Study on the Optimal Usage of Active and Passive Technology-Based Teaching Resources

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Abstract. Today's digital age is redesigning the educational process significantly, so the researchers have conducted a survey to explore the practice of teachers in the integration of contemporary information and communication technologies (ICT) at school level in Bulgaria. The paper presents and analyses findings of the teachers' views on the frequency of use and usefulness of passive and active teaching resources – presentations, simulations, virtual laboratories, and learning games. Furthermore, based on a mathematical approach grounded in the utility theory and stochastic approximation the researchers develop a quantitative model. This model presents a utility function that reflects the teachers' preferences for employing ICT tools and their impact on two of teaching approaches – passive and active. The derived utility functions help to reveal the sub-optimal proportions of the considered technological resources in the classroom education. The authors also provide some discussions, suggestions, and conclusions.

Keywords: Active and passive teaching · ICT-based resources
Teachers preferences · Utility function

1 Contemporary View on Teaching Methods

In today's highly digitized era, people around the world are already using ICT for a variety of activities, and for the younger generation, this is a daily routine. Education and technology are the two fundamental themes that shape our society. More innovations are being promoted in schooling for knowledge acquisition and practice, and students are increasingly using their digital culture in education. Modern technologies can make lessons more attractive, and motivate both students and teachers [1]. They can increase the chances of gaining new skills and achieving learning goals while reducing the number of dropouts.

The challenge of contemporary education is the adaptation to the digital generation. It is a difficult task because the traditional teaching methods have to be implemented by means of modern technologies. The innovative tools enable to perform various scenarios in an attractive and engaging manner. However, they should be used in the right

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situation, in the right way and in an appropriate amount thus to improve the teaching-learning process and make it efficient.

The basic ideas of the constructivist theory claim that people learn from both their own experience and the new knowledge they meet [2]. Modern technologies offer tools for implementing these active and passive learning methods (e.g., interactive learning content, virtual labs, simulations, videos, presentation, and computer games) [1, 3]. Thus, teachers have the opportunity to blend both approaches according to their views as well as to flexibly change the teaching method as per the specific situation. During lessons, this manner enables various interactions and effective communications both among students and with the teacher. Thus, a positive attitude of learners to the educational process can be established. Innovative teaching is based on the integration of contemporary pedagogical experience and ICT tools. It provokes curiosity and motivation in students; engages them in self-seeking information, learning by doing and through an emotional experience. In this way, students, besides being trained, have the opportunity for self-studying, exploring and investigating.

In this paper ICT-based resources are considered as passive (knowledge delivery through e-texts, presentations, animations, and videos) and active (experiments, virtual laboratories, process simulations and educational games). The research issue is to define what should be their optimal usage in the teaching process. For the aim of this exploration, the authors use the findings of a conducted survey revealing how often Bulgarian teachers implement ICT resources in the active and passive approaches as well as teachers' assessment of the usefulness of various technology-based resources [4]. Moreover, an analysis of what should be the best proportion of used digital resources in active and passive teaching to make the educational process more effective is a matter of consideration in the current paper.

2 Survey Findings

Respondents of the considered survey are among Bulgarian teachers who take part in events focused on innovative and technology-enhanced teaching. Above the half of all participants (190) are primary teachers, a quarter and nearly 20% are from low and high secondary schools respectively; in each group prevail more experienced teachers with more than 15 years of practice. They are distributed relatively evenly across the country. More details about the survey are available at [4]. Some results concerning learning activities in which ICT tools are employed, different types of digital resources used, and effects of their application, are already presented in [5]. This paper explores and analyses in-depth the findings concerning the use of various ICT resources in both passive and active pedagogical methods. The authors focus not only on the quantity (frequency of use) but also on the assessment of the educational value of technological resources (how teachers evaluate their usefulness).

