In: G. Magoulas and S. Chen (Eds.) Advances in Web-based Education: Personalized Learning Environments, Idea Group Publishing, 2005

An Adaptive Feedback Framework to Support Reflection, Guiding and Tutoring

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Abstract. In this paper, an Adaptive Feedback Framework (AFF) is proposed, which forms the basis for the provision of personalized feedback accommodating learners' individual characteristics and needs in the context of computer-based learning environments. Multiple Informative, Tutoring and Reflective Feedback Components (ITRFC) are incorporated into the framework in order to support reflection, to guide and tutor learners towards the achievement of specific learning outcomes and to inform learners about their performance. The proposed framework adopts a scheme for the categorization of the learners' answer, introduces a multi-layer structure and a stepwise presentation of the ITRFC and supports adaptation of the provided feedback both in the dimensions of adaptivity and adaptability. In the context of the COMPASS tool, the proposed framework constitutes the basis for the provision of personalized feedback in concept mapping tasks. A preliminary evaluation of the framework in the context of COMPASS showed that the AFF led the majority of the learners in reviewing their maps, reconsidering their beliefs and accomplishing successfully the underlying concept mapping task.

1. Introduction

Feedback is considered as a key aspect of learning and instruction (Mory, 1996). Bangert-Drowns et al. (1991) emphasize that "… *any theory that depicts learning as a process of mutual influence between learners and their environments must involve feedback implicitly or explicitly because without feedback, mutual influence is by definition impossible. Hence, the feedback construct appears often as an essential element of theories of learning and instruction*". Effective feedback aims to (i) assist learners in identifying their false beliefs, becoming aware of their misconceptions and inadequacies, and reconstructing their knowledge, (ii) help learners to determine performance expectations, identify what they have already learned and what they are able to do, and judge their personal learning progress, and (iii) support learners towards the achievement of the underlying learning goals (Mory, 1996; Mason and Bruning, 2001). Thus, feedback should guide and tutor learners as well as stimulate and cultivate processes like self-explanation, self-regulation, self-evaluation, which require reflection (Chi et al., 1994; Vosniadou, 2001). Moreover, feedback should be aligned, as much as possible, to each individual learner's characteristics, since individuals differ in their general skills, aptitudes and preferences for processing information, constructing meaning from it and/or applying it to new situations (Jonassen and Grabowski, 1993).

Characteristics that influence the effectiveness of feedback concern the type of feedback, the amount of the provided information as well as the adaptation to learners' individual differences. Various types of feedback have been proposed and investigated in literature (see reviews by Bangert-Drowns et al., 1991; Mory, 1996; Mason and Bruning, 2001), providing different levels of verification and elaboration. The level of verification and elaboration determine the amount of the provided information. Moreover, many researchers introduce the notions of *adaptive feedback* (i.e. different learners receive different information) and *adaptable feedback* (i.e. learners have the possibility to choose the feedback that suits their needs or preferences) (Sales, 1993; Jackson et al., 1998) in an attempt to compensate for the weakness of generic feedback to "communicate" with learners and to provide personalized feedback. Empirical studies, investigating whether the type and the amount of feedback are related to the learners' individual differences, draw implications for the degree of success or failure experienced by learners. Hedberg and McNamara (1985) found that Field Dependent (FD) learners had fewer errors when their errors were explained and they were given strategies for correcting them, whereas Field Independent (FI) learners had fewer errors when only the correctness/incorrectness of their answer was provided. In the study of Arroyo et al. (2001), it was revealed that boys benefit more from explanations that are fast to check and go through, while girls devote their time to go through any kind of explanation and do better with hints that are highly structured and interactive.

As far as the adaptation of the provided feedback to learners' individual characteristics and needs is concerned, little systematic research is available. The studies reported in the feedback literature discuss either theoretical frameworks for adapting feedback mainly to learners' knowledge level or research efforts in the context of computer-based learning environments. In the latter case, the adaptation of feedback is usually based either on the structured form of the feedback supported (i.e. the amount of the provided feedback is gradually increasing or different types of feedback are provided gradually) or on one or more learners' individual characteristics such as knowledge level and gender. As far as the adaptable dimension of feedback is concerned, the research reported in literature is minimal; the proposed approaches allow learners to intervene in the feedback presentation process at a limited degree, by enabling them to select the type of feedback they prefer at a specific stage of the feedback process.

The research work, presented in this paper, takes previous work on feedback one step further by proposing an Adaptive Feedback Framework (AFF) that integrates adaptivity and adaptability, supports processes of tutoring, guiding and reflection and provides as much as possible a general-domain independent form of feedback in order to serve various domains. Multiple Informative, Tutoring and Reflective Feedback Components (ITRFC) are incorporated into the framework in an attempt to stimulate learners to reflect on their beliefs, to guide and tutor them towards the achievement of the learning outcomes addressed by an activity/task, and to serve learner's individual preferences and needs. The adaptivity of the AFF is based on the gradual provision of the ITRFC, which are structured in different layers and on the adaptive presentation of the ITRFC, which accommodates learner's knowledge level, preferences and interaction behavior. The adaptability of the AFF enables learners to have control over the feedback presentation in order to guide the adaptive dimension of the framework. The AFF was realized and preliminary evaluated in the context of the web-based concept mapping tool COMPASS.

The paper is organized as follows. In Section 2, research on the feedback area and especially on adaptive feedback is reviewed and the discriminative characteristics of the AFF are introduced. Following, in Section 3, the AFF is presented in detail, in terms of the proposed scheme for the categorization of the learner's answer, the different ITRFC incorporated into the framework, the multi-layer structure of the ITRFC and their stepwise presentation, as well as the adaptive and adaptable dimensions of the framework. In Section 4, our effort to use the proposed AFF in the context of the COMPASS tool is presented. In Section 5, the paper ends with concluding remarks and further research directions.

