

Mental Models as a New Foundation for Instructional Design¹

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Three worlds of Instructional Design (ID) are distinguished. The *World of Knowledge* stresses the analysis of learning outcomes in knowledge structures and the selection of instructional strategies for particular outcomes. The *World of Learning* focuses on particular learning processes and the synthesis of strategies that support those processes. And, finally, the *World of Work* focuses on real-life task-performance and strategies that support learners while they work on authentic problems. Mental models offer a promising construct to build bridges between the three worlds, offering a new, more powerful foundation for ID.

Introduction

Education and training must accommodate a diverse, widely distributed set of students who need to learn

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and transfer complex cognitive skills to an increasingly varied set of real-world contexts and settings. This poses such a serious challenge to Instructional Design (ID) that the April 2000 article in *Training Magazine*, "The attack on ISD: Have we got Instructional Design all wrong?," suggests that ID in its current form is as good as dead because its foundation is not suitable for facing the new societal and technological demands.

To make ID viable again, we need to work towards a more comprehensive foundation of ID and to develop more powerful ID models that can deal with today's demands. This article aims to search for this new foundation by broadening the perspective on learning. First, it argues that three different worlds can be distinguished in the current field of ID: The World of Knowledge, the World of Learning, and the World of Work. These worlds represent different perspectives on the main issue in ID, namely, "how to help people learn better" (Reigeluth, 1999, p. ix). Second, it argues that a reconciliation of the three worlds will yield a stronger foundation for the future field of ID. The construct of mental models may be of great help to reach the desired reconciliation. The article closes with a brief discussion of these implications for a new generation of ID models.

Three Worlds of ID

Theories and models of ID come in different types, situating ID in different worlds. In these different worlds, ideas about "how to help people learn better" lead to different answers to the two basic questions of ID: "what-to-teach?" and "how-to-teach it?" We make a distinction between the World of Knowledge, the World of Learning, and the World of Work (see also van Merriënboer & Kirschner, in press).

The World of Knowledge

This world is most easily associated with the traditional field of ID, whose foundations were laid by Gagné (1965). In this world, the common answer to the what-to-teach question lies in taxonomies of learning outcomes, typically referring to particular knowledge elements (e.g., concepts, rules, strategies, etc.). Taxonomies of learning have a long history, with the taxonomies of Bloom (1956) and Gagné (1965) still in wide use. Gagné also made clear that specific learning outcomes could often only be determined on the basis of some kind of task analysis. He introduced the "learning hierarchy" as a means of task decomposition. This hierarchy holds that a more complex intellectual skill is at the top of the hierarchy, with enabling skills at a lower level. Later ID models further refined taxonomies of learning (e.g., Merrill's performance-content matrix, 1983) and detailed out the task-analytical procedures necessary for reaching a highly specific description of "what-to-teach" in terms of

particular learning outcomes (e.g., Leshin, Pollock, & Reigeluth, 1992).

In the World of Knowledge, the common answer to the how-to-teach question rests on Gagné's idea of "conditions of learning." Theories for the design of instruction (e.g., Merrill's Component Display Theory, 1983, and Instructional Transaction Theory, 1991; Scandura's Structural Learning Theory, 1983, and many others) presume that the optimal conditions for learning mainly depend on the goal of the learning process. By analyzing these goals, instructional designers can devise how to best achieve those goals. The theories assume that designers can describe a subject matter domain in terms of learning goals, and can then develop instruction for each of the learning goals—taking the optimal conditions of learning for each goal into account.

In an epistemological sense, the World of Knowledge takes an *analytical* perspective that can be traced back to Descartes' *Discourse on Method* (1960), in which the process of dividing and subdividing a problem until small, immediately understandable parts were found is described. But its major strength, namely its analytic approach, is at the same time its major weakness. As argued by Wilson (1998), "the reduction of each phenomenon to its constituent elements, [is] followed by the use of the elements to *reconstitute* [italics added] the holistic properties of the phenomenon" (p. 146). This process of reconstitution works well for a limited set of elements, but for complex learning situations, instructional designers face extremely large sets of highly integrated knowledge elements. They need to synthesize many instructional strategies that are all necessary to reach multiple learning goals. While ID models in the World of Knowledge are very helpful for analyzing learning goals and apportioning these goals into their constituent elements, they provide far less guidance for synthesizing the large number of instructional strategies that may help to make learning more effective, efficient, and appealing.

