Feedback Strategies for Interactive Learning Tasks

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Susanne Narciss
Technische Universität Dresden

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Susanne Narciss
Learning and Instruction, Technische Universitaet Dresden, Germany

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ABSTRACT

Modern information technologies increase the range of feedback strategies that can be implemented in computer-based learning environments; however, the design and implementation of feedback strategies are very complex tasks that are often based more on intuition than on psychologically sound design principles. The purpose of this chapter is to present theoretically and empirically based guidelines for the design and evaluation of feedback strategies. To this end, this chapter describes an interactive, two-feedback-loop model that explains core factors and effects of feedback in interactive instruction (Narciss, 2006). Based on these theoretical considerations, a multidimensional view of designing and evaluating multiples feedback strategies under multiple individual and situational conditions is presented. This multidimensional view integrates recommendations of prior research on elaborated feedback (Schimmel, 1988; Smith and Ragan, 1993), task analyses (Jonassen et al., 1999), error analyses (VanLehn, 1990), and tutoring techniques (McKendree, 1990; Merrill et al., 1992).

KEYWORDS

Cybernetics: System theory concerned with the issues of regulation, order, and stability confronting us in the treatment of complex systems and processes.

Feedback: Output of a system that is fed back to the controller of the system as an input signal to regulate the system with regard to a reference value (cybernetic definition); post-response information that is provided to learners to inform them of their actual state of learning or performance (instructional context).

Informative tutoring feedback: Multiple-try feedback strategies providing elaborated feedback components that guide the learner toward successful task completion without offering immediately the correct response.

Interactive learning task: Tasks providing multiple response steps or tries and instructional components such as feedback, guiding questions, prompts, simulation facilities, and so on.

INTRODUCTION

For almost a century researchers have investigated the factors and effects of feedback involved in instructional contexts; consequently, the body of feedback research is very large. This large body of feedback research has been examined and revisited extensively by Edna Mory in previous editions of this Handbook (Mory, 1996, 2004). As space is restricted, the body of feedback research that was included in these previous reviews will be not revisited in detail here, but the insights of this research will be organized and outlined on the basis of a conceptual framework for designing and evaluating feedback for interactive learning tasks. To introduce this conceptual framework, definitions of the term *feedback* will be discussed first.

FEEDBACK IN INSTRUCTIONAL CONTEXTS: DEFINITION

The term *feedback* is a widely used concept in many technical and scientific domains (e.g., economics, electronics, biology, medicine, psychology). The concept of feedback is derived from cybernetics (Wiener, 1954), which is concerned with the control of systems—that is, with issues of regulation, order, and stability that arise in the context of complex systems and processes. In cybernetics, feedback refers to the output of a system that is fed back to the controller of the system as an input signal. This input/feedback signal closes the feedback loop and, in combination with an externally defined reference value, controls the system. In addition to the reference value and the feedback signal, the controller and the variable to be controlled are key elements. The controller stores the reference value, compares it with the current actual value, and, on the basis of this comparison, assesses what correction is required; hence, the effects of a feedback signal depend not only on this feedback signal but also all the other functional elements of the causal loop.

Since the development of Thorndike's (1913) law of effect, it has become well established in psychology that the consequences of a behavior may influence the rate and intensity of that behavior in future situations. In the domain of learning and instruction, feedback has been considered to be either a fundamental principle for efficient learning (Andre, 1997; Bilodeau, 1969; Bloom, 1976; Fitts, 1962; Taylor, 1987) or at least as an important element of instruction (Collies et al., 2001; Dick et al., 2001).

Some instructional researchers consider feedback in instructional contexts to be any type of information that is provided to learners after they have responded to a learning task (Wager and Wager, 1985). This notion of feedback is far too large because of the large variety of post-response information, and it does not include the idea that the information is presented with the purpose of allowing the learner to compare his or her actual outcome with a desired outcome to regulate or control the next attempt with this learning task. Experimental researchers thus use a more limited notion of feedback. They use the term *informative feedback* to refer to all post-response stimuli that are provided to a learner by an external source of information, according to experimentally defined rules and conditions, to inform the learner on his or her actual state of learning or performance (Annett, 1969; Bilodeau, 1969; Holding, 1965).

According to the cybernetic and experimental definitions, a general definition for feedback in instructional contexts might be as follows: *Feedback is all post-response information that is provided to a learner to inform the learner on his or her actual state of learning or performance*. In instructional contexts, this definition of feedback requires the differentiation among feedback presented by an external source of information and feedback provided by internal sources of information (i.e., information directly perceivable by the learner while task processing, such as proprioceptive information when performing a pointing task). This differentiation is particularly important from a methodological point of view; consequently, in early experimental feedback studies researchers tried to eliminate or control internal sources of feedback to investigate the effects of external feedback on learning and performance (for a review, see Bilodeau, 1969). The differentiation among external and internal feedback is also crucial if one investigates the effects of feedback on the basis of recent instructional models viewing the process of knowledge acquisition as a process of active knowledge construction and communication (Jonassen, 1999) or as a self-regulated learning process (Butler and Winne, 1995). This differentiation should be kept in mind when revisiting feedback research and considering feedback strategies.

External feedback may confirm or complement the internal feedback, or it may contradict the internal feedback. The latter case raises at least three questions:

- How do learners treat or cope with the discrepancy between internal and external feedback?
- What individual and situational factors contribute to a discrepancy between external and internal feedback?
- How can we design and evaluate feedback strategies that support learners regulating their learning process successfully if there is a discrepancy between internal and external feedback?

The first question has been addressed implicitly by the response certitude model of Kulhavy and his collaborators (Kulhavy and Stock, 1989; Kulhavy et al., 1990a,b; Stock et al., 1992) and by the five-stage model of mindful feedback processing (Bangert-Drowns et al., 1991). Furthermore, it was explicitly the focus of Butler and Winne's theoretical synthesis regarding feedback and self-regulated learning (Butler and Winne, 1995). These models have been described and discussed in detail in Mory's prior reviews (Mory, 1996, 2004).

The second question has been answered indirectly as a result of meta-analyses that showed that external feedback effects are not always positive and thus tried to identify possible moderators for the efficiency of external feedback (Bangert-Drowns et al., 1991; Kluger and DeNisi, 1996). The insights of these meta-analyses are integrated in the conceptual framework elaborated below.

The third question, one of the most crucial questions for instructional design and practice, has been in part addressed by researchers developing and evaluating intelligent tutoring systems (ITS). Detailed reviews of the insights of ITS research are provided by Anderson et al. (1995) and VanLehn et al. (2005); see also Chapters 24 and 27 in this Handbook. Core issues and insights from prior research with regard to this question are discussed below.