2. Literature Review on Feedback and Rationale for the AFF

In most computer-based learning environments, *feedback* is provided to learners at the end or during the elaboration of an activity/task/assignment, either (a) automatically by the system (computer-generated feedback) such as in INSPIRE (Papanikolaou et al., 2003), where the correction/incorrection of the answer is provided in conjunction with explanations, hints and examples, or (b) by the tutor (human-generated feedback) such as in FFS (Wang et al., 2004), where the tutor can give scores and make comments/suggestions to learners based on the learners' answer to the provided reflective questions, or (c) by peers (human-generated feedback) (in case of peer and/or collaborative assessment) such as in NetPeas (Lin et al., 2001), where the peers provide feedback to learners as answers to specific evaluation criteria. Regarding the first case, usually, different types of feedback are exploited and immediate feedback is provided; however most of these environments do not focus on the provision of personalized feedback and the appropriateness of the provided feedback depends on the capabilities of the system in analysing and evaluating the learner's answer. In the second case, the analysis and the evaluation of the learner's answer is carried out by the tutor without being restricted to the capabilities of the system and the feedback can be characterized potentially as personal as the tutor knows the learners on an individual basis; however delayed feedback is provided and the frequency and the quality of feedback may be limited in cases where a large number of learners are supported/guided by the tutor (Ross and Morrison, 1993). Since, we are interested in computer-generated feedback, which is adapted on learners' needs and preferences, in the following, research approaches falling under this area are presented.

A review of literature regarding the provision of *adaptive feedback*, showed that there are several research efforts which can be grouped in the following categories: (i) adaptive feedback schemes proposed at a theoretical level (e.g. Mason and Bruning, 2001), (ii) research efforts, especially in the context of computer-based tutoring environments; these efforts are based on the idea that the gradual provision of the appropriate feedback information represents a way of adapting the feedback to learners' needs (e.g. Narciss and Huth, 2004; Mathan and Koedinger, 2003; Mitrovic and Martin, 2000; Arroyo et al., 2000; Fiedler and Tsovaltzi, 2003), and (iii) research efforts investigating the provision of feedback based on learners' individual differences, which mainly concern learner's knowledge level and/or gender (e.g. Stern et al., 1996; Arroyo et al., 2001).

In Table 1, a presentation of various adaptive feedback approaches is attempted according to (i) their context (theoretical level or computer-based learning environments),

(ii) the underlying domain,(iii) the goals/processes served (guiding, tutoring, reflection), (iv) the types of feedback supported, (v) the adaptation process (adaptivity and adaptability) followed and (vi) the adaptivity mechanism supported (gradual provision of the same type of feedback or different types of feedback and/or adaptation of feedback according to one or more learner's individual characteristics).

The adaptive feedback mechanisms presented in Table 1, accommodate mainly the learners' knowledge level while a limited degree of flexibility is provided to learners to adjust and intervene in the feedback presentation process. In case of the gradual provision of feedback, usually the same type of feedback is provided in different steps, while the amount of feedback is differentiated. Also, the research approaches are mainly focused on the guiding and tutoring processes and they usually restrict the provided help in a domain-specific context. Thus, open issues in the area are (i) the design of a framework which supports the provision of adaptive as well adaptable feedback in a way that enhances learning and serves processes such as reflection, and (ii) the design of a general domain-independent form of feedback able to be incorporated in different learning environments and to serve a variety of domains.

In an attempt to elaborate on the above issues and contribute to the adaptive feedback area, we propose the Adaptive Feedback Framework (see Table 1), which exploits different types of feedback, takes into account several learners' individual differences, and supports learner control in order to integrate adaptivity and adaptability in the feedback process. The proposed AFF builds on and expands the abovementioned research efforts in the provision of personalized feedback in computer-based learning environments. It interweaves the gradual presentation of help with the adaptive presentation of feedback accommodating not only the learners' knowledge level but also their preferences and interaction behaviour and enables learners to intervene in the feedback provision process at various levels.

The AFF incorporates various Informative, Tutoring and Reflective Feedback Components, aiming to serve processes of assessment and learning by (i) informing learners about their performance, (ii) guiding and tutoring learners in order to identify their false beliefs, focus on specific errors, reconstruct their knowledge and achieve specific learning outcomes addressed by an activity/task, and (iii) supporting reflection in terms of encouraging learners to "stop and think" and giving them hints on what to think about. The ITRFC follow as much as possible a general domain-independent form in order to serve various domains. Also, the ITRFC are structured in different layers in order to support the gradual provision of the right amount of feedback information. The stepwise presentation of the ITRFC follows their layered structure and enables learners to elaborate on the feedback information and try again. Moreover, the presentation of the appropriate feedback components on each layer is adapted to the learners' knowledge level, preferences and interaction behaviour. As far as the adaptable dimension is concerned, learners have the possibility to intervene in the feedback presentation process by selecting the preferred layer of feedback and the preferred feedback component, in accordance with their own perceived needs and preferences.

