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Interactivity in multimedia learning: An integrated model

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ABSTRACT

What does interactivity entail? What factors need to be taken into account in the design of interactive systems? Although interactivity is a widely used term accorded great prominence in discussions of multimedia learning, even a preliminary look at the literature suggests that how interactivity is defined, and what benefits it may offer, are not at all clear. The goal of this article is therefore to clarify the concept of interactivity. We present a unifying model that includes the user, the learning environment, and a system of connections and concepts that together make up interactivity. Such a model can help inform research, discussion, and design decisions on interactive multimedia instruction.

1. Introduction

Since the introduction of computers as educational tools, interactivity has been heralded by many as the one feature of this technology that holds the strongest promise for educational use. In 1988, for example, Hannafin and Peck argued that "perhaps the greatest advantage of computerized instruction over ... linear media is the potential for interaction during a lesson" (p. 17). More recently, Bransford and colleagues discussed the importance of interactivity in the context of video- and computer-based instruction, suggesting that "Interactivity makes it easy for students to revisit specific parts of the environments to explore them more fully, to test ideas, and to receive feedback" (Bransford, Brown, & Cocking, 1999, p. 209). Bransford et al. even suggest that "Noninteractive environments, like linear videotapes, are much less effective for creating contexts that students can explore and reexamine, both individually and collaboratively" (p. 209). In these and many similar claims, interactivity is presented as an attribute of learning environments that enhances the quality of educational materials and that can facilitate learning.

The notion that learning is not simply a process of information transmission, but that students have to become actively engaged for deep learning to occur, is certainly not new (e.g., Mayer, 2001; Piaget, 1969; Renkl & Atkinson, 2007; Wittrock, 1990). For example, constructivist approaches, while they may represent diverse views on learning (Gijbels, van de Watering, Dochy, & van den Bosche, 2006), share the assumption that the learner is a responsible, active agent in the process of knowledge construction (e.g., Blumenfeld, 1992; Cunningham, 1992; Harris & Alexander, 1998; Loyens & Gijbels, 2008; Loyens, Rikers, & Schmidt, 2008). Interactive learning environments are viewed as a promising option not merely for presenting information but for allowing the learner to engage actively in the learning process (Renkl & Atkinson, 2007).

But does interactivity in fact improve the quality and effectiveness of learning environments? Our review of the available empirical research showed that the answer may not be as straightforward as interactivity advocates would expect. Some studies have shown advantages in learning outcomes for interactive environments (e.g., Mayer & Chandler, 2001; Schwan & Riempp, 2004; Tung & Deng, 2006); some have pointed to mixed results (e.g., Moreno & Mayer, 2005); still others have revealed drawbacks or limitations of interactivity (e.g., Moreno & Valdez, 2005).

A closer review of the design of these studies shows that these results may simply reflect divergent approaches to what is meant by interactivity. In several studies, interactivity was defined in terms of whether learners were able to control the pacing or sequencing of the instruction. For example, Mayer and Chandler (2001) examined what they termed simple interaction – whether or not participants were able to control the pace of a multimedia presentation by choosing when to start each segment of the presentation. Similarly, Schwan and Riempp (2004) designed video instruction on tying nautical knots. Those in the interactive group could control start and stop, speed, and direction of instructional video clips; participants in the noninteractive condition could view the video clips as often as they liked, but only from start to finish without control.

Other research has defined interactivity in terms of controlling user response and system feedback. For example, Moreno and Mayer (2005) distinguished interactive multimedia environments, where participants had to choose a correct answer by clicking on the appropriate selection, from noninteractive multimedia envi-

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ronments, in which a pedagogical agent supplied the correct answer.

Yet another approach was to define interactivity as the opportunity to organize instructional content in a multimedia learning environment. In the Moreno and Valdez (2005) study, for example, participants in the noninteractive group were given a sequence of frames to study about the process of lightning formation. The interactive group received the same frames, but not in the correct order; participants had to organize the frames in the correct sequence before studying them.

Quite a different understanding was suggested by Tung and Deng (2006), who examined interactivity in the context of social presence – the computer as a "social actor" rather than an "inanimate tool" (p. 252). The active-interactivity group received a written greeting from the computer on pressing "START," while the passive-interactivity group received no greeting; there were also differences in the prompts provided to the different groups.

Even from this quick review of a small sample of empirical studies it becomes apparent that the meaning of interactivity can vary greatly. In order to usefully describe and investigate interactivity and interactive features, it seems critical to reconsider the definition of these terms.

2. Defining interactivity

Even though the overall meaning of interactivity seems clear on an intuitive level, the concept itself is so broad that it eludes simple definition. A number of definitions of interactivity have been proposed, but there is little agreement among them, resulting in an inconsistent use of the term (e.g., Bétrancourt, 2005; Johnson, Bruner, & Kumar, 2006; Kennedy, 2004; Quiring & Schweiger, 2008; Rafaeli, 1988; Wagner, 1994; Yun, 2007). This inconsistency is in part due to the fact that the term interactivity is used in a variety of fields, such as advertising, arts, information systems, communication, marketing, and educational psychology. Across these fields, three main bodies of literature can be distinguished (e.g., Downes & McMillan, 2000; Quiring & Schweiger, 2008): (1) interaction in human communication, stemming from a sociological tradition, (2) computer-mediated human communication, originating from mass communication approaches, and (3) human–computer interaction, derived from computer science but also applied in the field of educational technology.

From a sociological perspective, Jensen (1998) suggests that interactivity is "the relationship between two or more people who, in a given situation, mutually adapt their behavior and actions to each other" (p. 188). The computer-mediated human communication approach views interactivity as "an expression of the extent that, in a given series of communication exchanges, any third (or later) transmission (or message) is related to the degree to which the previous exchanges referred to even earlier transmissions" (Rafaeli, 1988, p. 111). In the context of human–computer interaction, Sims (1997), with reference to Bork (1980), suggests that "interactivity can be viewed as a function of input required by the learner while responding to the computer, the analysis of those responses by the computer and the nature of the actions by the computer" (p. 159). In the same vein, Moreno and Mayer (2007) cite Markus (1990) to define interactivity as "a characteristic of learning environments that enable multidirectional communication" (p. 310).