Figure 1 illustrates how often teachers use diverse types of ICT tools respectively in passive and active educational context. The majority (60%) most often uses passive ones as a substitute for traditional textbooks and workbooks, as a source of information, for sharing content, etc. Those who are technology proficient exploit the power of ICT for creating animations, multimedia as well as virtual and augmented reality. Most teachers use active training tools (virtual labs, experiments, and process simulations) only occasionally, despite the shared belief that to perform an experiment by yourself and to have a chance to test variants while doing it without any risk is exciting. Surprisingly, the highest frequency of the active tools is for educational games – 43%, which can be explained by the prevailed number of primary school teachers. An interesting observation is that almost the half (47%) of teachers have never employed active e-training tools.

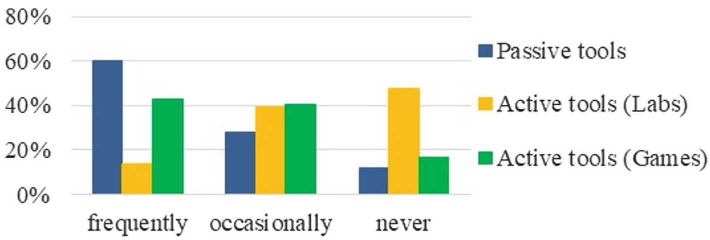

Fig. 1. Frequency of usage of passive and active ICT teaching tools

The most appreciated passive teaching tools are videos and presentations as Fig. 2 indicates. Undoubtedly, those easily attract students' attention and are convenient to put into practice. There are almost no negative assessments for each of the passive instruments.

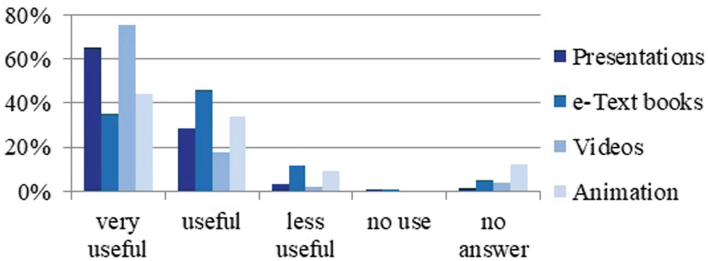

Fig. 2. Average usefulness of passive teaching tools

Respondents use active tools in the process of teaching through lesson presentations with interactive learning content and assignments, for individual and group projects, interactive online testing, discussions, etc. The survey findings show that considerable part of the respondents estimate each of the active teaching tools as very useful or useful (see Fig. 3). These resources often have equal value in the learning context, and in some cases are interchangeable.

The survey results displayed in both statistical graphics (Figs. 2 and 3) are an outcome of the recent increase in the availability and variety of e-learning resources for knowledge delivery. It is noteworthy that the resources for active training like virtual laboratories, software for experiments, etc. are still scarce or not so widespread; even many teachers have never used such in their practice. This is probably the reason for a relatively high percentage of respondents that do not give any assessment of the usefulness of the active teaching resources.

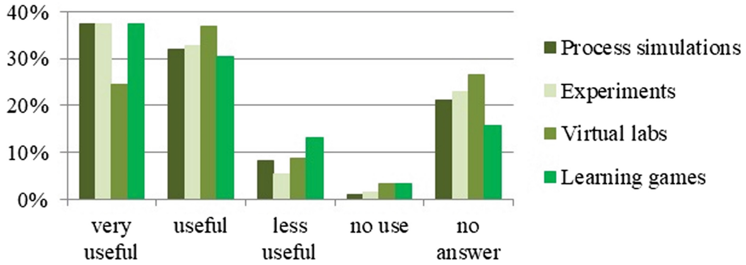

Fig. 3. Average usefulness of active teaching tools

3 Mathematical Modelling

The authors apply an evaluation methodology for modelling an aggregate opinion of surveyed teachers about using ICT-based resources in classrooms. It concerns the respondents' preferences to the employed resources respectively in passive (knowledge delivery through e-texts, presentations, animations, and videos) and active approaches (experiments, virtual laboratories, process simulations and educational games). The estimation of these preferences allows determining the best possible proportion of these teaching resources.