A CONCEPTUAL FRAMEWORK FOR FEEDBACK IN INTERACTIVE INSTRUCTION

This section focuses on feedback for interactive (computer-based) learning tasks that is provided by an external source of information (e.g., an instructional program, a teacher) to contribute to the regulation of the learning process in such a way that learners acquire the knowledge and skills required to master these tasks. As elaborated in the next sections, internal feedback is considered an important factor for treating the information provided by the external feedback. Conceptualizing feedback as an instructional activity that aims at contributing to the regulation of a learning process makes it possible to use the core insights provided by models of instruction and self-regulated learning (Bloom,1976; Boekaerts, 1996; Carroll, 1963) to analyze possible factors and effects of informative feedback. Instructional models are based on the assumption that the effects an instructional activity can have are determined by the quality of the instructional activity (e.g., scope, nature, and structure of the information provided and form of presentation), individual learning prerequisites (e.g., previous knowledge, metacognitive strategies, motivational dispositions, and strategies), and situational factors in the instructional setting

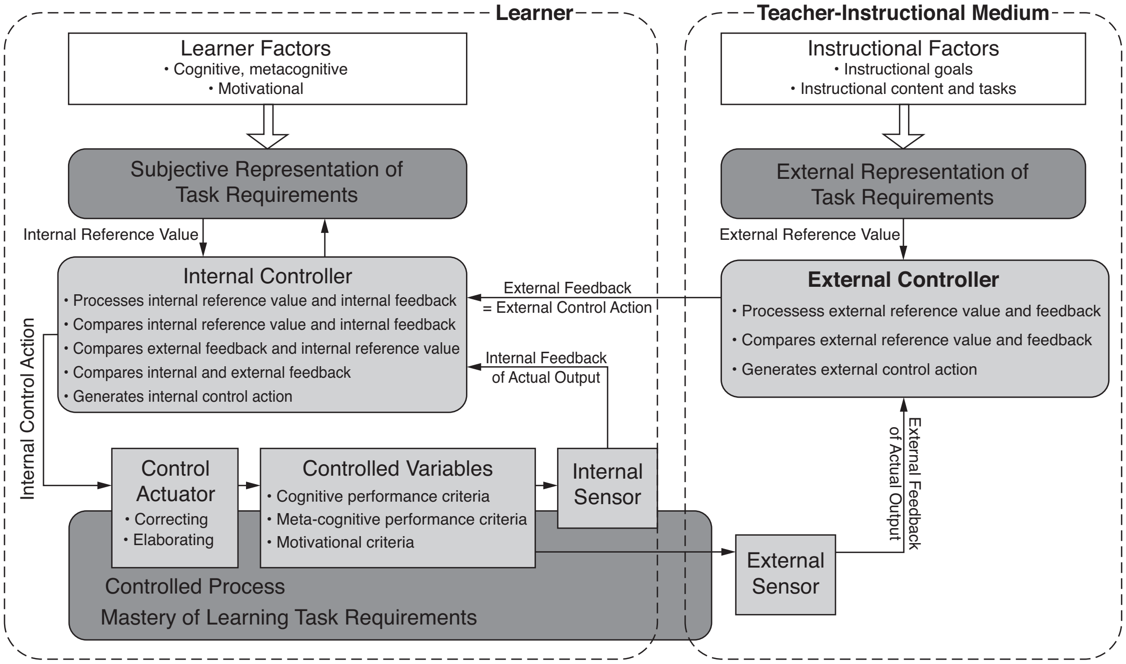

Figure 11.1 Overview of the components of the ITFL model. (From Narciss, S., *Informatives tutorielles Feedback. Entwicklungs- und Evaluationsprinzipien auf der Basis instruktionspsychologischer Erkenntnisse (Informative Tutoring Feedback)*, Waxmann, Münster, 2006. With permission.)

(instructional goals, learning content, and tasks). The current conceptual framework links these issues with systems theory and attempts to integrate findings from systems theory with recommendations from prior research on elaborated feedback (Schimmel, 1988; Smith and Ragan, 1993), on task analysis (Jonassen et al., 1999), on error analysis (VanLehn, 1990), and on tutoring techniques (Anderson, et al., 1995; McKendree, 1990; Merrill et al., 1992; VanLehn et al., 2005).

Basic Assumptions

The basic components of a generic feedback loop serve as the starting point for formulating a feedback model with two interacting feedback loops: the interactive, two-feedback-loop (ITFL) model:

- Identification or definition of the variables that should be controlled
- Continuous measurement of these controlled variables by a sensor
- Feedback of the actual values of the controlled variables to a controller
- Reference value for each controlled variable that is predefined and stored in the controller
- Comparison of the actual values of the controlled variables with (predefined) reference values by the controller

Note: If there is a discrepancy between the actual and the reference value, the controller must transform this discrepancy into a control action.

- Transmission of this control action to a control element (control actuator)
- Execution of the control action by a control actuator

According to systems theory, the control actuator that carries out the control actions, the controlled variables, and a sensor that measures the controlled variable are key elements of the controlled process. To regulate the controlled process, the controller requires the reference value, the actual value provided by feedback, and comparison and transformation procedures for generating the control actions.

In the ITFL model, the controlled process is defined as the carrying out of learning tasks or the mastering of the demands associated with these tasks. Building on models of self-regulated learning (Boekaerts, 1996) as well as the approach of Butler and Winne (1995), this model distinguishes among cognitive, motivational, and metacognitive demands (see Figure 11.1). Quantifiable controlled variables for these criteria could include carefully defined and operationalized cognitive, metacognitive, or motivational indicators of mastery of particular task requirements.

When regulatory paradigms from systems theory are applied to an instructional context containing external feedback, two interacting feedback loops must be considered: (1) an internal feedback loop that processes internal feedback, or the actual values to which the learner has direct access (e.g., confidence in answers, perceived effort); and (2) an external feedback loop that processes the actual values determined by the learning medium (e.g., the instructor, learning program, experimenter).

A distinction between external and internal feedback loops means that it is also necessary to differentiate between the following elements:

- *Sensors*—Internal and external feedback loops require a diagnostic component that registers the actual values of the controlled variables.
- *Reference values*—Control of internal and external feedback loops can only be carried out on the basis of relevant reference values. In the ITFL model, it is assumed that internal reference values are generated on the basis of a subjective representation of the demands of learning tasks, whereas external reference values are based on an external representation of these demands. Subjective task representations are mainly governed by individual prerequisites such as existing knowledge, metacognitive and motivational strategies, and individual learning goals. External representations of task demands are closely related to the features of an instructional context, particularly to the specific instructional goals.
- *Controller*—For the actual values registered by the internal and external sensors to be processed, each requires a component in which reference and actual values can be compared; thus, both external and internal controllers in which this process can be carried out are needed.