The World of Learning

The World of Learning is, not surprisingly, primarily rooted in educational and cognitive psychology. The focus is on the description and analysis of learning processes. The starting point for design is not an analysis of the content, but rather a study of the process of learning. Examples can be found in research on reading comprehension, which yielded guidelines for the optimal design of texts (see Hartley, 1978); on the acquisition of procedural skills, which yielded guidelines for the design of drill-and-practice computer programs (see Salisbury, 1990), or on discovery learning, which yielded guidelines for the design of computer-based educational simulations or discovery worlds (e.g., De Jong & van Joolingen, 1998). While the

World of Knowledge is heavily involved with task and content analysis in order to specify learning outcomes, the World of Learning is mainly involved with specifying the instructional conditions that may help to support a particular, often pre-defined kind of learning process.

In the World of Learning, the "how-to-teach" question is thus typically rephrased as a "how-to-support-learning" question. Whereas in the World of Knowledge, instructional strategies often take the form of delivery methods, specifying how to optimally deliver presentations, set up practice and assessment for particular learning outcomes, in the World of Learning, instructional strategies deal with methods that support specific learning processes. The focus is on the development of support systems, often called cognitive tools or learning tools, and feedback strategies.

From an epistemological viewpoint, the World of Learning takes a *synthetic* perspective with respect to the designer's activities. The focus is on what people do in the world and on an ontology of action. Activity Theory (Nardi, 1996) stresses, for example, that activities quite often involve other persons and various artifacts and that particular activities require a synthetic process (or "authoring" process) directed at the development of particular kinds of learning supports and facilitation. While the focus of the World of Knowledge is typically on "pre-authoring," that is, the analysis of content, tasks, context, and target group and the selection of instructional strategies, the World of Learning focuses on authoring and authoring tools (i.e., putting the instructional strategies together). The primary role of the real world is to provide a setting in which the curricular goals of the intended education can be applied. Context is for the authors primarily the organizational context in which the authored system will eventually be applied.

The World of Work

Finally, in the World of Work the common answer to the "what-to-teach question" lies in a description of real-life or professional tasks. This world is best associated with social-constructivist views on learning based on the idea that learners construct knowledge based on their own mental and social activity. Constructivism holds that in order to learn, learning needs to be situated in problem solving in real-life, authentic contexts (Brown, Collins, & Duguid, 1989) where the environment is rich in information and where there are no right answers (embedded knowledge).

In answering the how-to-teach question, theories within the World of Work take the viewpoint that complex knowledge and skills are best learned through cognitive apprenticeship on the part of the learner in a rich environment (Collins, 1988). Experiences are provided for the learners that mimic the apprenticeship

Table 1. The three worlds compared.

	World of Knowledge	World of Learning	World of Work
Foundation	Traditional field of Instructional Design	Educational and cognitive psychology	Social constructivism
Perspective	Analytical	Synthetic	Holistic
Begin point	Taxonomy of learning outcomes	Characteristics of learning processes	Real-life task performance
Goal	Optimize delivery, practice, and assessment of particular learning outcomes	Develop support systems and feedback strategies for particular learning process	Provide whole-task practice and coaching
Process	Analysis of task, content and target group, and selection of instructional strategies	Authoring learning environments	Modeling models of reality from a didactical perspective

programs of adults in trades, or teachers in internship. Although it is not possible to immerse the learner to the extent that an internship would imply, through the use of simulations and meaningful experiences, the learner would learn the ways of knowing of an expert. Meaning is negotiated through interactions with others where multiple perspectives on reality exist (Von Glasersfeld, 1988). Reflexivity is essential and must be nurtured (Barnett, 1997a, 1997b). Finally, all of this is best—and possibly only—achieved when learning takes place in ill-structured domains (Spiro, Coulson, Feltovich, & Anderson, 1988).