Research Efforts	Context	Domain	Goal/Processes	Types of Feedback supported	Adaptation Process	Adaptivity Mechanism
Mason and Bruning (2001)	Theoretical Framework	Domain Independent	Assist developers and instructors in developing effective feedback in computer-based educational settings	(i) Knowledge-of-correct-response with response-contingent (ii) Knowledge-of-correct-response with topic-contingent (iii) Knowledge-of-response with topic-contingent (iv) Knowledge-of-response with delayed knowledge-of-correct-response plus response-contingent (v) Answer-until-correct with delayed topic-contingent	Adaptivity	Based on the learners' knowledge level and prior knowledge Variables such as task complexity and timing of feedback are taken into consideration for the adaptation of feedback
Narciss and Huth (2004)	An adaptive tutoring feedback algorithm is proposed and implemented in the context of a multimedia learning environment	Mathematics	Tutoring/Guiding	(i) Knowledge of response (ii) Bug-related feedback	Adaptivity	Gradual provision of different types of feedback following a 3-step feedback procedure
Excel Tutor (Mathan and Koedinger, 2003)	Computer-based learning environment	Computer Science	Tutoring/Guiding	(i) Questions having the form of multiple choice (ii) Succinct explanations of errors	Adaptivity	Gradual provision following a 3-step feedback procedure
SQL Tutor (Mitrovic and Martin, 2000)	Computer-based learning environment	Computer Science	Tutoring/Guiding	(i) positive/negative feedback (ii) error flag (iii) hint (iv) all errors (v) partial solution (vi) complete solution	Adaptivity Adaptability supported only for the last three types of feedback	Gradual provision of the first three types of feedback
Animalwatch (Arroyo et al., 2000)	Computer-based learning environment	Mathematics	Tutoring/Guiding	Hints	Adaptivity	Gradual increasing the level of information
Animalwatch (Arroyo et al., 2001)				Hints: a classification of the hints is supported according to their degree of symbolism and their degree of interactivity	Adaptivity	Adaptation based on learners' cognitive development and gender
Fiedler and Tsovaltzi (2003)	An algorithm proposed in the context of the DIALOG project	Mathematics	Tutoring/Guiding	Hints (A taxonomy of hints is supported)	Adaptivity	Gradual provision from less to more informative hints based on the number and kind of hints produced so far, the number of wrong answers and the category of the learner's answers

Stern et al. (1996)	Computer-based learning environment	Mathematics	Tutoring/Guiding	Hints	Adaptivity	Gradual presentation from simple to more specific hints Adaptation based on learners' knowledge level
Adaptive Feedback Framework (AFF)	Theoretical Adaptive Feedback Framework realized in the web-based learning environment COMPASS	Domain Independent	Reflection/Tutoring/ Guiding	(i) Correctness-Incorrectness of Response (ii) Correct Response (iii) Performance Feedback (iv) Tutoring Feedback Units associated with various modes of knowledge modules such as a definition, an example, a similar problem and solution of others (v) Explanation of the Response (vi) Belief Prompt-Rethink Write (vii) Error-Task Related Questions	Adaptivity Adaptability supported for all layers of feedback and feedback components	Gradual provision of the different types of feedback (feedback components) following their layered structure (four layers are supported) and based on the category of the learner's answer Adaptation based on learners' knowledge level, preferences and interaction behavior

Table 1. Presentation of various research efforts providing adaptive feedback including the proposed Adaptive Feedback Framework

3. The Adaptive Feedback Framework

In the following, we present the AFF in terms of (i) the answer categorization scheme adopted, (ii) the multiple ITRFC included, (iii) the layered structure of the ITRFC and the way these are presented to the learner, and (iv) the adaptive and adaptable dimensions of the framework.

3.1. An Answer Categorization Scheme

The generation of effective feedback depends heavily on evaluating the learners' answers during the interaction. In the AFF, learner's answer on an activity/task is evaluated according to specific criteria with respect to the expected answer defined by the tutor (expert's answer). The evaluation process aims not only at the determination of the correctness/incorrectness of the answer but also at the localization of the errors, if any, and at a meaningful characterization of the answer conveying the learner's error(s). To this end, an answer categorization scheme is proposed. The characterization of the learner's answer feeds the process of the stepwise presentation of the feedback components (see Section 3.3 and Figure 1).

In order to formulate the scheme for the categorization of the learner's answer, we define as (i) part of the answer: one or more elements constituting the learner's answer (e.g. in a fill-in-the-blank question, the learner's answer is consisted of the different parts required to be filled), (ii) complete answer: the answer in which all the required parts are present, independently of the correctness of the given values, (iii) accurate answer: the answer in which the values of all the given parts are correct.

The answer categorization scheme and the evaluation criteria proposed in the AFF build on the scheme proposed by Fiedler and Tsovaltzi (2003), i.e. completeness, accuracy and missing out, which is further enriched with the criteria of superfluity and non-applicability. According to our scheme, the learner's answer is characterised as:

- InComplete: when, at least, one part of the answer is missing and the rest given parts are accurate.
- InAccurate: when the answer is complete, but, at least, one part of the answer is inaccurate.
- InAccurate-Superfluous: when the answer is complete, but, at least, one part of the answer is inaccurate, and in particular this part is characterized as superfluous, i.e. it contains the required elements plus one or more elements. The learner's answer could also be characterized as inaccurate. However, we decided to discriminate these two characterizations as they locate different types of errors that should be individually treated by concretising the feedback components provided.
- Missing: when all the expected parts of the answer are missing.
- InComplete-InAccurate: when, at least, one part of the answer is missing and at least one of the rest parts is characterised as inaccurate.
- Complete-Accurate: when the answer is the expected one.
- Not Applicable: when it is not possible to evaluate the learner's answer and infer a safe conclusion.

3.2. The Informative, Tutoring and Reflective Feedback Components

The term ITRFC refers to the different components of feedback, which aim to stimulate learners to reflect on their beliefs, and guide and tutor them towards the enrichment/reconstruction of their knowledge and the successful completion of an activity/task. The proposed ITRFC exploit various feedback types reported in literature and offer different levels of verification and elaboration in order to serve learners' individual preferences and needs. The ITRFC are classified in the following three categories (see Table 2 and Figure 3 for indicative examples):

Informative Feedback: aims to inform the learner about the correctness of his/her answer and his/her performance, and includes the following components:

(a) *Correctness-Incorrectness of Response* (CIR), which informs learners whether their answer is correct/incorrect (in literature it is mentioned as knowledge-of-response/knowledge-of-result).