In an instructional context that provides external informative feedback, the differentiations made in the ITFL model lead to the following assumptions regarding the interaction between internal and external feedback loops:

- The starting points for internal and external regulatory processes are the relevant controlled variables for the particular controlled process (i.e., mastery of learning task requirements).
- The actual value of the controlled variable or variables is registered by both the learner and by an external actor such as an instructor or a computer-based instructional system.
- External actual values are initially processed externally in the external controller of the teaching medium. The external reference value, the comparison between the reference value and the actual value, and the externally specified rules for calculating the correction value determine the initial value of the external controller. This initial value, which in systems theory would be referred to as an *external correction variable*, is fed to the internal controller as external feedback.
- This external feedback is processed in the internal controller along with the internal actual value (i.e., internal feedback). This means that several comparisons must be carried out by the internal controller. These include comparisons between:
  - Internally measured actual value (internal feedback) and internal reference value
  - External feedback and internal feedback
  - External feedback and internal reference value
- From these comparison processes a correction variable (i.e., an internal correction variable) must be generated. The learner's main task in this case is to locate the source of any discrepancies that are detected between these various values. Such discrepancies can occur when, for example, internal or external sensors register feedback values inaccurately, the quality of internal or external feedback is poor, or the subjective task representation is incorrect or imprecise and thus leads to incorrect reference values. The results of this causal analysis are important for calculating the internal correction variable. This means that the internal correction variable is the result of a number of internal processing procedures.
- The internal correction variable is channeled to the first stage of the controlled process—the control element—where it serves as the basis for selection and activation of corrective measures. These corrective measures can in turn have an impact on the controlled variables.

Factors Affecting the Efficiency of External Feedback

The assumptions of the ITFL model lead to the conclusion that the efficient regulation of task processing with external feedback may be affected by factors of both the internal and the external feedback loops. Both feedback loops contribute to the regulation of the same controlled process, which is characterized by the requirements of the learning tasks.

Requirements of Learning Tasks and Instructional Objectives

As mentioned above, the starting point for both feedback loops is the controlled process, which can be more or less complex depending on the requirements of the learning tasks and the instructional objectives. For a system to be regulated successfully, it is crucial that its controlled process be described carefully and precisely. At the same time, it is necessary to define which variables will serve as controlled variables that will be measured and regulated, how these are to be measured, and the procedures through which corrections are to be carried out. In instructional contexts, this involves initially analyzing exactly what requirements are associated with the instructional content, goals, and tasks. Moreover, to select corrective measures for the regulation of controlled variables, the errors and difficulties that could arise in connection with mastering task requirements must also be identified, as well as the information and strategies that are necessary to eliminate these errors or difficulties.

Instructional content, goals, and tasks may be more or less complex concerning their requirements. Bloom's revised version of the taxonomy of learning objectives may serve as a basis for categorizing task requirements (Anderson et al., 2001). Analyzing learning task requirements on the basis of this taxonomy makes it clear that it is more difficult to identify precisely the content-related, cognitive, metacognitive, and motivational requirements for complex tasks (i.e., those that require higher order, content-related knowledge or operations) than for simple tasks. As a consequence, one may assume that the internal and external feedback loops might function less efficiently for complex learning tasks. The notion that task complexity affects the internal feedback loop was, for example, identified in Mory's studies, which aimed at generalizing Kulhavy and Stock's model of response certitude (Mory, 1994, 1996, 2004). Mory found that for higher order learning tasks, students' response certitude could not be used as a reliable measure for adapting feedback, because students were not able to assess their answers to these tasks correctly (in terms of the ITFL model, they were not able to generate a reliable internal feedback).

This assumption is also reflected in many studies on elaborated feedback that were conducted to investigate the hypothesis that elaborated feedback is more effective with more complex tasks; however, results of these studies are rather mixed (see reviews by Azevedo and Bernard, 1995; Bangert-Drowns et al., 1991; Mory, 1996, 2004). Yet, feedback studies that developed elaborated feedback on the basis of thorough analyses of task requirements generally found the developed elaborated feedback types to be superior to simple outcome feedback (Birenbaum and Tatsuoka, 1987; Nagata, 1993, 1997; Nagata and Swisher, 1995; Narciss, 2004, 2006; Narciss and Huth, 2004, 2006). In some studies, however, with very complex and difficult tasks or with serious errors, elaborated feedback was not efficient even if it was developed on the basis of task analyses (Birenbaum and Tatsuoka, 1987; Clariana and Lee, 2001; Nagata, 1997).

Internal Loop Factors: Prior Knowledge, Cognitive, Metacognitive, and Motivational Skills

According to the ITFL model, the learner's representation of task requirements, the learner's ability to assess his or her responses (quality of the internal sensor), the learner's abilities and strategies with regard to analyzing and comparing internal and external information and identifying corrective actions (quality of the internal controller), and, finally, the learner's abilities and motivation in applying these corrective actions (quality of the control actuator) are core factors contributing to the efficiency of the internal feedback loop. All internal factors influence the external feedback loop because the two loops interact.

Subjective Task Representation: Prior Knowledge

The starting point for processes in the internal controller is a precise definition of reference values of controlled variables. These reference values are generated on the basis of how learners understand and represent the requirements of the learning tasks. Meaningful reference values can only be generated if the subjective representation of task requirements is adequate. Whether learners are able to represent task requirements adequately and precisely depends on the complexity of these requirements but also on individual factors such as prior knowledge, metacognitive knowledge, and strategies and motivation. How much individual difference in subjective task representations affects the impact of feedback on learning is an interesting question for future research.

Learners' Self-Assessment Skills

Comparing the reference values with the actual values of controlled variables yields meaningful information only if the actual values of the controlled variables are determined accurately. In the internal loop, this depends a great deal on learners' abilities or skills in assessing their responses and performance (Mory, 1996, 2004). Learners must identify indicators for each task requirement that can help them evaluate the extent to which the task requirements are fulfilled. How external feedback may support the acquisition of self-assessment skills is another interesting issue for future research.

Learners' Skills and Strategies in Information Processing

To generate an appropriate control action, learners must compare the internal and external feedback, the internal feedback and reference values, and the external feedback and the internal reference values. As discussed in the five-stage model of mindful feedback processing (Bangert-Drowns et al., 1991) and in Butler and Winne's (1995) synthesis on feedback and self-regulated learning, many individual factors may affect how learners process these informational components, particularly when discrepancies exist between the different components.

Learners' Will and Skills in Overcoming Errors and Obstacles

As shown in studies on feedback seeking, even the most sophisticated feedback is useless if learners do not attend to it (Aleven et al., 2003; Narciss et al., 2004) or are not willing to invest time and effort in error correction. In addition to having the will, students also need the skills necessary to fulfill the requirements related to error correction. Butler and Winne (1995) derived six maladaptive ways of feedback seeking and processing from Chinn and Brewer's (1993) work on how misconceptions may hinder conceptual change: Students may (1) ignore the external feedback, (2) reject the external feedback, (3) judge the external feedback irrelevant, (4) consider external and internal feedback to be unrelated, (5) reinterpret external feedback to make it conform to the internal feedback, or (6) make superficial rather than fundamental changes to their knowledge or beliefs. In all these cases, the effect of the external feedback will be small.

