Feedback adaptation in web-based learning systems

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Abstract: Feedback provided by a learning system to its users plays an important role in web-based education. This paper presents an overview of feedback studies and then concentrates on the problem of feedback adaptation in web-based learning systems. We introduce our taxonomy of feedback concept with regard to its functions, complexity, intention, time of occurrence, way of presentation, and level and way of its adaptation. We consider what can be adapted in feedback and how to facilitate feedback adaptation in web-based learning systems.

Keywords: feedback; feedback adaptation; adaptive web-based systems; web-based learning system.

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1 Introduction

Testing and assessment are widely used in web-based applications, including e-learning systems, psychological and medical diagnostics systems, sociological polls, and in e-commerce. Computer-based testing has a number of advantages, namely:

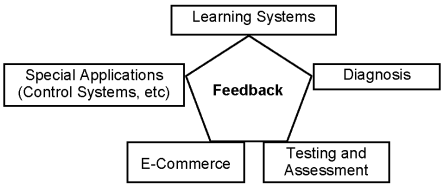
- facilitation of data analysis
- generation of quick or sometimes even immediate results
- reduction of time for tests development
- increase in user motivation in the case of frequent assessing
- possibilities of testing at any time
- appeal to a great number of users/respondents with a large variety of preferences, characteristics, education, goals, etc.

Generally, there exist many types of problems of testing and assessment in web-based learning systems, including both more technical ones such as user identity verification and security issues and more general aspects such as personalisation and adaptation of assessment process.

Lack of interaction between students and teachers is one of the main problems in web-based learning applications (Mory, 2003). During the learning process a student performs a number of actions where feedback is crucial, for example in assessments or in task solving. Therefore, the study of feedback provided by the system is one of the most important aspects of web-based testing. This paper analyses the problem of adaptation and personalisation of feedback provided by the system to a user during web-based learning. Here we interpret feedback as information that is provided in order to compare the user's performance with the performance expected by the system.

In Figure 1 the variety of web-based systems, where feedback is especially important, is presented. In the case of testing systems, feedback mainly consists of information about the tests results presented to a user. In web-based learning systems feedback presented by computer is usually aimed to replace feedback given to the student by the teacher and to improve student performance (Mory, 2003). The main role of feedback in web-based systems is to inform and to motivate the user to increase his or her effort and attention.

Figure 1 Feedback in web-based applications



The necessity of feedback in a computer system is emphasised by psychologists, pedagogists, and usability engineers (Mason and Bruning, 2001; Nielsen, 1993; Norman, 1998). In information systems area, feedback is studied within human-computer interaction where the main problems are two-fold:

- how to organise the systematic feedback to the user?
- how to predict and process the feedback from the user?

In this paper the first problem is studied.

Mory (2003) refers to the following research directions in the feedback studies as perspectives:

- analysis of the learner motivations and attitudes and prescribing feedback based on factors such as tenacity, self-efficacy, attributions, expectancy, and goal structure
- identification of measurable variables that can reflect internal cognitive and affective processes of learners that might potentially affect how feedback is perceived and utilised
- design of feedback that utilises the improved capabilities for instruction provided by the continuous advance of technologies
- identification and testing of interactive patterns among the learner, the environment, individual internal knowledge construction, and varying types of feedback.

The study of the feedback adaptation in e-learning system could help solving problems in all of these research directions.

Feedback can differ in the content and time of presentation and in the manner of representation. Properties of feedback are especially important in applications for users with a large variety of individual characteristics and goals. Feedback adaptation offers possibilities to deliver feedback that is the most appropriate for the user's skill level, personal characteristics, mood, behaviour, and attentiveness. For example, if the user's performance deteriorates and mistakes are made more often, then feedback can be presented more frequently than would be the case in normal circumstances. Another example might be a testing system for young illiterate or innumerate children presenting feedback in a graphical form instead of a textual or numerical form.

Mory (2003) describes a number of experimental studies where different types of feedback were presented to the students during the learning process. For example, in the Noonan (1984) study the content of feedback was varied with the following types: knowledge of correct response feedback, elaborated, and try-again feedback. In the studies discussed by Mory (2003, p.752–770) the results significantly varied – in some of them (for example Waldrop et al., 1986) the advantages of particular feedback types were shown, while in some other studies no significant difference in user performance with several types of feedback was found.

While there have been studies on different types of feedbacks, feedback adaptation remains an almost totally neglected area, even though its importance has been acknowledged. In one of the very few studies (Mory, 1991) analysed adaptive feedback that additively used three feedback types: task specific, instruction based, and extra-instructional ones in two learning tasks (verbal information and concepts). The aim of the study was to determine the effectiveness of various types of feedback on learning. In comparing adaptive feedback with non-adaptive feedback no significant differences were found in post-test performance in either verbal information or concept tasks (Mory, 2003). However, it should be noticed that feedback was not adapted to the personal characteristics of the students.