Although these definitions come from different perspectives, they share the idea that interactivity requires two fundamental conditions: (a) at least two participants must interact with each other, and (b) the actions of these participants must include an element of reciprocity. Reciprocity means that change occurs on both sides; the actions of one party trigger responses from the other, which lead in turn to changes in the first. Johnson et al. (2006) further point out that it is not only reciprocity – action followed by a reaction – that is required, but also responsiveness, the degree to which the (re)actions on both sides are related, relevant, and sustain the continuity of the interaction.

2.1. Interactivity in multimedia learning

Applying these fundamental conditions to the context of multimedia learning, we can define interactivity as follows:

Interactivity in the context of computer-based multimedia learning is reciprocal activity between a learner and a multimedia learning system, in which the [re]action of the learner is dependent upon the [re]action of the system and vice versa.

This definition emphasizes the dynamic relationship between the learner and the learning system. It acknowledges that a multimedia-learning environment per se cannot be interactive, but that it rather includes features with the potential to engage the learner. It is the learner, however, who must release this potential by responding to system activity in a meaningful way (Kennedy, 2004). Our definition focuses on this type of learner/system response rather than including learner/learner interactions that might be afforded by technology (cf. Renkl & Atkinson, 2007). Interactions between learners via technical means fall into the area of mediated human communication, but have less to do with human–computer interaction.

Though defining interactivity is a critical first step, the concept must also be operationalized in order to be applied in research and design. Among the existing approaches to operationalizing interactivity, technological and functional perspectives as well as psychological and learner-centered perspectives are most prominent. An examination of the resulting taxonomies reveals a fundamental question in the consideration of interactivity in the context of multimedia learning environments: Should the primary concern be the learning environment or the learner? We will argue below that an integrated perspective is needed.

2.2. Technological and functional perspectives

From a technological perspective, interactivity has been classified in terms of delivery media (e.g., web, videoconferencing, VoIP), input devices (e.g., keyboard, mouse, touch screen) or features provided (e.g., hypertext, simulations, multimedia) (see Johnson et al., 2006; Sims, 1997). In all of these cases, interactivity is defined as an attribute of the medium, downplaying the dynamic relationship between the learner and the learning system. Functional approaches shift the emphasis to affordances provided by the system that have the potential to engage the learner in behavioral activities (Schwier & Misanchuk, 1993; Sims, 1997). For example, Sims (1997) classifies interactive concepts such as "simulation interactivity" or "hyperlinked interactivity," which describe different ways in which the learner can navigate, access and manipulate learning material within a specific learning environment. Yet, the focus of classifications of interactivity based on these perspectives is clearly on the system, and not on the learner.

2.3. Psychological and learner-centered perspectives

From a psychological point of view, the above approaches are of only limited use for research on the effectiveness of interactivity in multimedia learning because they do not sufficiently consider the learner's internal cognitive processes (Kennedy, 2004). Several early discussions of interactivity explicitly address learner's cognition, but they focus on specific instructional strategies that can be implemented in interactive media rather than taking a broader view of the interactive process (e.g., Hannafin, 1989; Jonassen, 1985). Some more recent approaches to typologies of interactivity, introduced in a special issue on interactivity of the Educational Psychology Review, also take a psychological perspective. Yet, these approaches also incorporate aspects of the technological taxonomies described above in that they emphasize affordances of the medium rather than the cognitive processes these affordances might evoke. For example, Moreno and Mayer (2007) propose five types of interactivity: dialoguing (learner receives questions and answers or feedback), controlling (control over pace), manipulating (control over aspects of the presentation), searching (entering queries, selecting options), and navigation (selecting information sources). Kalyuga (2007) distinguishes three different types of learner control that can be afforded by the learning system: control over information delivery, representational forms, and content. He further proposes two dimensions, flexibility and dependence on learner's previous actions, which take the responsiveness of the learning environment into account. This distinction leads to a two-dimensional structure that can be used to define sublevels of interactivity when combined with the afforded learner activities.

These typologies of interactivity, although they approach the problem from a psychological perspective and refer to the importance of the learner's cognitive processes, still do not differ substantially from the technological view. Their goal is to systematize different features of learning environments that might classify these environments as more or less interactive. Consistent with this approach, several authors have suggested a continuum ranging from noninteractive or very low in interactivity to highly interactive (e.g., Moreno & Mayer, 2007; Rafaeli, 1988). The underlying assumption of such taxonomies is that more interactivity may enhance the quality of the product, the instruction, and the learning outcomes (e.g., Kennedy, 2004; Schwier & Misanchuk, 1993; Sims, 1997). However, others have noted that interactivity does not automatically create understanding, and may in fact impose an excessive extraneous cognitive load due to large amounts of information that need to be processed or the generation of split-attention that can interfere with learning (e.g., Kalyuga, 2007; Mayer & Moreno, 2003; Moreno & Mayer, 2007). Therefore, a focus on quantifying interactivity does not help to clarify its role in the learning process. Further, interactivity is neither a function of the affordances of the learning system alone nor merely a function of the cognitive activities of the learner, but rather a dynamic process between the learning system and the learner. A model of interactivity, then, cannot be limited to either the affordances of the medium or the activities of the learner, but must integrate both.

2.4. Towards a new approach to interactivity

A cognitive interaction model of multimedia interactivity that addresses the bidirectional relationship between the learning system and the learner, taking behavioral and cognitive activities of the learner into account, was introduced by Kennedy (2004). The model posits a continuous feedback loop between instructional events, behavioral processes, and the cognitive processes of the learner, acknowledging the fact that actions on both sides are a required ingredient of interactivity. Kennedy also suggests that interactivity may result in increased motivation in addition to other learning outcomes.