(b) *Correct Response* (CR), which supplies learners with the correct response (usually mentioned as knowledge-of-correct-response).

(c) *Performance Feedback* (PF), which informs learners about their current state; this information is included in the learner model, which is maintained by the system during the interaction, i.e. performance on the activity (before the provision of feedback), the concepts/topics that learners know, the number and the type of errors corrected, the number of attempts before each error correction, the number of errors for which the CR was provided, the total time spent for the accomplishment of the activity/task, the learner's preferences on the feedback components before and after the accomplishment of the activity/task (as they are recorded in the course of the elaboration of the activity based on the learner's interaction behaviour).

Tutoring Feedback: aims to tutor learners by enabling them to review learning material relevant to the attributes of the correct response and includes the following components:

(a) *Tutoring Feedback Units* (TFU), which supply learners with additional learning material. The TFU are structured in two levels, TFU1 (compulsory defined) and TFU2 (optionally defined), differing on the level of information detail they provide. In particular, TFU1 present the corresponding topic/concept in general and may be independent of the activity, while TFU2 present the corresponding topic/concept in more detail in the context of the activity/task under consideration. TFU2 are provided only if learner insists on his/her belief after providing TFU1. The TFU1 are associated with various modes of knowledge modules, which constitute multiple representations of the topic/concept under consideration. The knowledge modules are structured in two levels, *explanatory* level and *exploratory* level. The explanatory level includes the following modes of knowledge modules: (i) a *description* illustrating attributes relevant to the topic/concept under consideration and/or presenting the topic/concept in the context of related topics/concepts, and (ii) a *definition* of the topic/concept under consideration. The exploratory level includes the modes: (i) an *image*, (ii) an *example*, (iii) a *similar problem* followed by its solution, and (iv) any *solutions of others* given to the specific problem. It is considered necessary to provide, at least, one knowledge module from each level for every topic/concept. The multiple levels (i.e. explanatory and exploratory) and the different modes of knowledge modules aim to serve learners' individual preferences and to cultivate skills such as critical and analytical thinking, ability to compare and combine alternative solutions, ability to make generalizations, etc. In any case, the tutor is responsible to design and develop the appropriate knowledge modules of each level, taking into account several factors such as the content of the topic/concept under consideration, the difficulty level of the specific topic/concept, and the addressed learning outcomes.

(b) *Explanation of the Response* (ER), which informs learners about the correctness or incorrectness of their answer and explains why the incorrect response is wrong or why the correct response is correct.

Reflective Feedback: aims to promote reflection and guide learners thinking about their response, explore situational cues and underlining meanings relevant to the error identified. Two types of reflection prompts, generic prompts and directed prompts, are included. Generic prompts simply ask learners to “stop and think” without providing instruction in what to think about, while directed prompts give learners hints about what to think, attempting to point learners towards a particular direction (Davis, 2003). In this context, reflective feedback includes the following components:

(a) *Belief Prompt-Rethink Write* (BP-RW) (generic prompt), consisting of (i) the learner’s belief in order to bring the learner “in front” of his/her belief and encourage him/her to rethink his/her belief, and (ii) a prompt to write any keywords and/or explanations concerning his/her belief.

(b) *Error-Task Related Questions* (E-TRQ) (directed prompts), which gives learners a hint, in the form of question, to rethink and correct the identified false belief.

<table>
<tr><th>Categories of Feedback</th><th>Feedback Components</th><th colspan="2">The General Form of the ITRFC</th></tr>
<tr><td rowspan="3">Informative Feedback</td><td>Correctness-Incorrectness of Response (CIR)</td><td colspan="2">Your answer is [correct/incorrect]</td></tr>
<tr><td>Correct Response (CR)</td><td colspan="2">The correct answer is …………</td></tr>
<tr><td>Performance Feedback (PF)</td><td colspan="2">Your initial performance level on the activity is characterized as ……………..
You have learned the concepts ……..</td></tr>
<tr><td rowspan="2">Tutoring Feedback</td><td>Tutoring Feedback Units (TFU)</td><td colspan="2">A general form is not supported.</td></tr>
<tr><td>Explanation of the Response (ER)</td><td colspan="2">The answer is [correct/incorrect] because …</td></tr>
<tr><td rowspan="6">Reflective Feedback</td><td>Belief Prompt-Rethink Write (BP-RW)</td><td colspan="2">You believe that ……………………
Try to ……………
• [mention any keywords associated with your answer]
• [explain in a paragraph why you believe this]
• [execute the pseudocode statement by statement].
Do you insist on your belief?</td></tr>
<tr><td rowspan="5">Error-Task Related Questions (E-TRQ)</td><td colspan="2">The form of the E-TRQ depends on the categorization scheme for the learner’s answer (see section 3.1)</td></tr>
<tr><td>In case of a learner’s InComplete Answer</td><td>Do you really believe that the answer contains only the parts ……..?</td></tr>
<tr><td>In case of a learner’s Missing Answer</td><td>Do you consider that you could add ……...?</td></tr>
<tr><td>In case of a learner’s InAccurate Answer</td><td>Do you really believe that [Learner’s belief]? Or I believe that [Expert’s belief]. Do you agree with this?</td></tr>
<tr><td>In case of a learner’s InAccurate-Superfluous Answer</td><td>Do you want to reconsider the part ……. in your answer [Learner’s Belief]?</td></tr>
</table>

Table 2. The categories of feedback supported by the AFF, the feedback components included, and their general form (template). The general form of feedback (i.e. the sentence-starter and the questions) is denoted in italics, while in [], the learner’s or the expert’s belief as well as alternative statements that depend on the context are included.