Lütticke (2004) has experimentally demonstrated the effectiveness of feedback adaptation in a problem-solving task. In this study the contents of feedback was adapted to the user's individual errors, knowledge, preferences in support, and progress in solving the problem. The system could adapt the contents of the feedback presentation and present the user with many kinds of information: i.e., a statement about the degree of correctness of the solution, an error list, a description and explanation of the errors, hints for improvement of the solution, links to the recommended literature, links to easier related problems, links to examples of similar exercises, etc. These experiments showed that 80% of students favour feedback adaptation and most of them wish to have more adaptive feedback.

Lütticke's (2004) study is the only experimental study of feedback adaptation to the user personal characteristics in computer-based tutoring systems that we have managed to find. But the positive results of this experimental study seem to suggest that the prospects of feedback adaptation for web-based applications are promising, particularly for web-based testing and learning systems.

In this paper these possibilities of feedback adaptation in the web-based learning system to personal characteristics of the student are examined. The rest of the paper is structured as follows. We overview the concept of feedback, its definition, and classification in Section 2. Section 3 discusses the scope for feedback use in web-based learning and testing systems and emphasises the necessity of feedback adaptation in web-based testing applications such as e-learning systems, web-based diagnosis, and testing applications. The feedback adaptation problems are analysed and the conceptual framework of web-based learning system with adaptive feedback is suggested in Section 4.

2 Feedback studies: related work and background

2.1 Concept of feedback

The concept of *feedback* is used in many fields of science: education, psychology, biology, economics, and information systems, each examining it from its own perspective. It is difficult to detail the whole history of this concept. Kinds of feedback systems have been used in mechanical devices since their appearance. In science, early psychological research was strongly connected to feedback, but the term preferred then was *operant conditioning* (Skinner, 1930). As early as Thorndike (1912) had formulated 'the law of effect', which states that behaviours that are followed by pleasant consequences will be more likely to be repeated in the future (Pressey, 1926) tried to develop a machine based on these rules of learning. The idea of the machine was to help each student to proceed at his or her own pace. It seems that Pressey was the first to emphasize the importance of immediate feedback in education.

The studies on cybernetics are often referred to when discussing feedback (Nickols, 1995; Spink and Saracevic, 1998). Wiener (1948) used the feedback concept to distinguish processes by which a control unit gets information about the effects and consequences of its actions. The feedback in cybernetics is concerned with the mechanism of control. According to Spink and Saracevic (1998) the Wiener's feedback concept is viable in respect to engineering applications, but its extension into human activities suffers from many problems. Social sciences and information aspects of feedback should be added to the cybernetics perspective.

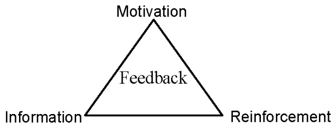
Feedback in all sciences is usually considered as a kind of a loop from an output of a certain action to its input. This view on feedback is based on the control system's feedback concept and helps us to better understand its nature in that context. In computer systems, feedback could be considered either as a loop from the computer to the user or from the user to the computer.

Doig (2001) argues that unlike in science where the term feedback is quite clear it is difficult to define it in education. However, at the same time the models of feedback provided by cybernetics can suggest how feedback could be used in educational contexts. As an example he demonstrated a feedback process of teacher-student interaction by analogy with the work of thermostat.

A good historical review of feedback research in the educational context is Mory (2003). Mory (2003) argues that the definition of feedback is dating back to the early 1900s. According to Mory (2003) those definitions are surprisingly similar to the ones used today. Kulhavy and Wager (1993) introduced the concept of a 'feedback triad' for the earlier three definitions of feedback (Figure 2). They are:

- "feedback as a motivator for increasing response rate and/or accuracy"
- "feedback reinforcing a message that would automatically connect responses to prior stimuli – the focus being on correct responses"
- "feedback providing information that learners could use to validate or change a previous response – the focus being on error responses".

Figure 2 Feedback triad



Feedback triad (Figure 2) clearly demonstrates the nature of the feedback problem: feedback should simultaneously function and be analysable on several levels: as a motivator, provider of information and reinforcement. Reinforcement can be seen as a concept on the behavioural level, motivator on the emotional level and provider of information on the cognitive level of function or analysis. These levels are especially important in the e-learning systems.