This model provides important insights into the dynamic relationship between instructional events and behavioral and cognitive activities of the learner. However, when viewed from a learning perspective it too has some shortcomings. Although a principal strength of the model is that it represents the process character of interactivity, the process idea has not been taken far enough, and critical components are missing. A model of interactivity – the reciprocal actions of two entities – should include not just the affordances of the environment but also the characteristics of the learners. It should consider the learner's emotions, which can play an important role in how interactions are initiated and maintained. A complete model should also acknowledge that the learner's motivation and the learning outcomes are not simply end products, but may feed back into the loop, influencing the cognitive and behavioral activities of the learner. We propose a model of interactivity that takes all these factors into account.

3. The Integrated Model of Multimedia Interactivity (INTERACT)

The Integrated Model of Multimedia Interactivity (INTERACT) consists of six principal components which together comprise an integrated system: the learning environment, behavioral activities, cognitive and metacognitive activities, motivation and emotion, learner variables, and the learner's mental model (learning outcomes). The interactivity process is represented by the feedback loops that connect these components (Fig. 1).

3.1. INTERACT: A learning scenario

To illustrate the utility of integrating these components into the INTERACT model, consider the following scenario. A high-school student in chemistry class opens a browser and types the URL for a chemistry simulation. A web page appears that asks her to register, and she enters her name and school. A new screen appears with a short narrative, which she reads; she then clicks "next" to proceed. The following screen displays the simulation. One side of the screen shows a closed container with an injector, and a burner below the container. The other side of the screen displays a graph (see Fig. 2). The student has a number of interactive possibilities to consider. She can inject gas particles into the container. She can select different types of particles, helium or argon, to inject. She can raise the temperature. She can exit from the screen. Each of these actions will affect the behavior of the simulation and the student's subsequent options.

From the perspective of INTERACT, a description of the above scenario can begin with the user's decision to type in a URL. Her decision is based on a combination of the learning context and her own learner characteristics, as well as affective, cognitive, and metacognitive factors: Perhaps she is in class, and the teacher instructs the students to begin working on the simulation. Because this student is interested in chemistry (motivation), enjoys working on the computer (emotion), and realizes that her grade depends in part on completing this assignment (achievement goal setting, motivation), she plans appropriate strategies (metacognition), assesses what she has to do (cognitive activity) and types

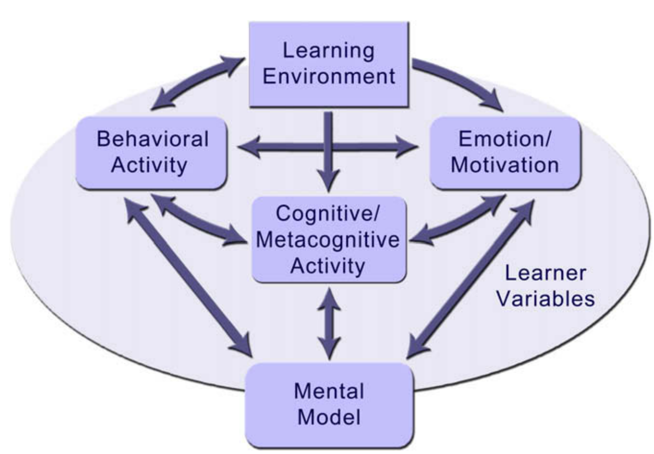

Fig. 1. The Integrated Model of Multimedia Interactivity (INTERACT).

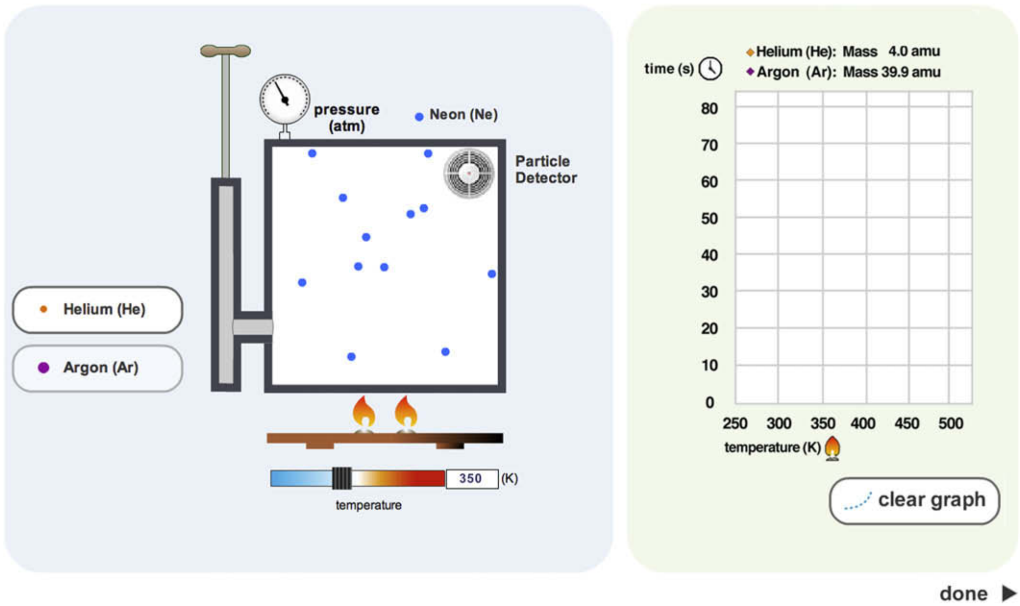

Fig. 2. Diffusion simulation (CREATE, 2010).

in the Web address (behavioral activity). As a result of her actions, the screen changes (system design and affordances). A new interactive loop begins as she reads the log-in options and proceeds to enter the requested information. Upon arriving at the simulation itself, she realizes that she can inject argon into the closed container, and chooses to do so. She finds that this causes a stream of particles to be released into the container, and, observing the movements of the particles, she notices that when a particle touches the "particle detector," the screen will freeze (learning outcome). Based on this, she chooses to perform the procedure again to see if she gets the same result repeatedly.