3.1 Mathematical Theory

Term "utility" in the decision-making refers to a property of an object that can be measured quantitatively through measuring human's preferences regarding the primary objective of the study. Utility evaluation methodology is grounded in the theory of measurement (scaling), utility theory, stochastic approximation and probability theory. Based on utility theory it is possible to develop complex models that analytically represent human preferences and allow the analytical inclusion of decision maker (DM) in mathematical modelling. The individual utility functions allow developing mathematical models of complex processes with human participation.

Until recently, procedures for an evaluation of the utility function have been mostly empirical and based on so-called lottery approach [6]. Lately, a mathematical approach and numerical methods for analytical evaluation of utility functions based on stochastic approximation as machine learning and pattern recognition are developed. Here, the utility evaluation approach is based on the potential function method [7]. By its nature, the evaluation is stochastic pattern recognition of two different sets that express positive and negative decision maker's preferences.

The mathematical implementation of evaluation methodology is carried out through a prototype of a decision support system for assessment of an individual's utility functions. The specialized software based on the numerical methods assess these functions. The evaluated utility functions correspond to the concepts of von Neumann [8]. Thus, a polynomial approximation of the utility function is made in Visual Studio and MATLAB environment. Assessment procedure has several steps, depending on the number of attributes of the utility function and their decomposition.

3.2 Method of Evaluation

The authors apply the abovementioned evaluation methodology for modelling an aggregate opinion of surveyed teachers about using ICT-based resources in classrooms. It concerns the respondents' preferences to the employed resources respectively in passive (knowledge delivery through e-texts, presentations, animations, and videos) and active approaches (experiments, virtual laboratories, process simulations and educational games). The estimation of these preferences allows determining the best possible proportion of these teaching resources. The value of the utility function shows if the use of considered tools in teaching practice is reasonable and if so what the appropriate proportion of ICT resources is.

The preferences about results of any potential choice under conditions of uncertainty are used to construct a multi-attribute utility function in frames of the normative approach of decision-making theory [6]. The first step in designing a quantitative utility model is a description and structuring the main objective and sub-objectives. In this study, the main objective is „Evaluation and analytical utility representation of the effectiveness of teaching methods." The sub-objectives are "Subjective preferences of the passive/active ratio in teaching" and "practical training/games ratio within active teaching." Figure 4 presents the structure of the problem.

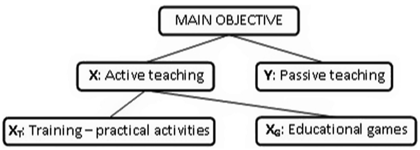

Fig. 4. Structure of the problem

This structure determines the multi-attribute utility function as a function of three variables. As criteria for a quantitative evaluation are used percentage of each variable: $\mathbf{x_T} \in [0\text{–}18]\%$, $\mathbf{x_G} \in [0 - 36]\%$, $\mathbf{y} \in [0\text{–}46]\%$. The empirical results from the survey help to derive these intervals. The most convenient way to evaluate the multi-attribute utility is to decompose the function into functions of fewer variables according to the structure of the problem. This decomposition base on utility theory and it uses notion as utility independence and lotteries. A "lottery" is called every discrete finite probability distribution over Cartesian product $X_G \times X_T \times Y$, where respectively the sets are $\mathbf{X_T} = [0\text{–}18]\%$, $\mathbf{X_G} = [0\text{–}36]\%$ and $\mathbf{Y} = [0\text{–}46]\%$. Let $z_1 = (x_{G1}, x_{T1}, y_1)$, $z_2 = (x_{T2},$

x_{G2}, y_2) and z = (x_T, x_G, y) are randomly distributed selected vectors. The lottery is denoted as <*z_1, z_2, α*>; here α is the probability of appearance of the alternative z_1 and (1 − α) is the probability of the alternative z_2. The most widely used evaluation approach is the assessments described in [6, 9] as follows:

$$z \underset{\prec}{\overset{\succ}{\approx}} < z_1, z_2, \alpha > \text{, where } z_1,\ z_2, z \in \mathbf{X}_{\mathrm{G}} \times \mathbf{X}_{\mathrm{T}} \times \mathbf{Y}, \boldsymbol{\alpha} \in [0, 1]$$