Webster's dictionary (Webster, 2001) defines feedback as "a process in which the factors that produce a result are themselves modified, corrected, strengthened, etc., by that result" and "a response, as one that sets such a process in motion" (Webster, 2001, p.520). But in the educational research the concept of feedback is mostly considered in the context of instruction (Mory, 2003). There it is defined as any communication or procedure that is aimed to inform a learner of the accuracy of a response to an instructional question (Carter, 1984; Cohen, 1985; Kulhavy, 1977; Sales, 1993).

According to Mory (2003), feedback is incorporated in many paradigms of learning – in the early view of behaviourism (Skinner, 1958), in cognitivism (Kulhavy and Wager, 1993), and in more recent models of constructivism (Mayer, 1999; Willis, 2000).

Ramprasad (1983) defines feedback in behavioural terms as "information about the gap between the actual and reference level of a system parameter which is used to alter the gap in some way". Within the behavioural terms of this definition Black and Wiliam (1998) have distinguished four elements of a feedback system:

- data on the actual level of some measurable attribute (for example, user's answer to the question)
- data on the reference level of that attribute (the correct answer)
- a mechanism for comparing the two levels and generating information about the 'gap' between the two levels
- a mechanism by which the information can be used to alter the gap (present the help to a user in the case of an incorrect answer).

Wiggins (2001) points out the difference between the concepts of feedback, guidance, and evaluation. *Feedback* gives information about what has happened, *guidance* suggests future directions and answers on the question: "what should I do, in the light of what just happened?", and, *evaluation* judges the user's overall performance against a standard. According to Wiggins (2001), feedback is value-neutral. Its main task is to report of the action occurred. Most of the researchers consider guidance and evaluation as possible contents of feedback (Hoska, 1993; Sales, 1993; Mory, 2003). Wager and Wager (1985) defined feedback in computer-based instruction as "*any* message or display that the computer presents to the learner after a response".

Learning without feedback can be compared to playing basketball with lights out, the player being unable to assess the quality of his or her throw. Another metaphor of missing feedback is presented by Norman (1998) who describes it as the process of writing with a pen without ink. Prompted by these metaphors yet another definition of feedback can be proposed:

> *Feedback* is a response to the result of action primarily aimed to correct future iterations of the action, or related action (Mason and Bruning, 2001). It is information about what happened as the result or effect of the user's action (Wiggins, 2001), and is provided to a user to compare his or her performance with the expected one (Johnson and Johnson, 1993).

We consider this definition of feedback as the most suitable for the context of the analysed problem, feedback adaptation in web-based learning systems. In this paper we examine only aspects of the system's feedback (not the user's feedback) to the students of web-based learning application.

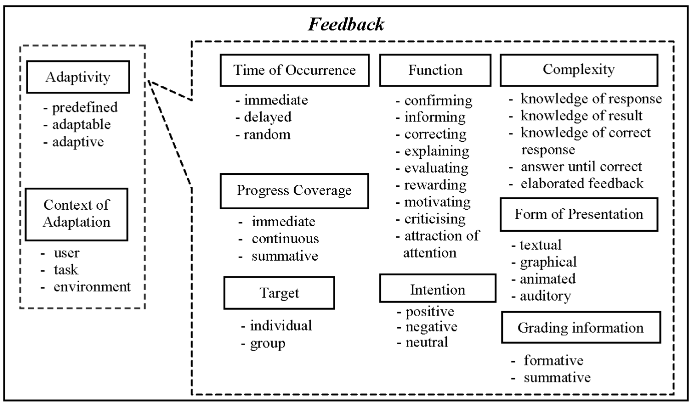
2.2 Feedback classification

In the feedback-related literature several types of feedback classifications having different parameters have been presented (Mason and Bruning, 2001; Mory, 2003; Narciss and Huth, 2004). In Figure 3 we summarise the existing taxonomies of the feedback concept including feedback adaptation. We started this work in Vasilyeva et al. (2005a) and here we revise and extend our taxonomy.

One of the main feedback classifications that have its origins in studies of control systems is the categorisation of feedback into *negative* and *positive*.

The feedback is called *positive* if the resulting action goes in the same direction as the condition that triggers it. The positive feedback tends to increase output and speed up the process. It is used in certain situations where rapid change is desirable. The positive feedback is more responsive than the negative one. When the resulting action opposes the condition that triggers it, then the feedback is called *negative*. The negative feedback is considered as more stable, because the system becomes more immune to changes of the input.

Figure 3 Taxonomy of the system's feedback concept



In non-technical sciences the positive and negative feedback have another interpretation (Nickols, 1995): positive feedback is considered as complimentary and pleasing, while negative feedback is seen as critical and almost as unpleasant to give as to receive.