Most of the ITRFC follow a general form (template), which is mainly domain-independent (see Table 2). However, specific parts of the general form depend on the domain under consideration, and the activity/task itself, aiming to provide meaningful help and guide learners to the appropriate directions. Moreover, the form of the E-TRQ depends on the proposed categorization scheme of the learner's answer (see section 3.1) and the TFU are domain-dependent feedback components.

3.3. Structuring and Presenting the Feedback Components

The ITRFC are structured in different layers and a stepwise presentation of the ITRFC, following their layered structure, is realized. The stepwise presentation offers the opportunity (a) to provide gradually the appropriate feedback information to each learner, and (ii) to enable learners at each step to exploit the feedback information and try again. To this end, the stepwise presentation of the ITRFC represents a way of adapting the feedback to learners needs. The following layers are supported:

- First Layer: The Belief Prompt-Rethink Write (BP-RW) feedback component and a combination of the Correctness-Incorrectness of Response (CIR) component with the BP-RW (CIR+BP-RW) are included. In case the learner's answer is characterized as complete-accurate, the BP-RW is provided in order to confirm the learner's confidence and enable him/her to rethink his/her belief (without informing him/her if it is correct or not) and explain the answer. In case the learner's answer is characterized as missing, the feedback components of the first layer are ignored. In all other cases, the CIR+BP-RW are provided. The provision of the feedback components of the first layer aims to enable learners to rethink their beliefs and to get into a self-explanation process in order to identify any errors made mainly by accident.
- Second Layer: The Error-Task Related Questions (E-TRQ) or the Tutoring Feedback Units (TFU) in conjunction with the E-TRQ (TFU+E-TRQ) are included. The provision of the specific feedback components aims to (i) guide learners and redirect their thinking by giving them a hint, and (ii) tutor learners by enabling them to review learning material relevant to the attributes of the expected answer. The specific components are provided according to the learners' individual characteristics (see Section 3.4).
- Third Layer: In the third layer, components that inform learners about the correct response as well as any accompanied explanations, if available, are included. The feedback components of the Correct Response (CR) or the CR in conjunction with the Explanation of the Response (CR+ER) are provided, according to the learners' individual characteristics (see Section 3.4). Also, the ER is provided in case the learner's answer is characterized as complete-accurate.
- Fourth Layer: Finally, in the fourth layer, the learners are informed about their performance. The Performance Feedback (PF) component is provided after the completion of the activity/task and enables learners to have access on their learner model as it is constructed in the course of the activity (see the adaptable dimension of the AFF in Section 3.4).

The proposed stepwise presentation is demonstrated below. At the beginning, the learner submits his/her answer, which is evaluated and characterized according to the proposed answer categorization scheme, presented in Section 3.1. The feedback components of the first layer are provided (1st step) in all cases except from the case of a "missing" answer (see Figure 1). Then, the learner elaborates on the feedback information provided and gives a new answer or insists on his/her belief. The former case (new answer) triggers the evaluation process and the presentation of feedback starts from the beginning (1st step). The latter case triggers the provision of the feedback components of the second layer (2nd step) (or the 3rd layer in case the learner's answer is complete and accurate), giving learner one more opportunity to exploit the feedback information. In case the learner does not insist on his/her previous answer and provides a new answer, the process starts from the beginning (evaluation and 1st step), while in case the learner insists on his/her belief, feedback components of the third layer (3rd step) are provided. The feedback component of the fourth layer is provided after the completion of the activity/task.

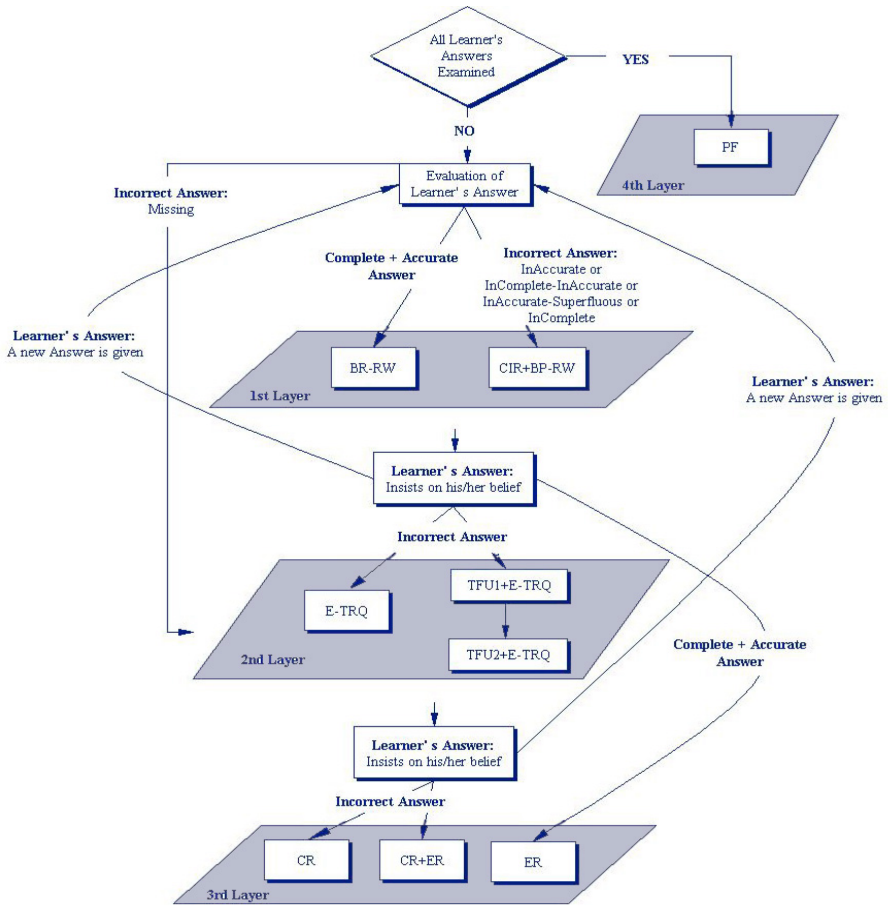

Figure 1. The stepwise presentation of the ITRFC based on their layered structure.