Closer analysis shows that, behaviorally, the student has done the following: entered text data (URL, name and school), clicked on a button to select chemical, and clicked on another button to inject the chemical. As she continues she will have further opportunities to adjust temperature by means of a slider, and to click on buttons to continue or to indicate that she is done. Cognitively, her activities can be described differently. Once she proceeds to the simulation she has to analyze the parameters of the simulation that she is able to manipulate, and understand the outcome of her input in order to generate hypotheses that she can test by repeating the procedure. Metacognitively, she plans, monitors and evaluates her actions. With respect to her learner characteristics, she may have a certain amount of prior knowledge of the topic that helps her to execute the cognitive and metacognitive activities. She may further have a low level of trait anxiety, which allows her to concentrate on the task rather than worrying about possible failure. An analysis of her affective states might reveal that she enjoys being able to manipulate the simulation and observing the outcome. She may feel increasingly confident as the outcomes confirm her hypotheses and may therefore develop situational interest that motivates her to continue with the task. In terms of learning outcomes, she may construct conceptual knowledge about the processes shown in the simulation. This would mark the optimal case in which an interactive feature successfully leads to engaging the student in deep cognitive processing which facilitates learning.

In a second scenario, another learner might also click on the buttons to select and inject chemicals and therefore engage in behavioral activities. But due to a lack of prior knowledge, he may not be able to understand why the simulation responds as it does to his input. As a result he is not able to generate appropriate hypotheses that he might test and that could guide his behavioral activities. His recurring failure to understand the responses of the system may make him feel angry or bored and lead to disengagement from the task.

The second case in particular highlights the importance of considering learner characteristics in the interactive process; they can affect the way an interactive feature is actually used and the cognitive processes in which a learner engages. Moreover, the cases exemplify that an analysis on the learning systems level or the behavioral level is not sufficient, as neither the system nor the behavioral activities of the students change from the first to the second case. Instead, it is the learner's cognitive activities which make the difference, and these are affected by the learner characteristics and the learner's affective states. Below, we will discuss the different components of the INTERACT model in more detail.

3.2. The learning environment

A starting point for consideration of the model is the learning environment, which includes both the instructional design and the affordances of the learning system. This is the part of the model within which taxonomies of interactivity can be considered (e.g., Schwier & Misanchuk, 1993; Sims, 1997), as well as characteristics such as the extent to which the system relies on learner responses (Kalyuga, 2007) or the speed with which it responds (e.g., Johnson et al., 2006; Steuer, 1995). However, classifications of features situated only within the learning environment itself do not help clarify the role of interactivity in learning. Rather, it is more useful to identify interactive features on the system level and then explore their possible contributions to the interactive process. After describing the interactive process in accordance with INTERACT, we will examine this approach with respect to the two concepts most commonly associated with interactivity in multimedia learning: learner control and guidance.

INTERACT's integration of the learning system into the model seeks to clarify two issues. First, the model includes feedback loops connecting the learning system, behavioral processes, and cognitive processes (Kennedy, 2004), and additionally introduces a unidirectional link between the learning system and cognitive activities. This link acknowledges that a learning environment may engage the learner in cognitive processes before or in the absence of any behavioral response to the system. Second, several of the discussions on interactivity previously cited here conflate affordances of the system and behavioral activities (e.g., Kennedy, 2004; Sims, 1997). Kennedy (2004), for example, specifies a category of "behavioural processes" which would include "moving forward or back" and "clicking on a button to answer a multiple choice question" (p. 49). According to INTERACT, which distinguishes between behavioral activities and system affordances, "moving forward and back" would be considered a feature of the learning system (what the system affords) while "clicking on a button" would represent a behavioral activity (what the learner does). The purpose of the activity, "to answer a multiple choice question" actually refers to a third category, cognitive and metacognitive activity.

3.3. Behavioral activities

The behavioral activities component of INTERACT describes what the learner does, physically, to interact with the learning system. Behaviors are a definitional component of human–computer interaction; it is through behavioral activities that a learner acts on a learning system, inducing changes in the system that may lead in turn to change in the learner. The range of possible behavioral activities in a multimedia learning system is determined by the input devices which direct or activate that system. Behavioral activities in the context of interactivity might consist, for example, of entering text, clicking a mouse, or waving a controller.

Distinguishing behavioral activity as a separate component within the model allows the implications of behavior to be considered apart from other processes. While different physical actions may have different effects in the same situation, it is also the case that identical physical actions may have different effects in different situations. For example, Péruch and Wilson (2004) looked at active users who explored a virtual environment freely, using a mouse to control their own paths; each was paired with a passive user who watched a recording of the active user's path. Though each linked pair was exposed to the same spatial information, active users experienced some advantage over passive users for spatial learning. The results suggest that the difference in behavioral activity affected the construction of the mental model.

It is also possible to imagine identical behavioral activity with significant differences in cognitive activity. For example, imagine two different computer environments, each displaying a screen with two buttons that allow the user to choose "Yes" or "No." The first screen reads, "Do you want to make the text size larger?" The text on the screen in the second environment reads, "Your avatar is threatened by an assassin. Do you wish to battle the aggressor?" In each case the user will use the same input device, clicking in the same way, to select either "Yes" or "No." However, the contexts are different, and call for different kinds of cognitive, metacognitive and/or affective processing. Considering behavioral activity as a separate element facilitates investigation of the implications of behavior for cognition.

3.4. Cognitive and metacognitive activities

Cognitive activities are mental operations, procedures and processes which the learner performs in order to select, mentally integrate, organize and integrate new information into a coherent knowledge structure (see Kennedy, 2004; Moreno & Mayer, 2007). Different approaches can be used to describe the processes which occur; the approach chosen will affect predictions as to the type of learning outcomes. One approach is to distinguish surface and deep-level processing (cf. Kennedy, 2004). Surface-level processing is associated with the use of cognitive strategies of repetitive rehearsal and rote memorization in order to encode new information into working memory (Marton & Säljö, 1976; Vrugt & Oort, 2008). Learning outcomes associated with surface-level processing are retention and recall. Deep-level processing, however, results from the use of cognitive strategies such as elaboration (Craik & Lockart, 1972), as well as organization, self-regulation, and critical thinking aimed at integrating the new information into prior knowledge (Marton & Säljö, 1976; Vrugt & Oort, 2008); deep-level processing is linked to deeper understanding and transfer.