In education, both of these terms can be considered beneficial – negative feedback prompts improvements, while positive feedback increases motivation. Already the early developers of the models for 'teaching machines' emphasized the difference between negative and positive feedback, stressing the importance of motivational aspects in learning (Skinner, 1958). In addition to this dichotomy, the feedback can also be *neutral*. It means that it does not necessarily provide any information about the results of the user's action; it just presents knowledge of response information.

There is also another point of view: positive feedback can be seen as informative per se, because it informs the performer that she or he is going to the right direction, while negative feedback does not do that. In this interpretation, negative feedback can be considered as non-informative and nonsensical. We are following the non-technical view on the feedback: positive feedback in the case of correct answer and negative feedback in the case of incorrect answer.

One of the main classification parameters of the feedback is based on how much and what kind of information it provides. Mory (2003) uses the term feedback complexity. According to this classification the feedback in computer systems is classified into (Mory, 2003; Mason and Bruning, 2001): *no feedback, knowledge of response feedback; knowledge of result or simple verification feedback; knowledge of correct response or correct response feedback; answer until correct or try-again feedback; and elaborated feedback*.

Knowledge of response feedback indicates whether the answer was received. However it does not necessarily give the response or information about correctness or incorrectness of the answer. This type of feedback is also referred to as confirmation feedback. It is usually used to motivate the user (student) to continue the interaction with the system. *Knowledge of results* or simple verification feedback informs the user of a correct or incorrect response. *Knowledge of correct response* feedback gives the correct answer (Ross and Morrison, 1993). This type of feedback is also called corrective feedback. The *answer until correct* feedback is a modification of the knowledge of response feedback. The user is engaged in active error detection and is given several additional attempts to get a correct answer. The *elaborated* feedback presents not only the correct answer, but also additional information, for example, the part of the lesson text in which the subject of the task is described. Informative-tutoring feedback is a kind of elaborated feedback. The informative-tutoring feedback provides information that is important for completing the task, but does not immediately offer the correct solution (Narciss and Huth, 2004).

The elaborated feedback is classified by Kulhavy and Stock (1989) into

- task specific feedback, which provides information based on the task demand or the correct answer
- instruction based feedback containing information from the learning materials
- extra instructional feedback that includes additional information not only from the lesson environment, but also from other sources.

Mory (2003) reviews studies of the elaborated feedback, which compared the effects of different types of elaborated feedback to learning. The results shown by those studies were somewhat contradictory. Some of the experiments (for example Kulhavy and Stock, 1989) showed the positive effect of the elaborated feedback that provides maximum information to the user. Quite to the contrary, the other experimental studies demonstrated the positive effect of feedback with the minimum of the additional information (Kulhavy et al., 1985). A large number of studies demonstrated no effect of changes in feedback complexity on learning (Mory, 2003). Only half of the task-specific feedback studies demonstrated any significant improvements in learning (Mory, 2003). According to Mory (2003), analysis of information-based feedback resulted in the most inconsistent findings. Thus it is difficult to prescribe any rule for the use of either elaboration of information-based feedback (Kulhavy and Stock, 1989). Effectiveness of extra-instructional feedback on learning has not been studied enough (Mory, 2003).

The feedback can be presented in *textual*, *graphical*, *animated*, *audio*, or *video* form or in a combination of these ones. The most commonly used information presentation form for feedback is the *textual* one. In testing it is usually just several worlds like ‘yes’, ‘ok’ or ‘well done’ for the case of the correct answer and ‘no’, ‘try again’ in the opposite case. In computer games feedback is usually presented in *graphical* form – it can be some picture that illustrates the completed levels or progress bar. The number of works (for example, Czerwinski and Larson, 2003) emphasises the role of *audio* in feedback presentation. It is argued that audio feedback increases the attention and can motivate the user. In Majaranta et al. (2003, 2004) the effect of auditory and visual feedback on eye typing was studied. Their results showed that the form of feedback presentation affects typing speed, error rate, and the user’s gaze behaviour during eye typing. Their results suggested that auditory feedback (click or spoken) is a more effective indication of selection during eye-typing than visual feedback alone. *Animation* and *video*-form of presentation are typical for multimedia systems and computer games.

Feedback can be classified into *immediate* or *delayed* feedback by its time of occurrence. *Immediate* feedback is given to the user directly after the answer to the task. *Delayed* feedback is presented after the group of tasks, the whole test, or, after some period when the test is performed. Dempsey and Wager’s (1988) summary of the types immediate and delayed feedback is represented in Table 1.

