various aspects of gamification in the system of university students training, Principles of the synergistic approach, according to which the complex open systems are considered as self-organizing, were used to study development by gamification of student's competencies, necessary for their future successful professional activity.

Pedagogical observation was carried out in the period from 2010 to 2021 for third-year students of "Control in technical systems" of the Chuvash State University (n>200). All the participants were informed about the research

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and informed consent was obtained from all individual participants included in the study. No other interests of the study participants were affected.

Results and discussion

We formulated the following principles that must be followed when using game techniques in teaching:

1. *Goal-setting: the connection between the part and the whole.* Interest in learning does not determine a vague desire to do something, but a conscious, actualized goal. The student must form an attitude that the educational and gaming activities being carried out are the most important for him, dominating over everything else at a given point in time. The student must have a holistic view of the set of related tasks, understand the system logic of everything that is being performed. The organizer of the lesson should provide measure of the degree to which private goals are achieved.
2. Feedback: "reinforcement" of the gamer's actions.
    a. *Positive reinforcement.* The student's next step in the game is assessed according to the scenario ("yes/no" or points), and the current rating is also determined (distance traveled, points). The reward should be appropriate for the level of performance and effort involved. It is about the use of teaching techniques (praise, reward for success or for diligence). The importance of this phenomenon results from the greater intensity and lower predictability of the results of educational research work (ERW), carried out in a game form. In addition, errors should be treated as feedback, assessing the degree of progress rather than the number of errors. It should be noted that constantly informing the student about correctness or incorrectness causes him/her to be tempted to express answers at random. A gamer should be given the opportunity to score additional points by the quality of the work performed - the depth of the answer, its connection with the previous tasks, and the creativity of the approach.
    b. *Negative reinforcement (restraining factors).* This is a reduction in points for failure to complete the task or in insufficient volume, for the delivery of work after the deadline and for other violations.
3. *Problem presence, which takes place in the case of information presentation that is research-based.* The new must be learned through resolving problem situations, i.e., based on search activities. There must be an emphasis on independence and creativity, on internal motivation for activity.
4. *External control.* Creativity is a search based on interest, carried out on one's own initiative. However, in the educational process, searches should not be carried out by trial and error. Exceeding a certain threshold of difficulty in independent work weakens the motivation. It is important that the difficulty of the assignments should be on the edge of the student's capabilities, the criteria for which can be the level of tension and the time for reflection. This is achieved with measured help from the teacher (so that the student is constantly in a state of a problem-solving). Consequently, it is necessary to increase the role of management of educational and cognitive activities, to provide optimal assistance to the student from the outside, in addition to the idea of self-determination.
5. *Satisfying the need for significance.* A respectful attitude towards the individual by other people satisfies the need for, recognition of their own significance, educational potential, and competencies, maintaining the feeling of self-esteem, self-respect, and feeling not worse than others, and, as a result, performing educational activities more successfully. For example, a public demonstration of a high rating or a statement about the non-triviality and importance of the task being performed (in particular, from the point of view of the interest of other people in the results obtained) increases the personal self-esteem and motivation of the gamer through pride in his/her achievements.
6. *Creating psychologically comfortable conditions.* A favorable psychological climate is needed to develop internal motivation since creative activity against the background of negative emotions is impossible. The teacher's attention to the level of anxiety of the individual, combined with the idea of learning against the background of positive emotions, is a factor of creating psychologically comfortable conditions for students. In educational gaming, a student should master the rules of the interface. To reduce psychological tension, s/he can periodically be reminded of the rules of the game, be encouraged and, possibly, motivated to the next step, prompted with the conditions for the next action, reminded of necessary steps for promotions and so on. Such control elements, which are not related to the content of the educational material, help the learner to focus on the essence of what is being studied.