An indicative example, in the context of an introductory programming course, which demonstrates the proposed ITRFC and the transition from one layer to the next, is given in Figure 3. The activity under consideration (Figure 2) focuses on the "While Loop" and the changes which learners should perform include (i) the change of the control condition (statement no. 2; the correct answer is "While (count <= 12) do"), and (ii) the addition of the update statement of the control variable (after the [4] statement, the learner should insert the statement [5] count ← count + 1). In Figure 3, indicative answers that may be given by a learner, illustrating and clarifying the answer categories, are presented. Regarding TFU1, indicative knowledge modules of exploratory and explanatory level are given. In order to avoid complexity, some arrows from the feedback components of the 1st and the 2nd layer to the ER feedback component of the 3rd layer are omitted.

Consider the following problem: The computer lab of a high school consists of 12 computers. The teacher wants to write a program in order to keep a record of the serial numbers of the computers. Write a program, in the form of pseudocode, which reads the serial numbers of the computers. The following is a given solution in the form of pseudocode. You have to make all the required modifications in order to have a correct solution according to the context of the given problem.

Solution:

```
count <- 1
While (count = 12) do
      Write 'give the serial number of the computer'
       Read s_n
end_while
```

Figure 2. An activity in the context of an introductory programming course

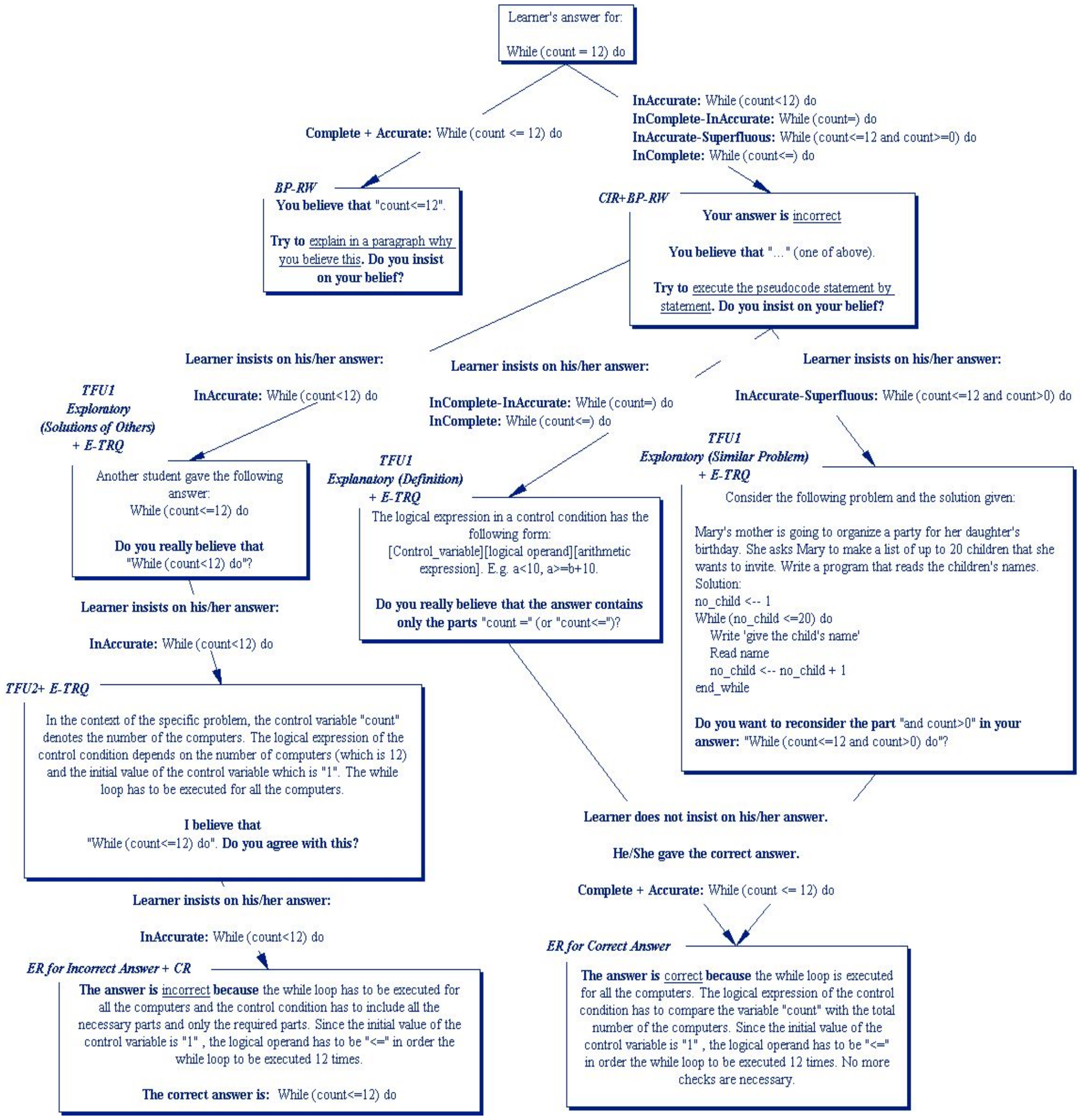

Figure 3. An example demonstrating the stepwise presentation of the ITRFC for a specific error on the control condition performed by a learner on the activity of Figure 2. In the boxes, the generated feedback messages are presented: the general form is denoted in bold, the part of the general form which is concretized in the context of the specific domain/answer is denoted in underline, the feedback content defined by the tutor is denoted in plain text, and the learner's belief (answer) or the expert's belief or the part of the learner's answer are denoted in " ".