Table 1 Immediate and delayed feedback: definition and categories

	Types of immediate feedback
Immediate feedback is informative, corrective feedback given to a learner or examinee as quickly as the computer’s hardware and software will allow during instruction or testing	Item by item
	Learner controlled
	Logical content break
	End of module (end of session)
	Break by the learner
	Time controlled (end of session)
	Types of delayed feedback
Delayed feedback is informative, corrective feedback given to a learner or examinee after a specified programming delay interval during instruction or testing	Item by item
	Logical content break
	Less than 1 hr (end of session)
	1–24 hr (end of session)
	1–7 days (end of session)
	Extended delay (end of session)
	Before next session

Source: Dempsey and Wager (1988)

The effect of immediate vs delayed feedback in learning has been experimentally tested by many researchers (Kulik and Kulik, 1988; Kulhavy and Wager, 1993). It is mainly argued that feedback should be immediate (Corbett and Anderson, 2001), because it maintains the user's attention, motivates him, and reduces unproductive floundering. However, the delayed feedback may contribute to better retention and transfer of skills (Schooler and Anderson, 1990).

Pashler et al. (2005) compare several different forms of feedback in learning of words task, assessing their impact on both immediate learning and delayed test of retention. The results indicate that when the learner gives a correct response, immediate feedback makes little difference for what can be remembered a week later. But in the case of the incorrect response the effect of immediate feedback significantly improves word memorisation.

In behavioural psychology there is classification of schedules of reinforcements (programs specifying the frequency and timing of reinforcements) into *ratio schedule* and *interval schedule*. The ratio schedule reinforcement rewards a subject after a certain number of responses, while interval schedule reinforcement provides a reward after a certain time interval (Zimbardo et al., 2006). Frequency and timing of reinforcements can be fixed or variable (time or number of the responses, after which the reinforcement is provided, can be fixed or variable, aperiodic or simply random (Ferster, 2002) that constitutes another dimension of classification of schedules of reinforcements (Zimbardo et al., 2006). Correspondingly, *fixed ratio* and *fixed interval* scheduling of reinforcements could be considered as delayed feedback, while *variable ratio* and *variable interval* reinforcements could be classified to *random feedback*. The concept of random reinforcement (also called intermittent or partial reinforcement) is based on Skinner's reinforcement theory (Skinner, 1957). The advantage of random feedback is that a user is motivated to continue learning because of expecting a reward, without knowing an exact time of its occurrence. According to Zimbardo et al. (2006) an advantage of random feedback is its resistance to extinction (commonly known as a process by which a learned response is weakened due to removal of reinforcement) that such (random) reinforcement produces.

Feedback could also be classified, by the user progress within the task, to *immediate, continuous* and *summative feedback*. *Immediate* feedback presents the results of one of the tasks. *Continuous* feedback provides the user with information about his or her performance in a number of tasks. *Summative* feedback presents a summarised result of a number of user's actions.

According to grading information feedback is classified into *formative* and *summative*. *Formative* feedback provides information about the learner's progress within the course. It includes grades, but it goes beyond grades with comments on written papers, brief conferences, or critiques (Dirks, 1997). *Summative* feedback is a final report on the learning outcomes and is characterised by the final grade (Dirks, 1997).

Feedback can be classified into *group* or *individual* feedback depending on the target (Hancock et al., 2005). *Individual* feedback is provided to an individual user. *Group* feedback is presented to a group of users who are working on the same task simultaneously or to a group of users with the same individual characteristics. It has been found (Hancock et al., 2005) that auditory feedback can be used to support individual performance or group awareness but it is difficult to support both simultaneously.

The feedback in web-based systems could perform the following functions:

- *confirmation* of getting the user's response
- *informing* the user about his or her performance (how many tasks were performed, number and ratio of correct answers, time of test processing, etc.)
- *correcting* the user (in the case she or he has not given a correct answer)
- *explanation* (the feedback could include an explanation about the reasons the user's answer was considered correct or guidance to the correct answer in the case of a wrong answer)
- *evaluation* (for example, in the case of an answer until correct feedback)
- *motivation* of the user
- *rewarding* the user
- *attracting* his or her attention.

The *motivational* functions can be divided into three main categories with regards to instructional goals and objectives (Narciss and Huth, 2004):

- cognitive, such as promoting information processing
- meta-cognitive
- reinforcement of correct responses.