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7. *Homogeneity of teams.* Depending on the nature of the tasks being performed, with the permission of the teacher, several students who are close in terms of their success in learning can be combined into teams. Teamwork is possible, for example, if the task is very laborious, and helps to develop teamwork skills, as well as involving weaker students in learning activities (thus increasing motivation).

As an example of implementation of the proposed principles, the automated laboratory work "Lighting automaton" is briefly described below (Fig. 1). In it the object of study is a microcontroller machine. This device controls the lighting in the office premises depending on the illumination and the presence of people. The training installation consists of software simulators of a microcontroller and a lighting automaton, as well as a control program. The latter creates problematic situations for the learner (principle 3), randomly introducing, firstly, deliberate errors into the microcontroller program, and, secondly, malfunctions in the hardware of the lighting machine (simulating a wire break at the place where its number is indicated). The student is invited to resolve problem situations. Errors are eliminated by sending a required code to the address of the command being corrected. The operability of the hardware part is restored by indicating the number of the expected open-circuit fault. After that, the student is informed of the number of points scored for the last task, the total score and the time of work (principle 2).

An integral part of the game scenario is a teacher (in blended learning). Firstly, s/he implements the tasks of goal-setting (principle 1), and, secondly, provides prompt assistance in case of difficulties that the students cannot cope with on their own (principle 4), and also, as far as possible, contributes to the implementation of other principles.