Definition of utility independence is following: attribute 1 is utility-independent of attribute 2, if conditional preferences on lotteries on attribute 1, given a fixed value of attribute 2, do not depend on that constant. Note that utility independence is not symmetrical: it is possible that attribute 1 is utility-independent of attribute 2 and not vice versa. If attribute 1 is utility-independent of attribute 2, the utility function in respect of attribute 1, for every value of attribute 2 is a linear transformation of the utility function for every other value of attribute 2. In the process of investigation, independence by the utility, determined by the decision maker, is among the following factors:

$$\mathrm{X} = \mathbf{X}_{\mathrm{G}} \times \mathbf{X}_{\mathrm{T}} \text{ from Y and vice versa; } \mathrm{X}_{\mathrm{G}} \text{ from } \mathrm{X}_{\mathrm{T}} \text{ and vice versa;}$$

Since the teacher assumes that the factors **X** and **Y** are mutually utility independent, the multi-attribute utility function is presented by the following equations as it follows from the utility theory [6]:

$$\mathrm{U}_{12}(\mathrm{x}_{\mathrm{G}}, \mathrm{x}_{\mathrm{T}}) = \mathrm{k}_1\mathrm{f}_1(\mathrm{x}_{\mathrm{G}}) + \mathrm{k}_2\mathrm{f}_2(\mathrm{x}_{\mathrm{T}}) + \mathrm{k}_{12}\mathrm{f}_1(\mathrm{x}_{\mathrm{G}})\mathrm{f}_2(\mathrm{x}_{\mathrm{T}}), \tag{1}$$

$$\mathrm{U}_{123}(\mathrm{x}_{\mathrm{G}}, \mathrm{x}_{\mathrm{T}}, \mathrm{y}) = \mathrm{b}_1\mathrm{f}_3(\mathrm{y}) + \mathrm{b}_2\mathrm{U}_{12}(\mathrm{x}_{\mathrm{G}}, \mathrm{x}_{\mathrm{T}}) + \mathrm{b}_{12}\mathrm{U}_{12}(\mathrm{x}_{\mathrm{G}}, \mathrm{x}_{\mathrm{T}})\mathrm{f}_3(\mathrm{y}) \tag{2}$$

In these formulas, k_1, k_2, k_{12}, b_1, b_2, and b_{12} are constants whereas $f_1(.)$, $f_2(.)$, $f_3(.)$ are single attribute functions. For evaluation of constants and utility functions, stochastic approximation procedures and particularly the potential function method are used.

The main stochastic procedure for evaluation of the single attribute utility function $f_1(.)$ is as follows [9]. First, $\mathbf{x_T}$ and **y** are fixed at chosen points, as long as it varies only $\mathbf{x_G}$. The DM compares the "lottery" <*x, y, α*> with the simple alternative z, the other variables x, y, $z \in X_G$, $\alpha \in [0, 1]$ are fixed at values $\mathbf{x_T}$ and **y**. The choices are: ("better $-\succ$, *f (x,y,z,α)* = 1", "worse $-\prec$ *f(x, y, z, α)* = (−1)" or "can't answer/equivalent **–~,** *f(x, y, z, α)* = 0"; *f(.)* denotes the qualitative DM's answer). This determines a learning point (*(x, y, z, α), f(x, y, z, α)*). The following recurrent stochastic procedure constructs the utility polynomial approximation:

$$u(x) = \sum_i c_i \Phi_i(x)$$
$$c_i^{n+1} = c_i^n + \gamma_n \left[f(t^{n+1}) - \overline{(c^n, \Psi(t^{n+1}))} \right] \Psi_i(t^{n+1}),$$
$$\sum_n \gamma_n = +\infty,\ \sum_n \gamma_n^2 < +\infty,\ \forall n, \gamma_n > 0\cdot$$