According to the adaptation possibilities, feedback can be classified into *predefined*, *adaptable* and *adaptive* feedback. *Predefined* feedback (it can also be considered as adapted feedback) assumes that the feedback settings are predefined before the interaction process (or has already been adapted). Predefined feedback refers to feedback that is developed for a particular user (group of users) according to that user's abilities, personal characteristics, professional skills, etc. The simplest example of predefined feedback is a presentation of feedback in learning systems in the audio form for people with impaired vision. *Adaptable* feedback is feedback that can be customised by the user during the interaction process. For example, a student could set the time of feedback presentation (to show the feedback after each fifth task instead of after each task). *Adaptive* feedback unlike adapted feedback is dynamic. It allows varying feedback settings to different users according to their individual characteristics and performance. As an example of this one might consider dynamic adaptation of the frequency of feedback presentation according to a current level of the user's attention which could be estimated by the number of his mistakes during the interaction with the system.

It is the task of the researcher or developer to determine how she or he defines adaptation in the system and according to which principles it should work. Feedback could be adapted not only to a user, but also to a performed task and an environment. For example, if the task is aimed on the development of the mathematical skills for children – feedback might be presented not in a digital, but in a verbal or graphical form. In the case of the environment adaptation – feedback could be adapted to the environmental conditions such as illumination and noise.

3 Feedback in web-based learning applications

In web-based learning systems feedback plays a crucial role in interaction. The feedback is especially important in testing and assessment that is organised within the learning process. According to Brusilovsky and Miller (1999) testing components are the best developed interactive components in web-based education. Nevertheless, we consider these components as being poorly designed still. Most of the current testing components in e-learning and other web-based applications do not support feedback adaptation. They do not give information about the user's performance in the most suitable time and form for him or her.

In traditional distance learning (external, but not computer-based learning) feedback has been examined from a number of different perspectives (Hyland, 2001). The studies have shown that students especially wanted detailed feedback and comments. The feedback was expected to provide positive comments on strengths, not vague generalisations. It is recommended that criticism in feedback be constructive and that students should have a chance to respond to comments (Hyland, 2001).

According to Mory (2003) the feedback mechanisms that are used by students have changed with the advances and growth of web-based learning systems. The use of student-centred and constructivist approach in learning system supposes the use of learner-to-learner interaction and provides meaningful peer and instructor feedback (Dabbagh, 2002). According to Bischoff (2000) students need regular feedback in order to know how their performance was evaluated, how they could improve it, and how their grades are calculated. The effective elements of online teaching include *frequent and consistent* online feedback, *diplomatic* online feedback, and *evaluative* online feedback. Based on qualities of online feedback (multidimensional, nonevaluative, supportive, student controlled, timely, and specific) outlined by Schwartz and White (2000) and Mory (2003) has suggested that feedback in the web-based learning system should have the following qualities:

- prompt, timely, and thorough online feedback
- ongoing formative feedback about online group discussions
- ongoing summative feedback about grades
- constructive, supportive, and substantive online feedback
- specific, objective, and individual online feedback
- consistent online feedback.

In web-based learning applications the main functions of the testing component are to evaluate the users, to give the user information about his or her performance, to motivate the user, and to focus the user's attention on further interaction with the system. Feedback differs from evaluation, where the main goal is to grade and record the result of the testing for the purpose of assessing the user.

There are several main problems with feedback in web-based applications. First of all, there is the problem of feedback representation. It is widely argued in favour of explicit presentation of feedback, but there are too few ideas about what should be included into feedback and what kind of structure it should have. Naturally, the feedback should correspond to the tasks and to the individual characteristics of the user.

The effectiveness of different types of feedback in web-based learning system has been experimentally studied by Mandernach (2005), who evaluated the educational impact of presenting various levels of computer-based, online feedback (no-feedback, knowledge-of-response, knowledge-of-correct-response, topic-contingent, and response-contingent). The results of this study have shown that the type of computer-based feedback did not have any influence on student learning, but at the same time the students reported distinct preferences for knowledge-of-response and response-contingent computer-based feedback. This allowed to conclude that the students prefer feedback that is direct and clearly addresses the correctness of their response.

The other problem of feedback is the time of its presentation. The user could be provided either with immediate or with delayed feedback. According to Mathan (2003) the problem of feedback timing is of crucial importance for tutoring systems. He argued about the trade-off between the benefits of immediate and delayed feedback: while immediate feedback is more effective, delayed feedback supports better transfer and retention. The advantages and disadvantages of immediate and delayed feedback can change with different learning goals and settings.

The important question of feedback is that it can draw attention away from the tasks increasing the time required to execute them. According to Oulasvirta and Saariluoma (2004) interrupting messages such as feedback in human-computer interaction influence the extent and type of errors in remembering.

We argue that the problems of feedback discussed could be partially solved by adaptation of feedback to the tasks and to the characteristics of an individual user. Feedback adaptation in web-based applications can provide a user with feedback that is the most appropriate for his or her personal characteristics, actual mood, behaviour, and attentiveness (Choe et al., 2004).