External Loop Factors: Instructional Goals, Diagnostic Procedures, Feedback Quality

In addition to these internal loop factors, the ITFL model attracts attention to external loop factors that might affect the efficiency of both feedback loops. These include the external representation of task requirements related to the instructional goals; the accuracy of the diagnostic procedures assessing learners' responses (equal to the quality of the external sensor); the teaching medium abilities and strategies with regard to analyzing learners' responses—namely, errors—and identifying corrective actions with regard to these errors (quality of the external controller); and, finally, the teaching medium's ability in communicating these corrective actions (equal to the quality of the external feedback).

External Representation of Task Requirements and Instructional Goals

The starting point for processes in the external controller is a precise definition of reference values of controlled variables. In the external loop, these reference values are generated on the basis of how the instructional medium (e.g., teacher, computer-based learning environment) represents the requirements of the learning tasks. As in the internal loop, meaningful reference values can only be generated if the representation of task requirements is adequate. This means that learning goals must be operationalized in such a way that valid and reliably verifiable learning outcomes can be defined in the form of reference values. As mentioned above, this might be more difficult for more complex task requirements.

Accuracy of Diagnostic Procedures

In the external loop, the controlled variables must also be diagnosed accurately to make the comparison between the reference values with the actual values of controlled variables meaningful. This, in turn, means that the indicators appropriate for measuring different levels of mastery in a valid and reliable way must be determined. How challenging an accurate diagnosis might be is elicited in a recent study of Chi et al. (2004) on the accuracy of human tutors. Chi and her colleagues found that tutors were only able to assess students' understanding from their own perspective, and they were not able to diagnose students' alternative understanding from the perspective of the students' knowledge.

Quality of External Data Processing and Feedback Design

If a discrepancy between the actual and reference values of controlled variables is detected, a correction variable must be defined. A key issue here is how well the external controller (i.e., the learning medium) is able to transform this discrepancy value into a correction variable that has a high level of information relevant to mastering the task requirements. Especially with difficult and complex learning tasks, a series of transformations may be necessary so learners can obtain information about the external correction variable (external feedback) that they can use to correct errors or overcome obstacles. The starting point for the necessary transformational steps is precise knowledge of the controlled process. It is necessary to know which factors, in the sense of controlled variables, are responsible for the system's performance and thus must be addressed by the correction variable—that is, the external feedback.

DESIGNING AND EVALUATING (TUTORING) FEEDBACK

Researchers used a large variety of feedback types. Widely used feedback types include:

- *Knowledge of performance* (KP) provides learners with a summative feedback after they have responded to a set of tasks. This feedback contains information on the achieved performance level for this set of tasks (e.g., percentage of correctly solved tasks).
- *Knowledge of result/response* (KR) provides learners with information on the correctness of their actual response (e.g., correct/incorrect).
- *Knowledge of the correct response* (KCR) provides the correct answer to the given task.
- *Answer-until-correct* (AUC) *feedback* provides KR and offers the opportunity of further tries with the same task until the task is answered correctly.
- *Multiple-try feedback* (MTF) provides KR and offers the opportunity of a limited number of further tries with the same task.
- *Elaborated feedback* (EF) provides additional information besides KR or KCR.

Complex elaborated feedback exists in multiple forms and is thus related to a large if not fuzzy set of meanings. Several authors have attempted to classify the numerous feedback types (Dempsey et al., 1993; Kulhavy and Stock, 1989; Mason and Bruning, 2001; Schimmel, 1988). There is some congruency with regard to classifying simple feedback types such as KR or KCR, even though these feedback types are sometimes denoted by different terms (e.g., knowledge of result, confirmation feedback, simple verification feedback, knowledge of the correct answer/response). The various classifications differ, however, in how they organize the different types of elaborated feedback: Kulhavy and Stock (1989) differentiate among *task-specific* elaborated information, which in cases of multiple-choice tasks is considered to be knowledge of the correct response; *instruction-based* elaborated information (e.g., hints to the section of the instructional text that is relevant for answering the task); and *extra-instructional* elaborated information, which goes beyond the instructional text and might, for example, address metacognitive strategies. Mason and Bruning (2001) differentiate among the following elaborated feedback components: *topic-contingent* (provides item verification and general information concerning the topic), *response-contingent* (provides KR, KCR, and explanations as to why answers are correct or incorrect), *bug-related* (provides KR and error-specific information) (Schimmel, 1988), and *attribute isolation* (provides KR and highlights the relevant attributes of the concept) (Merrill, 1987).

Comparing these classifications reveals that feedback types can vary in functional, content-related, and formal characteristics. One may conclude that the nature and quality of an external feedback message is determined by at least three facets of feedback: (1) functional aspects related to instructional objectives (e.g., cognitive functions such as promoting information processing, motivational functions such as reinforcing correct responses or sustaining effort and persistence); (2) semantic aspects related to the content of the feedback message (e.g., frequency, timing, mode, amount, form); and (3) formal and technical aspects related to the presentation of the feedback message (Narciss, 2006; Narciss and Huth, 2004).

The purposes of the following sections are (1) to present principles for selecting and specifying the functional, content-related, and formal dimensions of elaborated feedback components that can be implemented in a tutoring feedback algorithm, and (2) to outline implications for future feedback research.

Selecting and Specifying the Functions of External Feedback

Different theoretical frameworks use different types of feedback and attribute different functions to feedback in learning situations. From a behavioral viewpoint, feedback is considered to reinforce correct responses. In behavioral learning contexts, the focus of interest is therefore more on formal and technical feedback characteristics such as frequency and delay than on the complexity of the feedback contents; hence, behavioral studies use outcome-related feedback types such as knowledge of result or knowledge of the correct

TABLE 11.1
Feedback Functions in Four Sources

Cusella (1987)	Sales (1993)	Wager and Mory (1993)	Butler and Winne (1995)
Reinforcing	Stimulating	Confirming	Confirming
Informing	Informing	Informing	Informing
Indicating	Guiding	Indicating	Indicating
Motivating	Motivating	Motivating	Correcting
Regulating	Regulating	Correcting	Making suggestions
Instructing	Instructing	Instructing	Completing knowledge
	Assessing	Assessing	Differentiating
	Advising		Restructuring

response (for a review, see Kulik and Kulik, 1988). From a cognitive viewpoint, feedback is considered a source of information necessary for the correction of incorrect responses (Anderson et al., 1971; Kulhavy and Stock, 1989). The question of which type of elaborated feedback information is most efficient is of major interest in cognitive feedback studies; however, in most of these studies even elaborated informative feedback has only been conceptualized as seeking to confirm or change a learner's domain knowledge. Feedback models that view feedback in the context of self-regulated learning theorize that the most important function of feedback is tutoring or guiding the learner to regulate the learning process successfully (Butler and Winne, 1995).