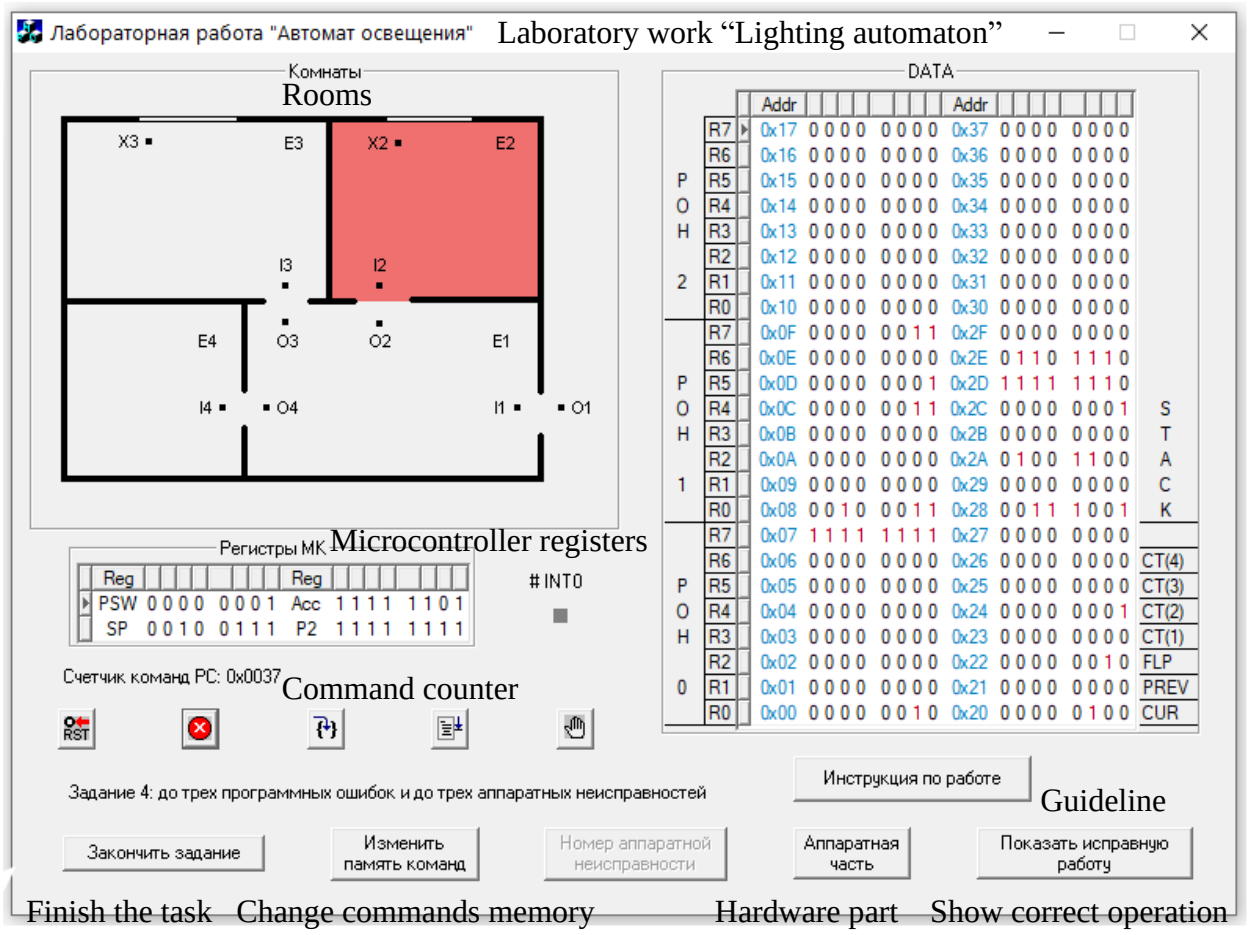

Fig. 1. The main screen of the automated laboratory work "Lighting automaton".

After starting the program, the main window appears on the monitor screen, presenting a plan of an office building with door sensors (O1, ..., O4 and I1, ..., I4), natural light sensors (X2, X3) and controlled lamps in rooms (E1, ..., E4). The current states of all microcontroller registers used and part of the data memory where program variables are located, for example, people counters in the corresponding rooms (CT (1), CT (2), CT (3), CT (4)) are also displayed.

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The goal was to test whether the given game setup was in line with the principles outlined above. For this purpose, we ordered the principles according to their importance (significance, "weight"), using expert assessments. This method is one of the approaches to the study of complex phenomena. It helps avoid the appearance of random assessments, to minimize unreasonable compromise opinions due to the formalization of information exchange between experts, and iterative formation of a collective opinion over several rounds.

After the next round on the most controversial issues, the experts are offered arguments in favor of different judgments, they are asked to give new answers (with justification), after which the average ranking is again calculated. Table 1 shows the results of the first round.

Table 1. Round 1. Expert survey. The last column "Variation" is the sum of modules of differences between expert opinions and the mean value.

Principles	Numbers of experts					Mean value / place	Variation
	1	2	3	4	5		
1. Goal setting	1 (-2.2)	7 (3.8)	1	1	6 (2.8)	3.2 / 2	13.2
2. Feedback	4	4	5	3	3	3.8 / 3	3.2
3. Complexity	6 (3.4)	1	3	2	1	2.6 /1	7.6
4. Control	5	4	4	5	2	4.0 / 5	4.0
5. "Significance"	3	6	2	4	4	3.8 / 4	5.2
6. "Comfort"	2 (-3.4)	7	7	6	5	5.4 / 6	8.6
7. Homogeneity	7	7	6	7	7	6.8 / 7	1.6

In the columns with expert assessments, the deviations of expert assessments from the average value of expert assessments are indicated in parentheses. Complexity (problemativeness) turned out to be the most important principle (first place), with a minimum mean value (2.6). The variation is calculated for the data by lines, the principles with the greatest variation are highlighted (goal-setting, complexity, "comfort"). Experts were identified who, according to these principles, have the greatest deviations from the mean value. For example, expert 1, putting the first principle in first place, gives this factor an excessive value in comparison with the group opinion (second place), and expert 2 noticeably underestimates this factor.

When substantiating their positions, the experts noted the following.

On goal-setting. This is the most important principle. Without a desire to improve in a professional direction, without a conscious, actualized goal, there is little point in studying something. Goal-setting is especially important in gaming technologies, when the process of activity itself can distract a student from the content of the educational task.