4 Adaptation of feedback in learning systems

We would like to remind that there exists a principal distinction between adaptive and adaptable systems (Fischer, 2001). The difference is in the organisation of the adaptation process. In Table 2 we have tried to summarise the existing types of adaptation by the way how adaptation is organised in the system.

Table 2 Types of adaptation

Type of adaptation	*User*	*Developer/teacher/administrator*	*Intelligent system*
Adapted	–	+	–
Adaptable	+	–	–
Adaptive	–	–	+
Personalised	+	–	+

Adaptation in an adaptable system is performed by a user (with substantial system support), who changes the functionality of the system. Pesin (2003) presents an example of adaptable feedback in an e-learning system: the kind of feedback could be chosen, i.e., one could decide whether to show the correctness of answer to the user and/or whether to give him or her references to a learning object which could help solving the current task. An adaptive system supports dynamic adaptation by the system itself to the current task and the current user. A distinctive feature of an adaptive system is an explicit user model that represents user knowledge, goals, interests, and other features that enable the system to distinguish among different users (Brusilovsky and Maybury, 2002). An adaptive system collects data for the user model from various sources that can include observing user interaction and explicitly requesting direct input from the user. The notion of 'personalisation' has recently become popular for the World Wide Web's adaptive and adaptable applications (Kobsa, 2004). Thus personalised system could be either adaptive or adaptable.

In this section we discuss adaptation of feedback in web-based systems to the individual user, by analysing two main questions:

- to which individual characteristics of the user (user model parameters) feedback can be adapted
- what can be adapted in feedback of web-based systems?

We propose also a general conceptual framework for feedback adaptation in web-based learning systems.

Feedback adaptation to the user's individual characteristics is traditionally organised on the base of a *user model* (Kobsa and Wahlster, 1989; Kobsa, 1993). A *user model* determines user's goals, tasks, beliefs, and characteristics, which are important for adaptation (Kobsa, 1993).

A user model can never be complete and accurate; it is usually a rough approximation (Koch, 2001). Thus, the context of using and the goals of the user model based application should be considered during the user model design. For the task of feedback adaptation, user model could include psychological and cognitive parameters such as user's attention (reaction time, types of errors and omitted contents), memory, cognitive abilities (intelligence, educational level, verbal or spatial skills, etc., as estimates of these abilities), cognitive and learning styles, personal decision abilities, physiological parameters (vision and hearing), and parameters that characterise user's interaction with the system (number of mistakes, frequency of using help, and user's tasks and goals).

The user model acquisition is traditionally performed in the following ways (Brusilovsky, 2001):

- by getting information from the user during the initial questioning;
- in the process of user observation.

According to Kass and Finn (1987) methods of user model acquisition could be classified into explicit (i.e., the system asks the user for information about him or her), implicit (i.e., the system does user modelling based exclusively on its normal interaction with him or her) and mixed-mode acquisition.

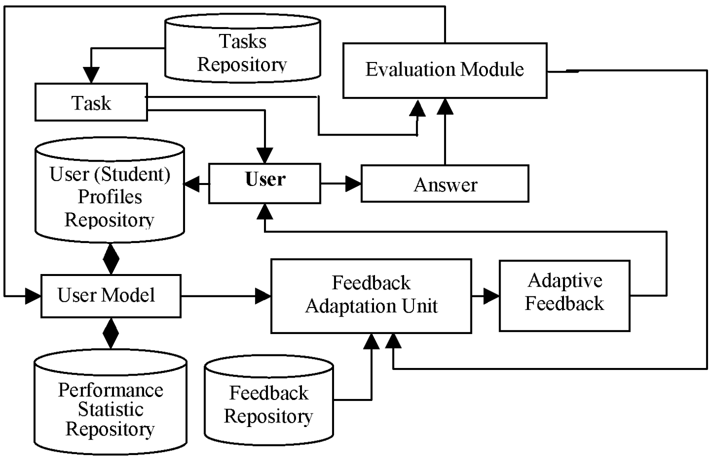
The user's features which are important for feedback adaptation can be collected in many different ways depending on the nature of the e-learning system. First, they can be collected using separate tasks developed for specific purposes or they can be derived from the performance of the user in the actual e-learning task. Secondly, the system can use some general 'prototypical' or stereotype user profile or previous information of the user's performance as a starting point.

The adapted parameters of feedback can be determined from a feedback taxonomy suggested in Section 2.2 (see Figure 3) and its characteristics analysis. The feedback in web-based systems can vary according to its *complexity*, *form of presentation*, *progress, function, lay-out* and *time of presentation*.