This brief summary of prior research reveals that feedback can affect the learning process at various levels, and can therefore have numerous different functions. For this reason, a number of authors have made more subtle distinctions (Butler and Winne, 1995; Cusella, 1987; Sales, 1993; Wager and Mory, 1993) (see Table 11.1). A comparison of these differentiated treatments of feedback functions reveals that all of these authors advocate feedback as an acknowledging or reinforcing function, an informing function, and some form of guiding or steering function. Moreover, all of them have postulated a regulatory or correcting function for feedback. In addition, Cusella (1987), Sales (1993), and Wager and Mory (1993) drew attention to the motivational and instructional function of feedback. Butler and Winne (1995) described at least three subfunctions of the instructing function (tuning or completing, differentiating, and restructuring). In addition, these authors have pointed out that feedback can activate metacognitive processes such as monitoring or information seeking.

If external informative feedback is viewed from the standpoint of the current ITFL model, it becomes clear that as a general rule multiple feedback functions come into play simultaneously, according to how the controlled and command variables are defined. On the basis of the models of good information processors (Pressley, 1986), intelligent novices (Mathan and Koedinger, 2005), and self-directed learning (Boekaerts, 1996), possible feedback functions can be defined from the cognitive, metacognitive, and motivational standpoints. Because finer differentiations of feedback functions make it possible to work out which information will be useful in which settings, careful selection and specification of the intended feedback functions provide the basis for designing tutorial feedback.

Cognitive Functions

In the case of complex tasks, incorrect answers and solutions can occur for widely varying reasons (VanLehn, 1990). The content-related, procedural, or strategic knowledge elements that a learner needs to arrive at a correct solution may be lacking, erroneous, or imprecise. The necessary knowledge elements may also be incorrectly linked or the conditions for their use incorrect or ill-defined. Feedback can offer information on all of these aspects. A distinction can be made between the following cognitive feedback functions in connection with incorrect responses:

- An informative function in cases where the number, location, and type of error or reason for the error are unknown
- A completion function in cases where the error is attributable to lack of content-related, procedural, or strategic knowledge and the feedback provides information on the missing knowledge
- A corrective function in cases where the error is attributable to erroneous content or erroneous procedural or strategic elements and the feedback provides information that can be used to correct the erroneous elements
- A differentiation function in cases where the error is attributable to imprecise content-related, procedural, or strategic knowledge elements and the feedback provides information that allows for clarification of the imprecise elements
- A restructuring function in cases where the error is attributable to erroneous connections between content, procedural, or strategic elements and the feedback provides information that can be used to restructure these incorrectly connected elements.

Metacognitive Functions

According to Butler and Winne (1995), external feedback can have numerous metacognitive functions apart from those listed in Table 11.1; for example, external feedback can address metacognitive strategies and their deployment options, provide criteria for monitoring and evaluating goals, or motivate learners to generate their own monitoring related information. In addition, it can serve as a basis for assessing the suitability of solution strategies employed or of error search and correction strategies; hence, at least the following feedback functions can be differentiated from each other with regard to mastery of metacognitive requirements:

- An informative function in cases where metacognitive strategies or the conditions for their use are unknown and feedback provides information about metacognitive strategies
- A specification function in cases where feedback provides criteria for monitoring goals or where conditions for the use of specific solution strategies or metacognitive strategies are specified
- A corrective function in cases where errors have arisen in the use of metacognitive strategies and the feedback provides information that can be used to correct erroneous strategies
- A guiding function in cases where learners are encouraged (e.g., through leading questions) to generate their own criteria for monitoring or evaluation or to assess the suitability of their own solution strategies or other actions

Recent studies on the effects of feedback addressing metacognitive processes and strategies have provided mixed results (Roll et al., 2006; van den Boom et al., 2004).

Motivational Functions

Even though feedback has been assigned an important role for both achievement and motivation (Hoska, 1993; Kluger and DeNisi, 1996; Mory, 1996), most studies on external informative feedback have focused on learner achievement and neglected the impact of feedback on motivation. At the motivational level, however, it is crucial, despite errors and the resulting negative effect, to maintain the level of effort, persistence, and intensity of task processing. Many theories of motivation suggest that perceived values of task processing and self-perceptions of competence are crucial factors in learners' motivation (Pintrich, 2003).

Generally, all types of feedback contain an evaluative feedback component (i.e., information regarding the correctness or quality of the solution) that reveals success or failure in task processing. Feedback thus has an impact on the attainment value of the task that might result in more effort or strategy investment and might affect performance. Symonds and Chase (1929) and Brown (1932) reported supportive results for this motivational effect of feedback. Recently, a study of Vollmeyer and Rheinberg (2005) revealed that this impact of feedback is present even if feedback is merely announced. Moreover, Ulicsak (2004) found that students spent more time reflecting group activities if they believed that the instructional system observes them and will provide feedback.

If feedback provides additional elaborated components that guide learners to successful task completion without immediately providing knowledge of the correct response, it offers mastery experiences that can be linked to personal causation. As such, mastery experiences are considered the most important source for developing a positive self-efficacy—in other words, positive perceptions of competence (Bandura, 1997; Usher and Pajares, 2006). Feedback may also affect how the difficulty of such tasks, the prospects of success, and the attributions of success or failure are assessed in future situations; hence, at least the following basic motivational functions should be considered when evaluating informative elaborated feedback:

- An incentive function, in that feedback renders the results of task processing visible
- A task facilitation function to contribute information for overcoming task difficulties
- A self-efficacy enhancing function, if it provides information that makes it possible to master tasks successfully, even if errors are committed or difficulties arise
- A reattribution function, if it provides information that contributes to mastery experiences that can be linked to personal causation

In addition to informative elaborated feedback types, a variety of motivational elaborated feedback types has been investigated by motivational researchers. Such motivational feedback types include reattribution feedback (Dresel and Ziegler, 2006; Schunk, 1983); mastery-oriented feedback, which makes learner's progress visible (Schunk and Rice, 1993); and task vs. competence feedback (Sansone, 1986,

TABLE 11.2
Content-Related Classification of Feedback Components

Category	Examples
Knowledge of performance (KP)	15 or 20 correct; 85% correct
Knowledge of result/response (KR)	Correct/incorrect
Knowledge of the correct results (KCR)	Description/indication of the correct response
Elaborated concepts	
Knowledge about task constraints (KTC)	Hints/explanations on type of task Hints/explanations on task-processing rules Hints/explanations on subtasks Hints/explanations on task requirements
Knowledge about concepts (KC)	Hints/explanations on technical terms Examples illustrating the concept Hints/explanations on the conceptual context Hints/explanations on concept attributes Attribute-isolation examples
Knowledge about mistakes (KM)	Number of mistakes Location of mistakes Hints/explanations on type of errors Hints/explanations on sources of errors
Knowledge about how to proceed (KH)	Bug-related hints for error correction Hints/explanations on task-specific strategies Hints/explanations on task-processing steps Guiding questions Worked-out examples
Knowledge about metacognition (KMC)	Hints/explanations on metacognitive strategies Metacognitive guiding questions

Source: Narciss, S., *Informatives tutorielles Feedback. Entwicklungs- und Evaluationsprinzipien auf der Basis instruktionspsychologischer Erkenntnisse (Informative Tutoring Feedback)*, Waxmann, Münster, 2006. With permission.