The philosophical roots of the World of Work can be traced back to a *holistic* perspective, which dominated classical Greek philosophy, then became less popular, but re-emerged in the last half of the 20th century (e.g., in Forrester's work on system dynamics, 1961). The main problem of a holistic approach is how to deal with complexity. Most authors introduce some notion of "modeling" to attack this problem. For instance, Spector's MFL framework (Model Facilitated Learning, in press) suggests that there must always be a number of phases in learning (cf., Piaget, 1970), with a graduated progression from concrete experiences towards more abstract reasoning and hypothetical problem solving. Achtenhagen's (2001) notion of "modeling the model" prescribes a two-step approach to didactic modeling, namely modeling reality and then modeling those models of reality from a didactic perspective. This modeling of the model for didactic purposes allows the designer to determine which elements of the original model can be omitted, and which elements can be made abundant (not in the

original, but introduced for supporting the functions of the model).

Summarizing this section, there appear to be at least three Worlds of ID (see Table 1). The World of Knowledge stresses the *analysis* of tasks and content in learning goals and prescribes optimal instructional methods for particular goals. The World of Learning stresses the characteristics of particular learning processes and yields guidelines for the *synthesis* of learning support systems in particular learning environments. Finally, the World of Work takes a *holistic* viewpoint and stresses real-life, professional task performance and instructional strategies to deal with the complexity of whole-task performance.

Bridges over Troubled Waters

Future work in the practical, eclectic field of ID should aim at bringing the three worlds of ID together. A broader foundation of ID is necessary to better accommodate a diverse, widely distributed set of students that needs to learn and transfer complex skills to an increasingly varied set of real-world contexts and settings. It might be impossible to reach a true reconciliation of the three perspectives underlying the worlds, but just attempting it may take the field of ID one important step further. What the ID community needs are bridges over the troubled waters between the three worlds.

The construct of mental models may offer a way to build those bridges (cf. Seel, in press). Mental models are cognitive artifacts or inventions of the human mind that can be considered to be the best-organized