Following notations are used in the formulas: $\boldsymbol{t} = (x, y, z, \alpha)$, $x, y, z \in X_G$, $\alpha \in [0, 1]$, and $\psi_i(t) = \psi_i(x, y, z, \alpha) = \alpha\Phi_i(x) + (1 - \alpha)\,\Phi_i(y) - \Phi_i(z)$ where $\{\boldsymbol{\Phi}_i(x)\}$ is a family of polynomials. The line above the scalar product $\overline{v} = \overline{(c^n, \Psi(t))}$ means: $(\overline{v} = 1)$, if $(v > 1)$, $(\overline{v} = -1)$ if $(v < -1)$ and $(\overline{v} = v)$ if $(-1 < v < 1)$. The coefficients c_i^n take part in the polynomials:

$$g^n(x) = \sum_{i=1}^{n} c_i^n \Phi_i(x), G^n(x, y, z, \alpha) = \sum_{i=1}^{n} (c_i^n \Psi_i(t)),$$

$$(c^n, \Psi(t)) = \sum_{i=1}^{n} (c_i^n \Psi_i(t)) = \alpha g^n(x) + (1 - \alpha) g^n(y) - g^n(z)$$

The procedure is, in fact, a pattern recognition through function $G^n(x, y, z)$ of positive and negative preferences, expressed by DM's comparisons of lotteries. Evaluated polynomial approximation of the utility $f_1(.)$ is g(.). The same procedure is used for evaluation of the utility $f_2(.)$ and $f_3(.)$. Learning points (lotteries) are set with a pseudo-random sequence. The next section shows the results: seesaw lines in figures depict pattern recognition whereas smooth lines are the von Neumann utility function approximations.

3.3 Mathematical Processing of Survey Findings

The implementation of the above-described procedure for evaluation of utility function shows that the most used teaching tools are the passive ones – the usage frequency reaches 46%. Figure 5 presents the constructed normalized utility function of passive teaching tools. After an initial increase (up to approximately 12% usage), a plateau-like section of the utility function is noticeable – up to 25% usage. This steep section represents the fact that the increase in the usage of the passive method causes the rapid

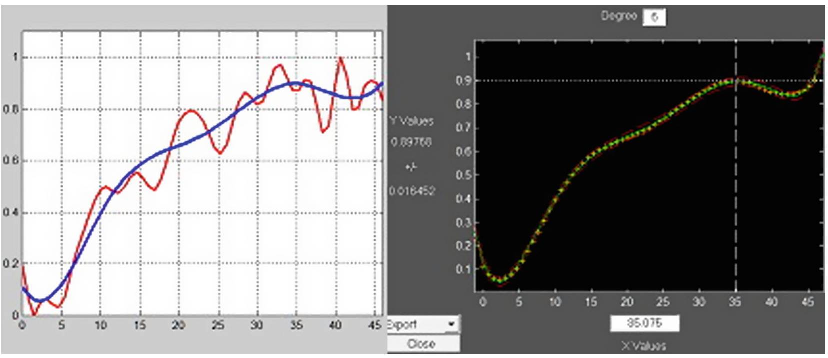

Fig. 5. Utility function of passive learning $\mathbf{f_3(y)}$: left part – without (seesaw line, red) and with approximation (smooth line, blue); right part – confidence range (dashed line, red), spline approximated (smooth line, green) and polynomial (least square – line with crosses, yellow). (Color figure online)

growth of its utility. The plateau section indicates a possibility for combining with other types of resources without diminishing the effectiveness of this one. The maximum of utility function lies at 36% usage frequency (which equals to 78% of the total frequency scale) after that follows a decrease of the utility function. Border values at the beginning and the end of graphics have to be discarded because of the calculations' uncertainty.