1989; Senko and Harackiewitz, 2005). In summary, elaborated motivational feedback components that had a positive impact on learners' motivation (namely, on perceptions of competence) (1) stressed the relation between effort, ability, and success; (2) made progress visible; (3) provided task information rather than performance information; or (4) elicited goal discrepancy.

Selecting and Specifying the Content of Feedback Elements

In general, the content of a feedback message may consist of two components (Kulhavy and Stock, 1989). The first component, the *evaluative* or, in Kulhavy's terms, the *verification* component, relates to the learning outcome and indicates the performance level achieved (e.g., correct/incorrect response, percentage of correct answers, and distance to the learning criterion). This component is attributed a controlling function (Keller, 1983). The second component, the *informational* component, consists of additional information relating to the topic, the task, errors, or solutions. Combining the evaluation and information component of feedback might result in a large variety of feedback contents.

Overview on Elaborated Feedback Components

Table 11.2 presents a content-related classification of feedback components that provides a structured overview of simple and elaborated feedback components by organizing the components with regard to which aspect of the instructional context is addressed. This content-related classification assumes that elaborated information might address: (1) task rules, task constraints, and task requirements; (2) conceptual knowledge; (3) errors or mistakes; (4) procedural knowledge; and (5) metacognitive knowledge. Five categories of elaborated feedback components can thus be defined:

- Elaborated components that provide information on task rules, task constraints, and task requirements are linked by the category of *knowledge on task constraints* (KTC).

- Elaborated components that provide information on conceptual knowledge relevant for task processing are linked by the category of *knowledge about concepts* (KC).
- Elaborated components that provide information on errors or mistakes are linked with the category of *knowledge about mistakes* (KM).
- Elaborated components that provide information on procedural knowledge relevant for task processing are linked by the category *knowledge on how to proceed* or, briefly, *know-how* (KH).
- Elaborated components that provide information on metacognitive knowledge are linked by the category *knowledge on metacognition* (KMC). To design feedback algorithms with elaborated components, several simple and elaborated feedback components can be combined. In most of the feedback studies, elaborated feedback was designed by combining knowledge of the correct result or knowledge of the result with elaborated components such as explanations of errors or to correct responses.

Cognitive Task and Error Analyses

Narciss and Huth (2004) derived the steps necessary to select and specify the feedback content from knowledge about cognitive task analysis and error analysis (for a detailed description, see Jonassen et al., 1999; VanLehn, 1990). Similar steps were proposed by VanLehn and his collaborators (VanLehn, et al., 2005) and by Rittle-Johnson and Koedinger (2005) based on insights and experiences in developing intelligent tutoring systems.

The first step consists of the selection and specification of instructional objectives (e.g., acquisition of a knowledge domain, mastery of learning tasks, literacy in the given context). The starting point of this step is the curriculum and its objectives, which in general have to be specified to obtain explicit, concrete, and measurable learning outcomes. The revised version of Bloom's taxonomy of educational objectives offers a well-founded framework for this specification of learning objectives (Anderson et al., 2001). The specified concrete learning outcomes provide the basis for the selection of the feedback functions, content, and forms.

Feedback is presented after the accomplishment of learning tasks; consequently, learning tasks are especially relevant to the design of feedback. The second step is, therefore, to select typical learning tasks and match them to the required learning outcomes.

The third step consists of analyzing the requirements for each type of task. The aim of these task analyses is to identify: (1) domain-specific knowledge items (e.g., facts, concepts, events, rules, models, theories), (2) cognitive operations related to these items (e.g., remember, transform, classify, argue, infer), and (3) cognitive and metacognitive skills involved in the mastery of the selected learning tasks. The informative components of a feedback message can refer to each of these aspects of a learning task; hence, the results of these task analyses provide an overview of both task requirements and possible informative components that can be implemented in a feedback message.

As mentioned above, from a cognitive and from a self-regulated learning viewpoint, elaborated or informative feedback is considered a necessary source of information, especially if the learner encounters obstacles or proceeds incorrectly. A next important step for the design of informative feedback is therefore to describe typical errors and typical incorrect steps. Furthermore, it is necessary to identify misconceptions and incorrect or inefficient strategies that can be attributed to the described errors (Crippen and Brooks, 2005; Narciss and Huth, 2004, 2006; VanLehn, 1990).

The steps described above are essential prerequisites for the selection and specification of helpful information. The results of the task and error analyses provide information that is necessary to select those informative components that match the task requirements. If the major function of the feedback message is tutoring learners to master the given learning tasks, then the related requirements feedback should not immediately provide the correct response or explain the correct strategy. This information should only be offered if the learners do not succeed otherwise; hence, offering adequate tutoring when learners encounter obstacles requires providing information that gives knowledge on how to proceed without presenting knowledge of the correct response. Table 11.2 presents examples of such informative tutoring feedback components.

Smith and Ragan (1993) recommended that the content should be tailored to the type of learning tasks; however, it should be kept in mind that studies comparing the efficiency of different types of information with regard to various learning tasks reported rather mixed results (for detailed review, see Mory, 1996, 2004). Furthermore, with the development of new paradigms for learning and instruction, the question of which knowledge should be addressed by the feedback content is getting more and more complex.

Selecting and Specifying the Form and Mode of Feedback Presentation

Feedback types vary not only in their content-related aspects but also in formal and technical aspects relevant for feedback presentation. Using formal criteria (e.g., timing, frequency), Holding (1965) differentiated, for example, 32 different types of feedback. The interactive capabilities of modern information technology increase the range of feedback strategies that can be implemented efficiently in computer-based instruction (Hannafin et al., 1993). Using the interactive capabilities of modern information technology, it is, for example, possible to combine elaborated feedback, tutoring, and mastery learning strategies to design *informative tutoring feedback*. The term *informative tutoring feedback* (ITF) refers to feedback strategies that provide elaborated feedback components to guide the learner toward successful task completion. The focus of this elaborated information is on tutoring students to detect errors, overcome obstacles, and apply more efficient strategies for solving the learning tasks. In contrast to elaborated feedback types, which provide learners with immediate knowledge of the correct response and additional information, ITF components are presented without immediate knowledge of the correct response. Additionally, ITF strategies offer the opportunity to apply the feedback information on another try (Narciss, 2006). These ITF strategies are rooted in studies on tutoring activities (McKendree, 1990; Merrill, et al., 1992, 1995). The following sections present an overview on important aspects of feedback that must be taken into consideration when choosing the form and mode of feedback presentation.