On the principle of complexity. The problematic nature of the information presented is the main principle of this laboratory work being carried out in resolving problem situations on the basis of independent creative search activity. Study assignments in the form of feasible research increase student's motivation, and contribute to the implementation of ideas of self-determination.

On the "comfort" of the educational process. If a student experiences psychological discomfort in the classroom, then all other measures to increase his motivation to study are devalued. Providing psychologically comfortable conditions for educational activity involves relying on positive emotions, on reducing the level of anxiety of the individual, on meeting the need for self-esteem.

After bringing this information to the attention of the experts, they were asked to provide new answers. Table 2 shows the results of round 2. It can be seen that the variation of opinions on each of the factors noticeably decreased, and it was decided to limit the study to this.

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Table 2. Round 2. Convergence of expert assessments.

Principles	Numbers of experts					Mean value/place	Variation
	1	2	3	4	5		
1. Goal setting	1	2	1	1	5	2.0 / place 2	6.0
2. Feedback	4	3	5	3	2	3.4 / place 3	4.4
3. Complexity	2	1	3	2	1	1.8 / place 1	3.2
4. Control	5	4	4	5	3	4.2 / place 5	3.2
5. "Significance"	3	6	2	4	4	3.8 / place 4	5.2
6. "Comfort"	6	5	7	6	6	6.0 / place 6	2.0
7. Homogeneity	7	7	6	7	7	6.8 / place 7	1.6

Above, we noted that "Lighting automaton" *principle 3* (setting problematic situations) and *principle 2* (feedback) are implemented in the laboratory work. It is also stipulated that in the "manual" mode a teacher implements the tasks of goal-setting (*principle 1*) and prompt assistance to students (*principle 4*). The authors did not pay attention to the principles 5 – 7.

We summarized the information from the expert assessments as follows. Since 7 positions were ordered, the "weight" of the last place was taken as one quantum, and the first place - seven quanta. In this case, the sum of all positions is 28 quanta. Taking this amount as 100%, the correspondence of the author's educational setting to the discussed principles of gamification can be scored as follows:

- the software part, i.e., educational technology, software-based principle 3 (task of problem situations) and principle 2 (*feedback*) – ((7 + 6) / 28) 100% = 43%;
- "manual" aspects, i.e., goal-setting (*principle 1*) and prompt assistance to students (*principle 4*) – 32%;
- reserve for improvement, i.e., *principles 5, 6, 7*, which were ignored in this educational setting – 25%.

This technique gives a first approximation to "digitize" what is being discussed and to present its advantages and disadvantages more clearly.

Analyzing the relationship between the principles and their subordination.

What is the value of gaming in the educational process? Some of the game characteristics are:

1. the development of the game according to unpredictable scenarios and a non-obvious result;
2. the development during the game, of situations that are not predetermined, requiring timely decisions in real time;
3. the collection, processing, study and analysis of information in order to assess the effectiveness of decisions made;
4. collecting, processing, study and analysis of available information related to the game in order to predict possible scenarios for the development of the game.

In the game, the activity itself brings satisfaction, even without taking into account the results. The game has a certainty of goals, the ability to be active and get immediate results. Mechanisms of imagination, creation of hypotheses, guesses, insights work in interconnection. The emotional aspects develop thanks to the joy of success, professional development, overcoming cognitive barriers. In general, even if it is subjectively uninteresting, difficult, and with unclear benefits, the material is mastered better.

Why participate in the game? Without goal-setting, as a conscious, actualized goal, consisting, for example, of gains, new knowledge, real-life self-realization, etc., the subject's participation in the game turns into a formality. It also happens that goal-setting, the desire to complete a given task requires discipline, the need to get the next grade. In gaming technologies, goal-setting is especially important, because interest in the activity itself can distract from its content. However, it is known that teachers do not always pay enough attention to the initial stage - the creation of motivation -in each quantum of learning. We did not study the effect of this principle; nevertheless, experts speculatively ranked it in second place in importance.