The mathematical representation of teachers' assessments of the usefulness of both active teaching methods – practical exercises and games – is similar (see Fig. 6). The derived utility functions are normalized. The maximum of the utility function lies approximately at 13% for active training (X_T) and at 27% for educational games (X_G) (which respectively equal to 72% and 75% of the corresponding total frequency scales). There are plateau-like sections (between 4% and 8.5% for X_T and between 7.5% and 20% for X_G), the latter is more noticeable. As mentioned above, the plateau sections indicate possibilities for combination with other types of resources without compromise with the effectiveness of the considered ones. Boundary values at the beginning and the end of graphics should not be taken into account because of the algorithm uncertainty.

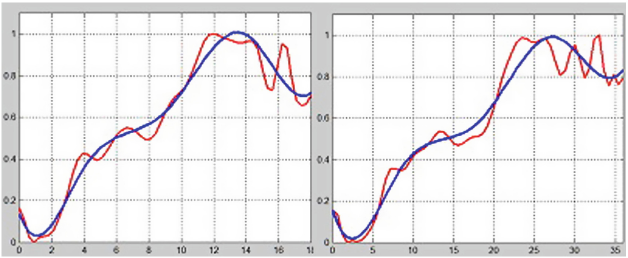

Fig. 6. The utility function of active learning through training $\mathbf{f_1(X_T)}$ (left) and games $\mathbf{f_2(X_G)}$ (right): without approximation (seesaw line, red) and with approximation (smooth line, blue). (Color figure online)

It is noteworthy that the learning games are used twice more often than practical tools like virtual laboratories. The authors see various reasons for this unexpected finding. Considering these particularities, results of the study on the frequency of use of active learning tools are not surprising. Digital tools cannot entirely replace real experiments and laboratory – software instruments only can make a simulation of a process. What is more, the school subject matters too. Biology, physics, mathematics, and chemistry can often use active learning tools such as laboratory, simulations, and experiments. Other subjects – geography, history, philosophy, literature, languages or arts are more probably to use educational games as active training. Further, the school level of education also make a difference. In primary schools where the same teacher teaches almost all subjects, educational games occupy a great deal of the active learning. In the secondary, school subjects are of a very diverse nature so are taught by different teachers and the teaching methods and tools are fundamentally dissimilar.

The authors apply the above-described mathematical procedure to evaluate the multi-attribute utility over both single-variable functions for passive and active teaching tools. Following formulas (1 and 2), two surfaces presenting multi-attribute utility functions are constructed (see Figs. 7 and 8). Figure 7 shows the teachers' preferences regarding the sub-optimal allocation of ICT-based active teaching tools $\mathbf{X_G}$ (games) and $\mathbf{X_T}$ (training).

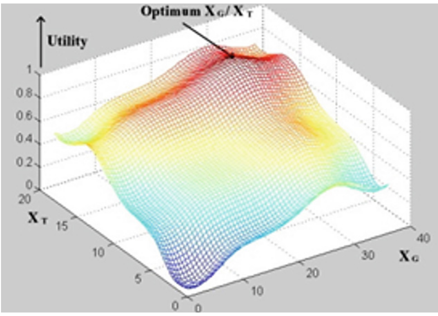

Fig. 7. The utility of active teaching: relation of educational games to e-training

The utility function has a definite maximum and a quite noticeable plateau-like area in which the proportions of these teaching tools can vary and yet be equally successful employed. The overall utility function has relatively high value.

Figure 8(a) displays the teachers' preferences concerning the sub-optimal allocation of ICT-based passive teaching in relation to the active one through $\mathbf{X_G}$ (games). The value of the active training tool $\mathbf{X_T}$ is set approximately at its maximum utility ($\mathbf{X_T}$ = const. and is 13% of overall teaching activities).