Immediate vs. Delayed Feedback Timing

An aspect of feedback that received much attention in feedback research is the *timing* of the feedback (Dempsey and Wager, 1988; for a review, see Kulik and Kulik, 1988). From Skinner's operant learning theory, one might assume that the feedback should be provided soon after the response; however, experimental studies that used paradigms similar to those of studies testing the effects of blocked or massed vs. distributed practice found that delaying feedback can be beneficial, especially for retention in a delayed post-test. This effect is referred to as the *delay retention effect* (Brackbill et al., 1963). Kulhavy and Anderson (1972) explained the delay retention effect by an interference perseveration hypothesis, which suggests that immediate feedback might proactively interfere with the incorrect response, and this interference might hinder the acquisition of the correct response. Delayed feedback is not related to proactive interference, because the incorrect response is not present and probably forgotten. Research based on the interference perseveration hypotheses provided mixed results (Kulhavy and Anderson, 1972; Kulhavy and Stock, 1989; Markowotz and Renner, 1966; Peek and Tillema, 1978; Rankin and Trepper, 1978; Schroth and Lund, 1993; Sturges, 1969, 1972, 1978; Surber and Anderson, 1975). Kulik and Kulik (1988) proposed a dual-trace information processing explanation for the delay retention effect. They pointed out that, with immediate feedback, learners only have one trial, whereas with delayed feedback they have two separate trials with an item. In the case of memorization, two separate trials are better than one, and delayed feedback might be superior to immediate feedback.

Clariana has developed a connectionist description of feedback timing to better explain the existing results and to provide a basis for new insights on immediate and delayed feedback (Clariana, 1999; Clariana et al., 2000). With regard to the potential effects of immediate vs. delayed feedback, Clariana's model proposes a strengthening effect for incorrect responses with delayed feedback, whereas immediate feedback weakens the association between incorrect responses and items. These hypotheses were confirmed by a study of Clariana and Koul (2005); yet, the superiority of delayed feedback (i.e., the delay retention effect) was only found in experimental situations with test items, and it was not found in applied studies (Kulik and Kulik, 1988). Because researchers used a variety of immediate and delayed feedback types—item per item vs. end of session; directly after the session vs. hours or days after session (Dempsey and Wager, 1988)—Mory (2004, p. 256) stated that the field of research on feedback timing is "muddied."

Recently, Mathan and Koedinger (2005) reconsidered the debate on feedback timing from a metacognitive perspective. They suggested that the question of when to provide feedback following an error has to be answered on the basis of a model of desired performance. If this model includes metacognitive skills for error detection and correction, then feedback providing knowledge of the correct response should not be offered immediately, because it does not foster the acquisition of these skills. In contrast, feedback offering knowledge of the result together with knowledge about mistakes implemented in a multiple-try algorithm that requires students to analyze their erroneous responses and to identify error correction steps can be provided immediately (e.g., Mathan and Koedinger, 2005; Moreno and Valdez, 2005; Narciss and Huth, 2006).

Single Try vs. Multiple Try: Simultaneous vs. Sequential Presentation of Elaborated Feedback

A second formal aspect is related to the question of how many tries are offered to learners after they have received feedback. Many studies offer only a single try per item; that is, learners respond to an item, are provided with feedback, and do not have the opportunity to respond again to this item; however, some studies have offered multiple tries after providing feedback. Most of these studies use answer-until-correct (AUC) feedback (for a review, see Clariana, 1993). Clariana's review of 30 studies that compared single-try feedback types (immediate knowledge of result, immediate knowledge of the correct response, delayed feedback, no feedback) to multiple-try feedback/AUC found a superiority of all feedback types over no feedback, but no differences between single-try and multiple-try feedback. In a more recent review, Clariana and Koul (2004) contrasted multiple-try feedback effects (AUC) for verbatim outcomes with higher order "more than verbatim" outcomes (i.e., drawing and labeling biological diagrams). This review revealed that AUC is less effective for verbatim outcomes but more effective for higher order outcomes (Clariana and Koul, 2005).

Multiple-try feedback types other than AUC can be developed if one considers a third formal aspect of feedback presentation: Complex elaborated feedback can be presented simultaneously (i.e., all information in one step) or sequentially (cumulatively or step by step). Most studies on complex elaborated feedback provide the elaborated information simultaneously with knowledge of the result or knowledge of the correct response (e.g., Kulhavy et al., 1985; Phye, 1979; Phye and Bender, 1989). However, only half of the studies utilizing this simultaneous presentation of elaborated feedback produced significant positive effects (Kulhavy and Stock, 1989; Mory, 1996, 2004).

In addition to these empirical findings on presenting complex elaborated feedback simultaneously, research on cognitive load in instructional contexts would suggest that a sequential presentation of complex elaborated feedback should be superior to a simultaneous presentation (Chandler and Sweller, 1992). Indeed, the few controlled experimental studies that have investigated the tutorial feedback types that present elaborated feedback components sequentially have reported positive effects (Albacete and VanLehn, 2000; Heift, 2004; Nagata, 1993; Nagata and Swisher, 1995; Narciss and Huth, 2006; VanLehn et al., 2005).

Because a sequential presentation of feedback components requires offering multiple tries with the same item, a direct comparison of the effects of simultaneous vs. sequential feedback presentations is very difficult if not impossible. An important issue for future research, however, would be addressing the question of how many feedback steps of cycles are effective under which individual and situational conditions.

Adaptive vs. Nonadaptive Feedback Presentation

A fourth formal aspect of feedback presentation is whether the feedback is presented in an adaptive or a nonadaptive way. The adaptation issue is related at such questions as these:

- *Which learner characteristics are critical for adaptation?* Crucial characteristics that have been extensively addressed by feedback research and by most research on tutoring systems include the learner's prior knowledge or knowledge state (Albert and Lukas, 1999; Hancock et al., 1995a) and the learner's metacognitive state in general measured by the learner's response certitude (Hancock et al., 1992, 1995b; Mory, 1991, 1994). Other important characteristics that have received attention only in recent studies include the learner's motivation (e.g., self-efficacy) (Narciss, 2004), goal orientation (Senko and Harackiewicz, 2005), and metacognitive skills other than response certitude (Aleven et al., 2006).
- *Which task characteristics are critical for adaptation?* According to Sanz (2004), this question is sometimes neglected by instructional designers; however, adaptation may be more or less necessary for different tasks, and there might be critical task characteristics (i.e., specific task requirements) that can be used as indicators for deciding when and how much adaptation would be reasonable. In the algebra tutoring system Ms. Lindquist, the three feedback strategies are, for example, determined by the exercise and its structure (Heffernan, 2001).
- *How do we diagnose the individual characteristics in a reliable and valid way?* Several approaches to diagnosing learner characteristics have been investigated by researchers developing intelligent tutoring systems: manually authored finite state machines (Koedinger et al., 2004); generative approaches, such as model tracing

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(Anderson et al., 1995); evaluative approaches (Mitrovich et al., 2002); and decision theoretic approaches (Murray et al., 2004). Recently, several authors have suggested using observable data on students' activities to infer nonobservable learner characteristics (Kutay and Ho, 2005; Melis and Anders, 2005; Romero et al., 2005).