Next is *comfort*. If a subject has made a decision to participate in the game, then the principles and rules of the game, and interactions with other participants, as well as with "coaches" should not create discomfort for anyone. In particular, rules and principles should not conflict with generally accepted norms of behavior and morality. Unless conditions are provided for psychological comfort (reliance on positive emotions, reducing the individual's level of anxiety, meeting the need for self-esteem), measures to increase the motivation to study are devalued.

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Unfortunately, enough attention has not yet been paid to the conditions for ensuring comfort in the educational process, therefore this principle was ranked sixth.

For the *principle of satisfying the need for significance*, which was ranked fourth, the gamer must understand in advance that a successful game is the key to achieving public recognition of success. The publicity of the results of the educational game affects the self-esteem, the gamer's motivation (pride or shame) and stimulates him/her to devote more time to initial self-preparation.

These three principles determine the degree of the subject's involvement in the game.

The next question for the subject is how long to stay in the game? Further involvement in the game is determined by feedback. The effectiveness of *the principle of external control* is inextricably linked with the effectiveness of *feedback* (which ranked 3) as a means of assessment and emotional support for the student's according to the game scenario ("yes / no", points, rating, praise). *External control* (ranked fifth) is a measured rational aid according to the situation, taking into account the tension and the time for thinking of the student.

The presence of these conditions will ensure the successful resolution of problematic situations that arise in the game. This allows the student to delve deeper into the task, to pay attention to what s/he would miss in other circumstances. Without this principle, the game model disappears, and only programmed learning remains. The priority of this principle is also confirmed because the search for defects is a research activity - one of the most important means of ensuring students' motivation. Our experience of using the game model in the educational process testifies to the high efficiency of the method of deliberately introducing defects into the object to encourage search through educational and research activities. For our specific installation, the experts gave first place to the problematic principle.

Team *homogeneity* is a factor that ensures the achievement of the goal, where all participants comprehend the essence of the game. Gamers with higher potential will reach the goal faster. The less strong will need more time but will still fully learn the essence of the game. The ways in which the material is mastered are different for students with different levels of training. Fast learner students are interested in testing themselves and showing others their capabilities; the slower learners prefer to work together with someone, and to be in the shadows. The strong try to reason, while the weak seek ready answers and are lost without them. The strong put forward hypotheses, and test decisions; the weak work haphazardly, chaotically, by trial and error. The strong use different ways to find a solution; the weak cannot comprehensively analyze the assignment conditions. Therefore, there should be differentiated teaching in homogeneous groups, otherwise the weak will not learn, especially not develop, and at best be spectators simply memorizing information about the material being studied. With the transition to individual training, when it will not be necessary to synchronize the work of students, the role of this principle will increase, but for now it is ranked seventh.

Conclusion

Instead of dozens of gamification techniques considered in numerous publications, this study formulated seven principles for the implementation of educational gaming technologies in a technical university, established their ranking according to two criteria, and assessed the compliance with the proposed principles of an automated training installation with elements of gaming technologies.

The need for a link between learning quality and reward is universally recognized, but the importance of positive reinforcement in learning is underestimated. The desire to learn materializes into skills through independent activity. Only resolving a problem situation develops the student, but the tasks should not exceed his/her capabilities. In this case, motivation should be based on responsibility and interest. Responsibility and discipline are formed not so much by constraints that can negatively affect one's self-esteem, but rather by the continuity of control, and careful observance of the established rules.

The laboratory setup described in the article with elements of gaming technologies, showed that such a technique arouses interest among students, enhances students' motivation to study, and activates their independent work.

The use of the idea of gamification makes the educational process more interesting, emotionally and personally significant, contributes to the formation of in-depth knowledge of the device, programming and debugging of hardware and software of microcontrollers, and frees the teacher from routine operations to control the correctness of the student's actions.

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Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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