The teacher selects the appropriate means according to the specifics of the considered students' group – most likely the combination will vary for different classes. The new technology delivers just those characteristics – flexibility and speed in choosing and applying the specific tools and approaches.

It is not necessarily only to use the optimal point (function's maximum). A sub-optimal area with an amply high utility (e.g., over 70% or 80%) is large enough and allows for multiple combinations and variants.

Figure 8(b) depicts teachers' preferences regarding the sub-optimal allocation of ICT-based passive teaching in relation to the active one through $\mathbf{X_T}$ tool (e-training). In this case, the value of active tool $\mathbf{X_G}$ (games) is constant, approximately fixed at the maximum of its utility function ($\mathbf{X_G}$ = 27% of the overall teaching process).

Both multi-attribute utility functions presented in Fig. 8 are very similar, which is understandable because of the similarity of the single-parameter functions and the reasons given above (see in Fig. 6). There is a plateau-like area in which the proportions of active and passive teaching methods can vary, so several different types of tools (educational games, electronic simulations, virtual labs, e-experiments, etc.) can be successfully mixed as needed.

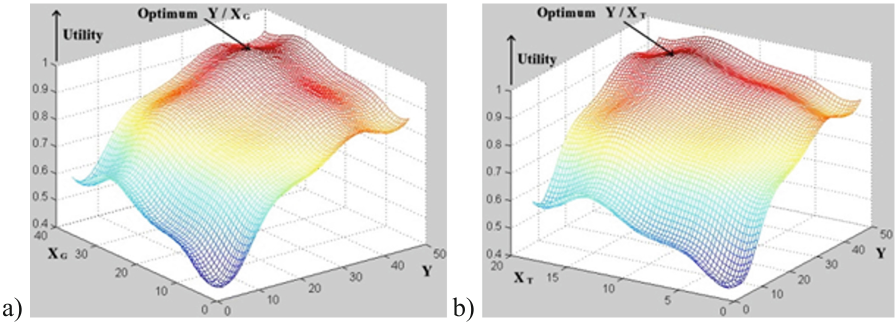

Fig. 8. The utility of passive in relation to active teaching through: (a) games; (b) e-training

The graphics (see Figs. 7 and 8) outline some aspects of the proportion of passive and active technology-based teaching approach derived through a utility evaluation of teachers' preferences. The resulting surfaces clearly show the relatively high benefit of ICT-based teaching tools. The utility of a combination of passive and active teaching lays over 80% when the use of teaching tools is as follows: passive is over 27%, an e-training is over 22% and a game – over 10.5% respectively. In fact, this utility function is an indicator of the considerable pedagogical value of innovative instruments, which is already appreciated by teachers.

4 Conclusion

This paper explores the employment of technology tools in the educational process in Bulgarian schools. The authors suggest a scientifically grounded approach to determine the usefulness of digital resources in the schooling context recognizing their frequency of usage. For this purpose, the researchers considering teachers' opinions obtained by a survey implement a mathematical procedure to define the utility of examined passive and active teaching tools. The resulting utility functions give a clear mathematical evaluation of the effectiveness of different combinations of technology-supported teaching approaches. They have practical application in developing reasoned recommendations to the integration of technology tools in teachers' practice.

These guidelines can serve teachers and school authorities to construct sub-optimal combinations of diverse active and passive ICT-based educational resources to increase the effectivity of the teaching process. Besides the indisputable balance between both passive and active teaching approaches, a balance must also be struck between the used various technology-based tools. There is no one fit-for-all teaching method, so the implemented approaches have to be flexible and manifold to meet the specifics of each student and learning subject. ICT gives the opportunity for application of high quality, modifiable, adaptable and easy-to-use teaching resources to build an effective teaching-learning process.

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