- *How do we adapt feedback to the critical situational and individual factors?* Adaptive feedback can be implemented in several ways. An approach used frequently in intelligent tutoring systems involves controlling the sequence, content, and instructional activities (program-controlled adaptation). A second type of adaptation is based on the idea that the learner has to take an active part in instruction and thus is presented with a choice of instructional activities (learner-controlled adaptation). Unfortunately, learners sometimes lack the metacognitive skills and motivation required to decide which instructional activities would be best for them (for reviews on the effects of learner- vs. program-controlled instruction, see Steinberg, 1977, 1989; see also Corbett and Anderson, 1990; Narciss et al., 2004). Recent studies and frameworks on adaptive feedback include metacognitive feedback components that should foster the acquisition of metacognitive skills (Aleven et al., 2006; Gouli et al., 2005). A third type of adaptation consists of combining program and learner control, which offers a variety of other possibilities for adapting feedback and raises new issues for future research (e.g., when and how to shift from program to learner control and *vice versa*).

Unimodal vs. Multimodal Feedback Presentation

The capabilities of modern information technologies allow the presentation of feedback not only as written text but also as narrated text (Narciss and Huth, 2004, 2006) or as a static or dynamic graphic. Furthermore, feedback can be provided by animated agents (Moreno, 2004). When and how to apply the principles of multimedia learning derived from Mayer's theory of multimedia learning (Mayer, 2001) for the multi-modal presentation of feedback have yet to be investigated.

Implications for Evaluating (Tutoring) Feedback

The design principles outlined above show that external feedback, particularly informative tutorial feedback, is a multidimensional instructional measure. Moreover, the interactive, two-feedback-loop model described earlier suggests that the effects of external feedback occur through an interaction with the learner (i.e., with a complex information processing system). This in turn means that the effects of external feedback are not general but only emerge in specific situational and individual settings; for example, the amount of time it takes for errors to be eliminated with the help of external feedback depends on (1) the individual characteristics of the learner; (2) the quality of the external feedback components; (3) the type, complexity, and difficulty of the tasks; and (4) the type of error. In highly skilled learners or for easy tasks or simple slips, for example, knowledge-of-result feedback alone is sufficient to yield a correct response the next time. In learners with a low level of skill, for very complex and difficult tasks, or in the case of serious errors, it is possible that even informative tutorial feedback may not be sufficient for mastering the high demands.

The effects of various feedback strategies also largely depend on how learners process and interpret the information provided. In addition to cognitive requirements (e.g., prior knowledge, strategic knowledge), individual motivational factors, such as self-efficacy and perceived task values, and individual metacognitive factors, such as monitoring competencies and strategies, play a role. To draw differentiated conclusions about the effects of various types of feedback, not only cognitive but also individual motivational and metacognitive factors, and the nature of individual feedback, processing should be controlled.

External feedback can contribute to changes that occur (1) during the treatment, (2) shortly after the treatment, or (3) long after the treatment; thus, evaluating the effects of various feedback strategies requires collecting data both during and after the treatment (Phye, 1991, 2001; Phye and Sanders, 1994). When investigating the effects of various types or strategies of external feedback, it should no longer be a question of which feedback type is the best but rather one of the following questions:

- Under which individual and situational conditions do which feedback components or strategies have high information value for learners?

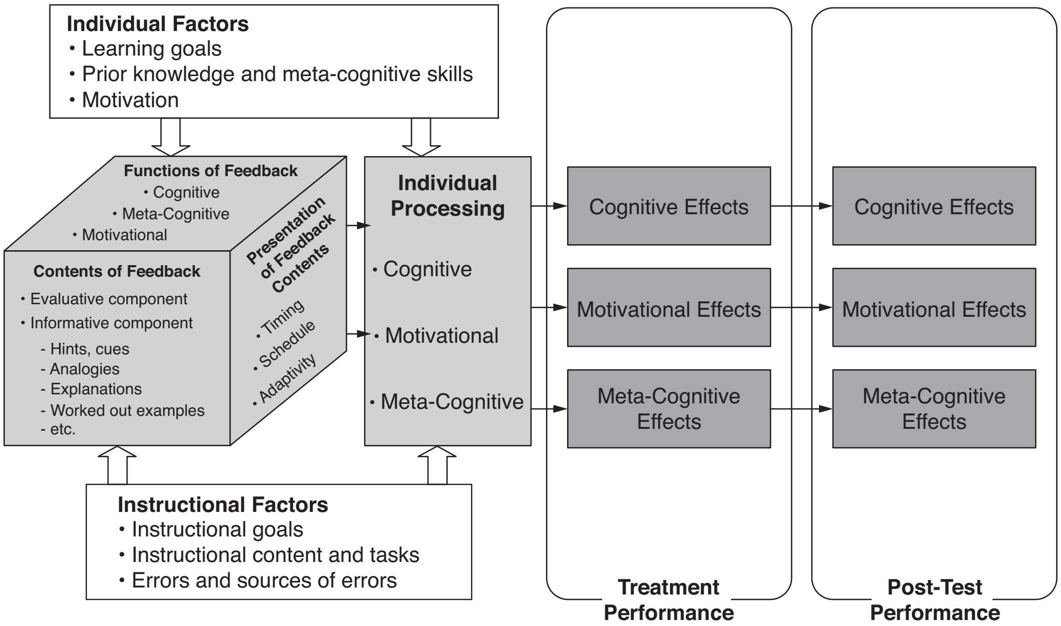

Figure 11.2 Summary of factors and effects of external feedback. (From Narciss, S., *Informatives tutorielles Feedback. Entwicklungs- und Evaluationsprinzipien auf der Basis instruktionspsychologischer Erkenntnisse (Informative Tutoring Feedback)*, Waxmann, Münster, 2006. With permission.)

- Under these individual and situational conditions, what cognitive, metacognitive, and motivational effects do the various feedback components or strategies have?
- When are these effects expected to occur, and what is their expected duration?

Figure 11.2 summarizes these considerations regarding requirements for and the effects of various kinds of external feedback.

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* Indicates a core reference.