Mental Models

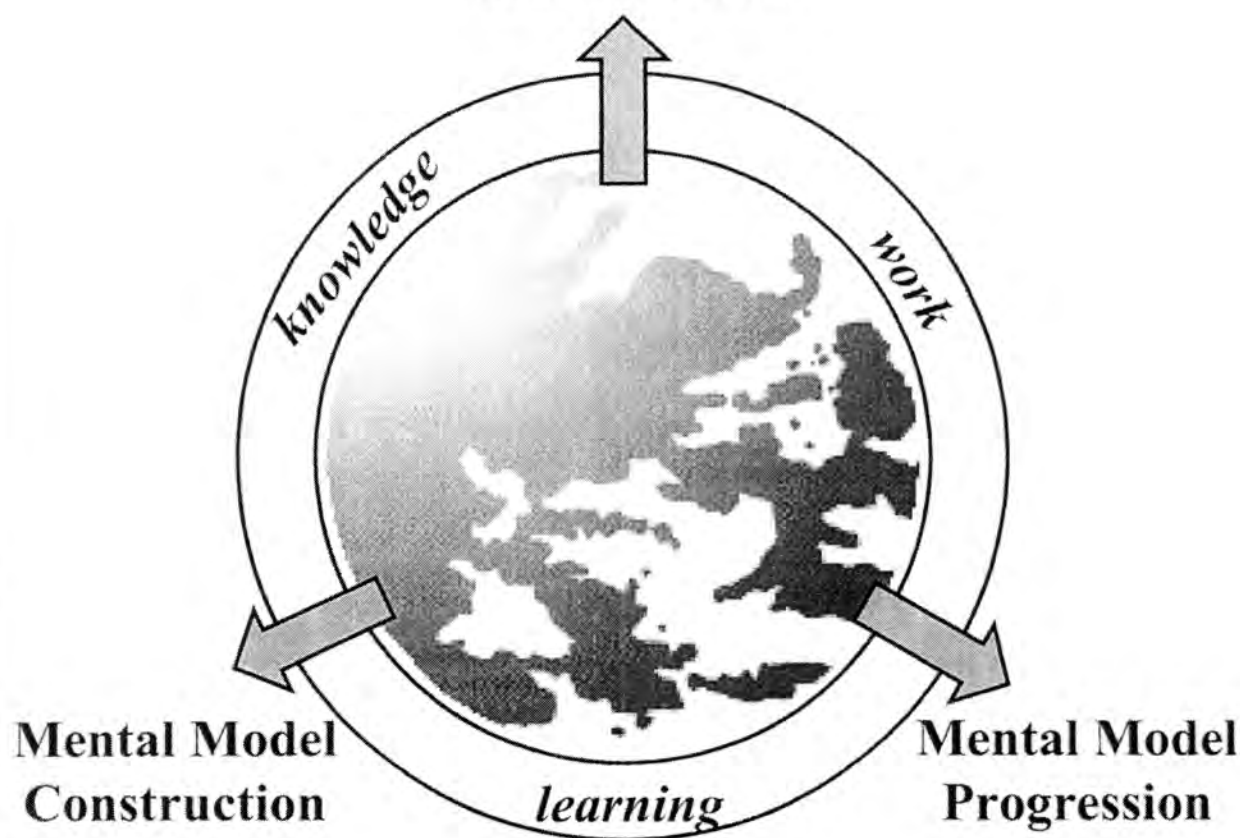


Figure 1. Bridges over troubled water: How mental models link the three worlds of ID.

representations among declarative learning results. Theorists, such as Johnson-Laird (1983), have used the term mental model to refer primarily to the *content* of mental representations which learners actively construct in order to create subjective plausibility with regard to complex phenomena of the—observable or imagined—world. As qualitative knowledge representations, mental models play a central role in learning. On the one hand, learners dynamically construct mental models on the basis of their generic world knowledge and the particular learning environment they are facing. On the other hand, effective instruction (i.e., presenting a conceptual model in the beginning of instruction) positively affects the successful construction and stability of mental models during situated learning.

Simply speaking, the claim of a central role for mental models in ID means that such an approach does

not fit the World of Knowledge, since it rejects a taxonomy of learning outcomes as the starting point for design. Instead, mental models are seen as meaningful wholes. It does not fit the World of Learning because there is no clear focus on particular learning processes. Instead, the *ad-hoc* nature of mental models is emphasized (Seel, 1991) and primacy is given to the students' constructions of content knowledge through an inquiry process of analysis, experimentation, and simulation. Finally, it also does not fit the World of Work because realistic task performance is not a starting point for design. Learners may indeed construct mental models to reflect such performance, but the models do not simply represent or reproduce it. At the same time, it might be argued that mental models offer a theoretical construct that may help to combine the three worlds of ID. Figure 1 shows the necessary three bridges over troubled water.

First, mental models may provide a bridge between the World of Knowledge and the World of Work. Mental models are meaningful *wholes*. They can be seen as qualitative mental representations which have been developed by learners and which are based upon generic world knowledge together with domain-specific knowledge with the aim of solving problems or acquiring competence in a specific subject matter domain. Mental models represent the whole body of knowledge that enables the performance of a professional skill in a particular situation and thus fits the World of Work well. From a psychological point of view, mental model approaches may lack the simplicity of systems based on knowledge objects or rules, but from an instructional point of view it is worthwhile to think in terms of mental models because they provide a higher level of reasoning about the knowledge underlying the performance of complex tasks. Mental models may, for instance, be used to make instructional-sequencing decisions (see below). In addition, mental models are liable to further analysis as in the World of Knowledge. It may be argued, for example, that people have a set of highly interrelated knowledge structures for representing the form, structure, and function of various objects, events, and activities. They also have a set of procedures and heuristics for both reasoning about these objects, events, and activities as well as for generating purposeful behaviors with respect to them. In principle, mental models might be analyzed in such knowledge structures, procedures, and heuristics if this is necessary for the ID process (e.g., Anderson, 1988; van Merriënboer, 1997), although this analysis is in a relatively immature state as compared to the analysis of distinct skills and declarative knowledge structures. Seel and coworkers (e.g., Seel, 1991; Seel, Al-Diban, & Blumschein, 2000) have described the development of representational formats for mental models in terms of semioses and associated analysis techniques.