However, if the goal is to understand how and to what extent interactive features can be used to promote cognitive activities of the learner, a more differentiated view is preferable to the distinction between deep and surface-level processing. Using Anderson and Krathwohl's (2001) revision of Bloom's taxonomy (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956), the cognitive process dimensions *remember*, *understand*, *apply*, *analyze*, *evaluate*, and *create* can be distinguished. These can be linked to the knowledge dimensions of *factual*, *conceptual*, *procedural*, and *metacognitive* knowledge that describe the quality of the learning outcomes (Anderson & Krathwohl, 2001).

Metacognition refers to knowledge about cognition and the regulation of cognitive activities (Brown, 1978; Flavell, 1979; Veenman, Van Hout-Wolters, & Afflerbach, 2006; Vrugt & Oort, 2008). Numerous sets of metacognitive activities have been named that learners can apply to regulate their cognition and control their learning. Vrugt and Oort (2008) identify three commonly cited essential strategies: planning, monitoring and evaluation. Planning refers to selecting appropriate strategies and allocating resources to the task, such as time or help from others. Monitoring involves the continuous self-assessment of comprehension and task performance. Evaluation includes judgments about learning outcomes and the efficiency of the learning process as well as the ongoing evaluation and reevaluation of the learning goals. It has been shown that metacognitive activities are positively related to appropriate learning strategy use (Luwel, Torbey, & Verschaffel, 2003; Metcalfe, 1996; Sperling, Howard, Staley, & DuBois, 2004), which in turn is positively related to exam scores as learning outcomes (Elliot, McGregor, & Gable, 1999; Pintrich & De Groot, 1990; Wolters, 2004; for an overview see Vrugt & Oort, 2008). The use of learning strategies however results in corresponding cognitive activities that lead to quantitatively and qualitatively different learning outcomes as pointed out above.

3.5. Emotions/motivation

Emotional and motivational states are conditions of the learner that arise from the given situation. They can be products of as well as inputs into the interactive process. Emotions in particular have been widely neglected in educational psychology, although it has been shown that they can affect both information processing (e.g., Bless et al., 1996; Levine & Burgess, 1997) and learning outcomes (e.g., Pekrun, Goetz, Titz, & Perry, 2002; Um, Song, & Plass, 2007). Interactive features such as learner control over pace and content may influence the learner's emotions and motivation, as suggested in models of emotional and motivational design such as ARCS (Keller, 1983; Keller & Kopp, 1987), ECOLE (Glaeser-Zikuda, Fuss, Laukenmann, Metz, & Randler, 2005) and FEASP (Astleitner, 2000). An example that underlines the link between system affordances and affective states is the effect of speed of response of the system on the user's emotional response. One can conjecture from his or her own experiences with slow Internet connections that long response times may elevate anger and helplessness as well as impair motivation. Some approaches have previously incorporated affective factors into cognitive models of multimedia learning (CATLM, Moreno, 2005), suggesting that both motivational factors and metacognitive factors mediate learning (Moreno

& Mayer, 2007). Motivational factors can affect cognitive engagement (Pintrich, 2003), whereas metacognitive factors regulate cognitive processing and affect (McGuinness, 1990). The CATLM model suggests a unidirectional relationship in which affective variables exert an influence over processing and memory.

INTERACT, on the other hand, considers affective variables as interrelated elements in a feedback loop, influencing and in turn being influenced by cognition. This is consistent with recent approaches to integrating emotion, motivation and cognition, such as those discussed in the recent special issue on Emotion Research in Education in the Educational Psychology Review. Here, the authors agree on a bidirectional, reciprocal relationship among emotion, motivation and cognition, but vary in their assumptions as to whether these factors are separable or integrated (Linnenbrink, 2006). This issue also provides a detailed discussion from different theoretical perspectives of the effects of emotions and motivation on cognition and vice versa. An overview about the connections among metacognition, motivation, cognition, and achievement is given by Vrugt and Oort (2008). The assumed intertwined relationship among cognition, motivation, and emotion emphasizes the importance of integrated models. INTERACT is such a model.

3.6. Mental model

A critical component of the interactivity loop is the learners' mental model. In the context of INTERACT, we use the term mental model to refer to both the existing knowledge structures that the learner brings to the learning activity, and the knowledge that the learner gains as a result of the learning activity. Knowledge gains lead to the revision of existing mental models or to the construction of new models. According to INTERACT, the mental model is not the end point of an interaction, but part of an integrated process in which knowledge structures not only result from but also lead to changes in behavior, cognition, and emotion. Empirically, such changes are most frequently measured as learning outcomes, such as recall, comprehension and/or transfer (Lee, Plass, & Homer, 2006; Mayer, 2001).

Existing knowledge structures, which include a learner's episodic and semantic memory, impact cognition but also determine the learner's motivational and emotional state. For example, existing declarative or procedural knowledge will influence subsequent activity such as cognitive processing or metacognitive strategies (Kalyuga, 2005, 2007), and a learner's motivation will affect his or her level of engagement with the learning materials (Corno & Mandinach, 1983; Pintrich & De Groot, 1990). Because differences in existing knowledge have significant implications for the learning process, we also include prior knowledge as an important element in the learner variables component of our model.

3.7. Learner variables

The learner is an integral partner in any interactive event, bringing to the interactive situation a set of cognitive and metacognitive characteristics, such as degree of prior knowledge and self-regulation, and affective traits such as self-efficacy and trait anxiety. Such characteristics, most notably prior knowledge (e.g., Chi, Glaser, & Farr, 1988; Kalyuga, 2005; Kalyuga, Ayres, Chandler, & Sweller, 2003), have been shown to be strong predictors for learning outcomes. Trait variables that are relatively stable over time and vary by person are regarded as learner characteristics. To acknowledge the distinction between affective traits and more transitory emotional and motivational states which arise from the given situation (e.g., Linnenbrink, 2006), the latter are treated separately in the model (see emotion/motivation component).

Learner variables can affect each component of the interactivity process. For example, the way in which an individual engages in specific behaviors afforded by a learning environment may be influenced by that individual's degree of self-regulation. To reflect the pervasive influence of individual learner characteristics, INTERACT represents the learner variables component as underlying the other components of the model.