3.4. The Adaptive and Adaptable Dimensions of the Feedback Framework

In the context of the AFF, adaptation is considered as the concept of making adjustments in the presentation of the available feedback components (see Section 3.3) in order to accommodate a diversity of learners' needs and preferences. The adaptive and adaptable dimensions of the AFF are based on learner's individual characteristics, which are maintained in his/her learner model. Thus, the learner model needs to keep information on learner's knowledge level, preferences on different feedback components and different levels of TFU1 (i.e. explanatory and exploratory), number and types of errors identified, learners' interaction behaviour (e.g. the times that specific feedback components have been selected by the learner). Initially the learner denotes his/her preferences and initiates the learner model, which is continuously updated during the interaction in order to keep always the "current state" of the learner.

With regard to the adaptive dimension of the framework, the learner's knowledge level, preferences and interaction behaviour are used as the main sources of adaptation during the feedback provision process. In particular,

- The *knowledge level* determines which feedback components of the second (E-TRQ or TFU+E-TRQ) and the third layer (CR or CR+ER) are going to be provided. For example, for learners with low knowledge level, the TFU+E-TRQ component is provided at the second layer, while for learners with high knowledge level, the CR component is provided at the third layer.
- The learners' *preferences* determine (i) the feedback components that will be available in case the learner's knowledge level is characterized as mediocre, and (ii) the levels of the TFU1 (i.e. explanatory or exploratory) that will be available in case that the TFU+E-TRQ is provided. For example, if the TFU+E-TRQ is to be provided and the learner prefers the explanatory (exploratory) level of TFU1, then one of the knowledge modules belonging to the explanatory (exploratory) level is provided (knowledge modules are selected randomly if all of them are available).
- The learners' *interaction behaviour* influences the presentation of the feedback components in the course of the second and the third layer. The attributes that are taken into account concern the number of times that the learner accessed specific (a) feedback components, (b) levels of TFU1, and (c) knowledge modules of TFU1. For example, if the exploratory level of TFU1 is to be provided and the favourite knowledge module of the learner is the example (as it is recorded from his/her interaction behaviour) and it is available for the specific concept/topic under consideration, then the example is provided, ignoring the random selection of the available knowledge modules. As the interaction behaviour of the learner may supersede the rules for the provision of feedback according to learners' knowledge level and preferences, it is necessary to define a threshold (may be the tutor) denoting the importance of the different types of rules. If the learner's observable behaviour exceeds the particular threshold then the interaction behaviour is taken into account.

The adaptable dimension of the AFF provides learners the option to (i) control the feedback presentation process by selecting the feedback component they prefer, the levels of the TFU1 (i.e. explanatory or exploratory) and the knowledge modules of the TFU1, ignoring the ones proposed by the framework, and (ii) check their learner model and update their initial preferences as well as their preferences inferred by the system during the interaction. This flexibility allows learners to play an active role in their own learning and make their own decisions to meet their own needs and preferences.

4. Providing Personalized Feedback in COMPASS on the basis of the AFF

The AFF was exploited and preliminary evaluated in the design of the feedback process of the web-based concept mapping tool COMPASS (COncept MaP ASSessment). In COMPASS learners undertake assessment activities, which are based on concept maps. A concept map is comprised of nodes (concepts) and links (relationships between concepts) (Novak and Gowin, 1984). Concept mapping is the process of organizing concepts in a hierarchical manner and forming meaningful relationships between them. As concept maps provide a means to capture, elicit and represent qualitative aspects of the learners' knowledge and promote meaningful learning (Novak and Gowin, 1984; Mintzes et al., 2000), they have been successfully used in many disciplines, particularly in science, as an instructional tool, as a tool to promote meaningful learning, as an assessment tool, and as a curriculum organization guide in teaching (Mintzes et al., 2000; Jonassen et al., 1997). In concept mapping environments, feedback is usually tailored to specific common errors identified on the learners' concept maps, without taking into account the learner's individual characteristics or needs (Chang et al., 2001; Cimolino et al., 2003).

Having as an objective to interweave assessment and instruction and exploit the value of concept maps as assessment and learning tools, we have developed COMPASS (Gouli et al., 2004b), which serves (i) the assessment process by employing a variety of activities and applying a scheme for the qualitative and quantitative estimation of the learner's knowledge, and (ii) the learning process through the "Knowledge Reconstruction + Refinement" (KR+R) process. The "KR+R" process aims to provide feedback, tailored to each individual learner in order to support reflection, to guide and tutor the learners and subsequently to enable them enrich/reconstruct their knowledge. To this end, the proposed AFF has been exploited in the design of the "KR+R" process. Following, we briefly present how each feature of the AFF has been used and "adapted" in the context of COMPASS. More specifically:

- The learner's answer categorization scheme supported by the AFF has been concretized and realized according to the proposed error categorization scheme for concept mapping tasks, presented in (Gouli et al., 2004a), and has been incorporated and implemented in the diagnosis process of the tool. More specifically, the characterizations used are: *incomplete* when an "incomplete relationship" or a "missing relationship" or a "missing concept and its relationships" or a "missing concept belonging to a group and its relationships" error is identified, *missing* for a "missing proposition" error, *inaccurate* for an "incorrect concept" or an "incorrect relationship" or a "concept at different palce" or "difference in arrow's direction" error, and *inaccurate-superfluous* for a "superfluous concept and its relationships" or a "superfluous relationship" error.
- The structure of the feedback components follows the four layers of the AFF.
  - The feedback components regarding the first, the third and the fourth layer, have been developed on the basis of the proposed general form of the ITRFC (Table 2).
  - The form of the error-task related questions (E-TRQ) (feedback component of the second layer) has been differentiated according to the specific error categories identified for concept mapping tasks (Gouli et al., 2004a).