Above we listed a variety of feedback adaptation options. However, it is important to study the interrelations between the characteristics of the user model and adaptable feedback parameters to enable the implementation of the feedback adaptation in web-based learning systems. Studies of such interrelations between user characteristics and interface parameters have a long history in adaptive user interfaces research and usability studies (Benyon, 1993; Nielsen, 1993). Commonly, the results of such experimental studies enable discovery of certain pieces of knowledge related to how the feedback should be presented (adapted) to a user under certain circumstances (so-called preconditions which may include, for example, personal user characteristics and current state of the user modelling). This knowledge is usually presented in 'if-then' rules where 'if' preconditions, when they are true, cause 'then' adaptation effects. We analysed the knowledge used for adaptation of web-based learning systems in Vasilyeva et al. (2005b). Discovering pieces of knowledge and representing them in the 'if-then' rule form enables their direct use by an intelligent engine of an adaptive system as it has been done for example with the AHA! system (de Bra et al., 2003).

In Figure 4 we present the conceptual framework of feedback adaptation in web-based learning system.

Figure 4 Feedback adaptation in web-based learning system



The *User* of a web-based system is identified by the system (either his or her profile is in the repository or it is created by the system). During an interaction with the system the user gets a *Task* from the *Tasks Repository* and provides an *Answer* or an *Item.* The answer is compared with an expected 'correct' answer to this *Item* by the *Evaluation Module*. The result of the evaluation as well as the user model (information about the user from the *User (Student) Profiles Repository* and *Performance Statistic Repository*) is the input to the *Feedback Adaptation Unit*. Feedback adaptation unit includes a knowledge base where the logical rules that associate user (task, environment) characteristics with certain feedback parameters from *Feedback Repository* are stored. In feedback adaptation unit the most convenient form and time of feedback presentation is inferred according to the characteristics of the user (task, environment). The user model (*User Profile* and

Performance Statistic Repositories) is updated with the information obtained by the *Evaluation Module*.

5 Conclusions and further research

The paper presents a review of feedback studies. We proposed our taxonomy of the feedback concept with respect to the feedback adaptation in web-based learning systems. In this paper we considered the general framework of the feedback adaptation in web-based learning applications based on the user model. We overviewed the main characteristics of the feedback that could be adapted to the individual user characteristics and to the application's task. We hypothesise that feedback adaptation should improve the efficiency of the interaction with learning system and the efficiency of the learning process. The adaptation of feedback could help to solve such important dilemmas as feedback's timing and user's cognitive overload.

On the base of the existing feedback studies' review we can make the following conclusion. Feedback adaptation in web-based learning systems has been studied very selectively in the e-learning related research community. Our analysis and the examination of the existing studies according to taxonomy suggested in Section 2 allow finding out the kinds of feedback not (fully) addressed yet.

For further research an experimental study of the influence of user characteristics to the adaptable feedback parameters is necessary. It is important to investigate what user characteristics have an influence to the adaptable feedback parameters and how do they affect interaction and learning process. The experiments should allow obtaining knowledge about the interrelations between user model characteristics and adaptable parameters of feedback that could be used by an adaptation engine of a web-based learning system.

In the experiments it is necessary to determine personal user characteristics that are included to the user model. In experimental conditions this can be done by testing the user. During the study the user should perform a task, while being subjected to different types of feedback (one or several adaptable feedback parameters are varied), i.e., selected pairs of user's and feedback's characteristics should be studied. Such pairs could be, for example, user's attention – feedback time, user's age – feedback's complexity, etc. The effectiveness of a certain type of feedback could be evaluated by the analysis of the interaction results, the interaction process and the opinion of the user about the interaction. Principles of machine learning and statistics (correlation analysis) could be used for looking for patterns in two fixed sets of parameters (user model and set of adaptable feedback parameters) and analysis of interrelations between them.

Naturally we talk about an iterative process of research. Person characteristics, previous knowledge and contextual variables always create a complex intertwined system, where changing one variable may cause a large change in other relationships and, consequently, in results. These accumulated research results could then be used for construction of expert rules of interdependencies between user model parameters and adaptable feedback parameters. The resulting expert rules could be included to the adaptation unit of web-based learning system. This way the 'feedback generator' can become a feedback hypothesis testing machine, which tries to find suitable parameters for each user based on the expert rules and the adaptive feedback system (see Figure 4).

The study of how adaptation of feedback influences the users' performance is one of the prospective directions for the further research. The suggested classification of feedback could also serve as a map for the researchers to place their particular studies into the general framework of feedback research.

The ontological approach could be applied to further develop the understanding of the concept of feedback and possibilities of its adaptation. That will also help to understand how certain settings of feedback are related to or influence other settings.

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