3.8. A process approach to interactivity

Together, the elements of the INTERACT model and the relationships among those elements represent the complex and dynamic interplay between a multimedia learning system and a learner. Different events and activities can be understood as tracing different paths through the model. Though all elements of the model are always in play to a certain degree, different elements may be emphasized at any given time depending on the situation. Many of the constructs and features typically discussed in the context of interactivity, such as learner control, guidance and feedback, can be reconceptualized in this integrated approach, which we will discuss below.

4. Rethinking interactive features

The INTERACT model, which proposes a system of linked elements that comprise interactivity, can serve to clarify existing findings as well as to structure future research. Existing studies can be classified in accordance with the six components of the model; clarifying which components are examined in a given study enables useful comparisons. The application of the model provides a framework for in-depth comparisons that highlight the similarities and differences.

As suggested earlier, much interactivity research to date has been concerned with specific features, such as learner control, feedback, and guidance. Due to the complex process nature of interactivity, such features need to be considered in an integrated systems context. Below we will show how these common concepts related to interactivity are explained by INTERACT.

4.1. Learner control

The most prominent feature discussed in conjunction with interactivity is learner control. Scheiter and Gerjets (2007) claim that the terms learner control and interactivity can be used interchangeably; however, our model suggests that learner control is just one possible type of system affordance feeding into the interactivity process. Although learner control is assumed to promote cognitive activities as well as learner's interest and motivation, research so far has yielded mixed results (Scheiter & Gerjets, 2007). Several forms of learner control can be distinguished. *Control over pacing* enables the learner to start, stop, pause or replay; this is also referred to as control over information delivery. *Control over content* ranges from selecting information units from a menu or Internet search results and adjusting the amount of information displayed (access to hints, help or extended feedback) to segmenting information into appropriate units (e.g., by zooming in or out). Finally, *control over representation* allows the learner to choose the modality or angle of view (Kalyuga, 2007; Plass, Homer, & Hayward, 2009). Although navigation is sometimes treated as a discrete form of interactivity (Moreno & Mayer, 2007), it incorporates aspects of each type of learner control and therefore does not require separate discussion in this context.

Despite the number of different types of learner control, with respect to the proposed model, all of them emphasize the same elements of the interactive process. An opportunity for learner control offers the learner the potential to manipulate the learning

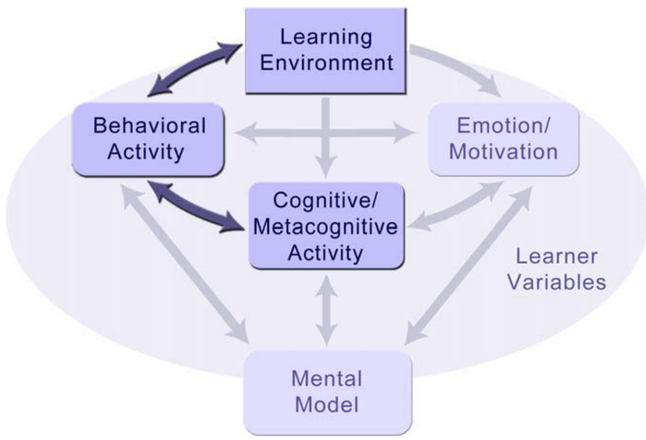

Fig. 3. Learner control in INTERACT.

environment through behavioral activities. These behavioral activities, in turn, are directed at facilitating or even enabling the learner's cognitive and metacognitive activities (Fig. 3). All types of learner control can help the learner to adjust information to his or her cognitive needs. Pacing allows learners to slow down information delivery, while control over content as well as control over representation allow learners to access information that is appropriate to their prior knowledge and that they need in order to construct a coherent mental model.

A reexamination of the two studies on learner control cited earlier (Mayer & Chandler, 2001; Schwan & Riempp, 2004, experiment #2) illustrates the use of the proposed model as a framework for the systematic comparison of different studies and their outcomes. Both studies look at the same type of learner control (pacing) as a feature of the learning system. In the Mayer and Chandler study, learner control consisted only of the ability to proceed to the next segment of the presentation by clicking a button. In the Schwan and Riempp study, learners in the interactive condition were able to play, pause, replay, reverse direction and change the speed of the presentation by clicking buttons and moving a tile; those in the noninteractive group could view the video as often as desired, but only from start to end. Deciding simply to go to the next segment involves lower-level metacognitive activities than using the more complex options provided in the Schwan and Riempp study; the studies therefore differ in the affordances provided by the learning system as well as in the afforded behavioral and (meta)cognitive activities. Additionally, in terms of learning outcomes, the subject matter in the Mayer and Chandler study consisted of factual and conceptual information (process of lightning formation), while Schwan and Riempp investigated the acquisition of procedural knowledge (tying nautical knots). Both studies reported an advantage for the learner control group. Mayer and Chandler found an advantage on transfer but not on retention tasks, although the results have to be carefully interpreted as this group also spent more time on the learning task. In the Schwan and Riempp study the learners made heavy use of the learner control features, as measured by log-files. The learner control group spent the same amount of time watching the videos, but needed less practice time to learn to tie the knots. In line with the assumptions from our model, the authors explain the advantage of the learner control group in practice time with the possibility of adapting the presentation to individual cognitive needs. According to our INTERACT model, an alternative explanation can be suggested when considering the affective state of the learners. The noninteractive group might have spent more time trying to tie the knots themselves since they would otherwise be forced to watch the whole video again, without being able to skip the parts which they had found easy.