- The tutoring feedback units (TFU) (feedback component of the second layer) concern (i) the concepts represented on the expert's concept map and/or the concepts included in the provided list of concepts (in case a list of concepts is supported) (TFUC), and (ii) specific propositions that the tutor anticipates errors/false beliefs (TFUP). Both the TFUC and the TFUP follow the structure described in the AFF for TFU.

The incorporation of the AFF in the "KR+R" process of COMPASS was based on two pilot empirical studies conducted in a real classroom environment of secondary education; the teacher simulated the function of the AFF, while the learners elaborated on concept mapping tasks addressing issues of the "Introductory Informatics" course (see Gouli et al. (2004a) for a detailed description of the studies). The aim of the first study was to investigate whether the stepwise presentation of the feedback components and the design of the E-TRQ, as the only source of feedback for the second layer, can help learners towards the direction of identifying their errors, reconsidering and correcting them appropriately. The results indicated that (i) all the learners after the provision of feedback improved their performance, (ii) the provision of the feedback components of the first layer was proved to be adequate and helped learners to check for accidental constructions, (iii) the form of the E-TRQ helped learners, especially those with knowledge level above average, in revising their beliefs and refining their knowledge, and (iv) in cases of learners with low knowledge level, a form of tutoring feedback was required in order to help them identify and revise their beliefs. The aim of the second study was to investigate whether the design of the adaptive dimension of the framework, can stimulate learners to revise their maps. As the study was carried out in a simulation mode, the learner's interaction behaviour was not considered as a source of adaptation. Although, the results were primitive, they have been encouraging, indicating that the proposed feedback framework led the majority of the learners in reviewing their maps, reconsidering their beliefs and accomplishing successfully the concept mapping task. However, data gathered from a larger sample, using COMPASS as a concept map assessment tool, under longer periods of time, are considered necessary for the evaluation of the AFF.

5. Discussion and Concluding Remarks

The research work, presented in this paper, contributes to the field of adaptive feedback in computer-based learning environments by proposing a feedback framework, which provides specific guidelines for incorporating an adaptive, an adaptable, and domain-independent feedback mechanism. The discriminative characteristics of the AFF, compared to other approaches in the area, are: (a) the use of multiple Informative, Tutoring and Reflective Feedback Components, which follow, as much as possible, a general domain-independent form and serve processes of guiding, tutoring and reflection, (b) the adoption of reflective feedback components that encourage learners to "stop and think" and give them hints indicating potentially productive directions for their reflection, (c) the structure and the variety of the tutoring feedback components (i.e. explanatory and exploratory levels and different modes of knowledge modules) that support learners with different preferences and cultivate various skills, (d) the structure of the ITRFC in multiple layers and their stepwise presentation that supports the gradual provision of feedback and enables learners to elaborate on the feedback information and try again, (e) the adaptive dimension of the framework that interweaves the gradual provision of the ITRFC with the adaptive presentation of the feedback, accommodating learners' knowledge level, preferences and interaction behaviour, and (f) the adaptable dimension of the framework that enables learners to undertake control over the feedback presentation in order to guide the adaptive dimension of the framework.

The design of the AFF and subsequently the structuring and presentation of the ITRFC follow specific guidelines for (i) encouraging the mindful behaviour that is the active examination/exploration of the feedback information by the learner (Bangert-Drowns et al., 1991; Morrison et al., 1995), (ii) prompting the learner at the beginning for rethinking his/her belief and providing self-explanations instead of the correct response (CR) (Chi et al., 1994; Rose et al., 2001), (iii) decreasing the risk that learning will be superficial by organizing in different layers and presenting in different steps the TFU and the CR (Schimmel, 1988), and (iv) allowing learners to try to accomplish the activity on their own (Narciss and Huth, 2004) before providing the CR or any explanations about the response (ER). The preliminary evaluation of the AFF during the implementation phase of COMPASS, was the first step towards a comprehensive evaluation study that needs to investigate several issues such as the effectiveness of the AFF in learner's learning achievement, in supporting processes of guiding, tutoring and reflection, in accommodating learner's individual differences as well as in supporting learner control of the feedback presentation. This evaluation study will be conducted in the context of a real computer-based learning environment, in the near future.

Furthermore, although the AFF may serve various domains, the extent to which a computer-based learning environment can incorporate AFF depends on the ability of the environment to automatically analyse the learner's answer in its constituent's parts in order to be assessed on the basis of the proposed answer categorization scheme (see Section 3.1). Moreover, in the AFF, the learner's answer is assessed with respect to the expected answer defined by the tutor. Further research should investigate the way that the AFF can be incorporated in learning environments where alternatives approaches of analyzing/assessing learners' answers (e.g. latent semantic analysis approach) are supported.

Finally, open issues in designing and developing computer-generated adaptive feedback that could direct future research are (i) the adaptable dimension of a feedback mechanism, i.e. how can the learner contribute to the feedback process and under which conditions s/he should undertake control over the system, (ii) how a feedback mechanism can stimulate and engage learners in the processes of self-regulation and self-explanation by enabling them to judge their answers in relation to those of peers, or judge their peers, (iii) how learners' cognitive and learning styles influence the effectiveness of particular components/modes of feedback and how these characteristics can be accommodated in the feedback process, and (iv) the use of natural language techniques for analysing/assessing learners' answers and generating adaptive feedback.

7. References

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