4.2. Guidance/feedback

Another educational design feature frequently associated with interactivity is guidance. Guidance aims at directing cognitive processes of the learner such as generating hypotheses, monitoring, and structuring the overall process (De Jong, 2005). Similar to learner control, guidance can take many different forms. De Jong and Njoo (1992) distinguish direct and nondirect support. Direct support guides the learner in a specific direction (e.g., direct advice, suggestions, hints), whereas nondirect support offers open tools with which the learner can add, reorganize and save information (e.g., hypothesis scratchpad, monitoring tool) (De Jong, 2005). Another typology by Reid, Zhang, and Chen (2003) distinguishes interpretative, experimental and reflective support (De Jong, 2005). Interpretative support guides the learner in structuring knowledge from the domain by activating prior knowledge, modeling or concept-mapping tools as well as elaborated feedback. Experimental support helps the learner to set up and interpret experiments by hints, guiding questions and feedback on experiments, for instance in a simulation. Reflective support assists learners in reflecting on the learning process and new information by implementing reflection tools. Reflection prompts and asking the learner to generate self-explanations (Wouters, Tabbers, & Paas, 2007) can be categorized as types of reflective support.

Feedback is another concept connected to interactivity. Although sometimes treated as a distinct category (e.g., Moreno & Mayer, 2007), it is typically described as a guidance technique (Plass et al., 2009). Different types of feedback (for example, providing the correct answer with or without elaboration or requiring the learner to keep trying until he or she gives the correct answer) provide different kinds of instructional support (Narciss, 2006; Narciss & Huth, 2004).

Guidance as an interactive feature, then, entails numerous diverse concepts such as feedback, reflection prompts and direct advice. Nevertheless, the INTERACT model offers a way to examine the similarities between the various guidance concepts. All types of guidance aim to promote learners' cognitive and/or metacognitive activities. In the case of an interactive environment, the cognitive processes afforded by the system should facilitate behavioral activities and guide students in making appropriate choices that promote their learning (see Fig. 4). For example, a student might receive hints that prompt her to think about and select appropriate items of information from a menu (cognitive and metacognitive processes) by clicking a button (behavioral activities). However, in contrast to learner control, guidance does not primarily target behavioral activities. In fact, some forms of guidance may be intended to promote cognitive activity only; consider a question that

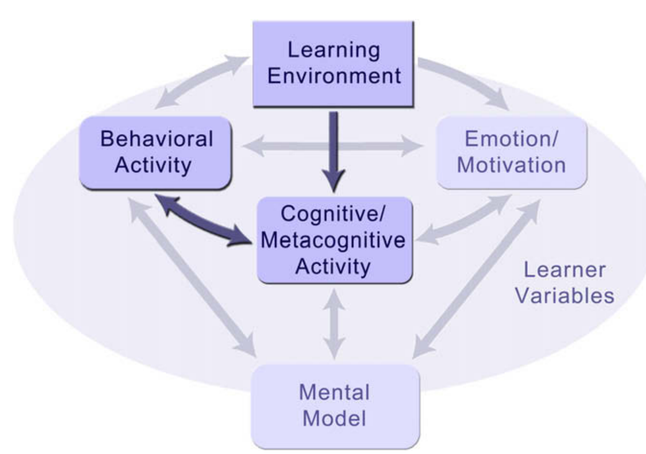

Fig. 4. Guidance in INTERACT.

pops up at the end of a multimedia unit and simply asks the learner to "think about what you have just read." Guidance can only be considered an interactive feature if it enables or promotes some kind of behavioral response in the learner. Again, behavioral activity of the learner is a defining feature of interactivity.

Because guidance is not necessarily interactive, and involves so many different concepts, INTERACT may be particularly helpful in providing a framework to clarify the features that have been investigated in previous studies as well as some findings that to date have seemed contradictory. Three studies mentioned in the beginning of this paper can be understood to concern guidance: Tung and Deng (2006), Moreno and Mayer (2005), and Moreno and Valdez (2005). The findings of these studies can now be interpreted in terms of INTERACT.

Although Tung and Deng do not present their study in terms of guidance, guidance is in fact one of the elements examined. Participants were assigned to either an active-interactivity or a passive-interactivity condition. In the active-interactivity condition, when learners answered questions correctly they advanced automatically to the next question. If they answered incorrectly the system prompted them to press a key in order to proceed. Before moving on, they were automatically presented with the correct answer. In the passive-interactivity group the system displayed "right" or "wrong" for each response, but did not present any prompts on how to proceed. The correct answer was displayed only if the user pressed an "answer" key. The active-interactivity group thus received guidance that the passive-interactivity group did not receive. Although both conditions required a behavioral response from the learner (clicking the button), the passive-interactivity condition aimed at (meta)cognitive as well as behavioral activities. Learners had to decide for themselves how to proceed before they could behaviorally respond. According to INTERACT, both conditions can be viewed as interactive, since both aim at behavioral responses of the learner. However, applying the model highlights that the labels "active-interactivity" and "passive-interactivity" are misleading. It is the passive-interactivity condition that invites the user to be (meta)cognitively more active, while the active-interactivity condition allows the user to remain (meta)cognitively more passive. Further, the two conditions in this study differed along another variable: only the active-interactivity group received personalized messages or comments from the computer (e.g., "hi, welcome!"). Personalization is an affordance of the learning system which aims at the motivational and emotional state of the learner; since it does not aim at behavioral responses, it is not an interactive feature. Results indicated that the participants in the active-interactivity condition reported higher social presence and social attraction. In this case the outcome measures concerned the affective state of the learner rather than specific learning outcomes. However, as the experimental conditions included two confounded variables, it is not possible to decide whether the effects found are due to the presentation of the personalized messages or the prompts (guidance).

Moreno and Mayer (2005, experiment #2) examined reflection (either asking or not asking learners to give self-explanations of their answers) and interactivity (learners either selected the right answer from a list or were presented with the right choice). While the reflection treatment clearly concerns guidance, the nature of the interactivity treatment can be clarified based on the INTERACT model. In the interactivity treatment, the learning system provided the correct answers for one group (the noninteractive group). By providing the answer, the system offered direct advice, a form of guidance. In contrast, the interactive group was given no direct advice, but had to choose the right answer without guidance from the system. Therefore both treatments in this study, reflection and interactivity, deal with guidance. According to INTERACT, the critical difference lies in whether the presence of guidance (reflection treatment) or its absence (interactivity treatment) lead to both cognitive and behavioral activity. Guidance in the reflection treatment was an interactive feature: Learners had to reflect (cognitive activity) and generate self-explanations (behavioral activity). In the interactivity treatment, however, guidance was not an interactive feature. Students in that treatment who received guidance were presented with the correct answer; they did not have to make a selection (no behavioral activity) and in fact they did not necessarily have to think about the material (no cognitive activity). In contrast, those who were not given guidance had to decide on their answer (cognitive activity) and make a selection (behavioral activity). This distinction may clarify the reported results. Moreno and Mayer (2005) refer to an interaction effect between the interactive and reflection treatments, concluding that "reflection techniques help students learn from noninteractive conditions but not from interactive environments" (p. 125). Applying INTERACT's terminology, the comparison is not between interactivity and reflection, but rather between two affordances of the learning system, reflection and direct advice. Reflection aims at engaging learners in cognitive activities, in this case in thinking about their answers. The group that was required to make their own decisions about answers (no direct advice – interactive condition) had already thought about these answers and did not require additional reflection prompts. But for those that had been presented with the answers (direct advice – noninteractive condition), the reflection prompts were needed to engage them in cognitive activities. From an INTERACT perspective, in each case the condition which emphasized both cognitive and behavioral activities benefitted the learners, but redundant demands did not enhance learning.

Moreno and Valdez (2005) examine another form of guidance, corrective feedback. This study demonstrates that even a different design of the same interactive feature can have different effects in the interactive process. Here, undergraduate students were presented with 16 frames about the causal chains leading to lightning formation. The students were given 4 frames at a time. The noninteractive group was presented with the frames in the correct sequence and viewed them for 4 minutes; the interactive group had 3 minutes to organize each set of 4 into the correct order and an additional minute to study them. Corrective feedback (guidance) was given each time a learner placed a frame. The authors anticipated that in order to organize the frames, the interactive group would engage in cognitive processing, which would promote deeper learning. Contrary to expectations, however, the noninteractive group did better on retention and transfer tasks than the interactive group. The authors suggest that this may be because the design of feedback encouraged a trial and error technique instead of "promoting mindful activities" (Moreno & Valdez, 2005, p. 41). This explanation is consistent with the INTERACT model. The task assigned was meant to aim at cognitive activities of the learners (thinking about correct sequence) leading to a behavioral response (placing the frames). The corrective feedback might have encouraged learners to bypass cognitive activities and instead use a simple, behavior-based technique. Given the limited study time, this might have taken time that the student could otherwise have used for studying the process. In this case the interactive task would interfere with learning since it adds a behavioral task that is not linked to cognitive activities. In a follow-up study, Moreno and Valdez (2005) examined whether the design of the feedback explained the detrimental effect of the interactive task. One group received corrective feedback after each frame (as in experiment #1); the other group had to organize all four frames before receiving corrective feedback. In line with the expectation that the second form of feedback would engage learners in cognitive processing and therefore promote learning, the second group outperformed the first on retention and transfer. However, because the follow-up did not include a control group without the interactive task, it can only be concluded that feedback on each set of frames is more appropriate than feedback on each single frame.

In summary, applying the INTERACT model as a framework to discuss existing studies on guidance highlights the utility of an integrated model that can be used to define and describe the conditions compared in a research study, as well as to provide a well-defined terminology to discuss the outcomes. The INTERACT model shows that guidance, unlike learner control, can be either an interactive or a noninteractive feature. Our review shows that the first case holds for Tung and Deng's (2006) study as well as the "reflection" condition in Moreno and Mayer's (2005) study. The "interactivity" condition of the latter, however, exemplifies the second case, in which guidance (direct advice) constitutes a noninteractive condition. Moreno and Valdez's (2005) study further shows that guidance as an interactive feature must be carefully designed: Providing features that engage learners in behavioral activity does not mean that they automatically engage in appropriate cognitive activities. Therefore, the proposed model not only provides a meaningful framework for the review of existing studies but can also be applied to the design of future studies.

5. Summary and conclusion

The goal of this paper was to address the lack of definitional clarity of the concept of interactivity in the context of multimedia learning. To that end, we have proposed a definition that describes interactivity as reciprocal activity between a learner and a multimedia learning system, in which the [re]action of the learner is dependent upon the [re]action of the system and vice versa. We have argued that interactivity is not a function of the affordances of the learning system alone, nor merely a function of the cognitive activities of the learner. Rather, a full understanding of the concept of interactivity must incorporate the dynamic process between the learning system and the learner. We have introduced a new model of interactivity, which integrates the affordances of the medium and the activities of the learner. The Integrated Model of Multimedia Interactivity (INTERACT) consists of a system of six integrated principal components: the learning environment, behavioral activities, cognitive and metacognitive activities, motivation and emotion, learner characteristics, and the learner's mental model (learning outcomes). The interactivity process is represented by the feedback loops that connect these components (Fig. 1).

The INTERACT model described in this paper has several important theoretical as well as practical implications. On the theoretical side, INTERACT is a process model that shows how the concept of interactivity in the context of multimedia learning is amenable to decomposition, allowing for the separation of six specific components that together comprise interactivity. The identification of these specific components introduces a conceptual clarity of the interactivity concept that was necessary in order to interpret past research findings, which had been inconclusive, as well as guide future research on interactive learning environments. We have discussed how concepts related to interactivity, such as learner control, guidance, and feedback, can be meaningfully operationalized in this model. We have demonstrated how the application of the model to previous studies allows for a new interpretation of some of the findings that is more consistent with educational theory. Our discussion has shown that asking simply "Does interactivity promote learning?" is not productive, as this question treats interactivity as a static feature rather than as a process. Instead, research questions to be investigated should focus on the dynamic relationships among the six components of interactivity, asking "Under what conditions, and for whom, are specific interactive elements or combinations of elements effective?"

On the practical side, the INTERACT model provides educators and educational designers with a process approach that allows them to design and evaluate specific interactive components for their multimedia applications. By incorporating the learning environment, behavioral activities, cognitive and metacognitive activities, motivation and emotion, learner characteristics, and the learner's mental model, INTERACT clearly relates to the instructional design process and provides designers with a foundation for the interaction design of their animations, simulations, microworlds, or educational games.

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