Second, mental models may provide a bridge between the World of Knowledge and the World of Learning. The key concept here is *mental model construction and revision*. The question is how learners construct mental models, or, how they revise them when expertise develops. It is as yet unclear how learning and constructive processes with respect to mental models can be best described. Often, authors describe mental model construction in a terminology that originated from the World of Knowledge. Van Merriënboer (1997), for example, describes mental model construction in terms of the well-known distinction between schema construction and schema automation. The problem with this approach is that these learning processes are coupled to knowledge elements (rules and schemata) at a level of abstraction that is far below that of mental models as meaningful wholes. Taking this into account, Seel (1991) described

the basic cognitive processes of analogical reasoning upon which the stepwise construction and revision of mental models are grounded. In this he followed a constructivist view on learning with a focus on the transitions from naive mental models to more effective mental models with increasing expertise in a domain (e.g., Snow, 1990). In this approach, model-building is considered as an effective method for problem solving in complex domains, and the experimental and heuristic tools for analyzing this are structured in such a way that it is possible to localize the errors of a constructed model and to attribute them to some parts, aspects, assumptions or components of the model. Research indicates that this kind of "piecemeal engineering" can substantially improve the model by modifying its offending parts (cf., Seel, 1995).

Finally, mental models may provide a bridge between the World of Learning and the World of Work. The key concept here is *mental model progression*, an approach to instructional sequencing in which to-be-presented learning tasks are based on increasingly more elaborated versions of to-be-constructed mental models (e.g., Spector, in press; Stewart *et al.*, 1992; White & Frederiksen, 1990). A progression should start with a model that contains the ideas that are most simple, representative, fundamental, and concrete. This model must, however, also be powerful enough to enable the formulation of non-trivial tasks that learners may work on. Subsequent models then add complexity or detail to a part or aspect of the former models and become elaborations of them—or provide alternative perspectives on solving problems in the domain. This process continues until a set of mental models is reached that allows for different perspectives and may underlie required exit behavior (van Merriënboer, 1997). In a sense, this process is complementary to mental model construction because knowledge about mental model construction is translated into a series of models that underlies professional task performance in different phases of expertise development. Research should answer the question how models of expertise can be made most useful for instructional purposes. This is an important process of didactic specification, which was called "modeling the model" previously (Achtenhagen, 2001).

Discussion and Conclusion

This article has argued that the construct of mental models might be helpful to build bridges between three worlds of ID, broadening our views on learning and eventually leading to more powerful ID models. Such ID models that go beyond a taxonomy of learning outcomes and associated methods, but that build on our knowledge of learning processes and stress the holistic, indivisible nature of learning are now beginning to appear (see Merrill, 2000, for a review).

One example discussed by Merrill is van Merriënboer's 4C/ID-model (Four-Component Instructional Design Model, 1997; see also Clark & Estes, 1999). This model prescribes the synthesis of a learning environment for complex learning from four interrelated components: (1) learning tasks, (2) supportive information, (3) just-in-time information, and (4) part-task practice. Each component is connected to another category of learning processes, which usually occur simultaneously (in order: induction, elaboration, restricted encoding, and compilation). Furthermore, the first, central component of the model pertains to learning tasks that provide whole-task practice and thus stress the holistic nature of learning. Finally, the 4C/ID-model focuses on construction of mental models of (a) how the world is organized, and (b) how task performers' actions should be organized in this world so as to reach particular goals (also called "cognitive strategies").

To conclude, the main point made in this article is that future research should aim at the development of a common language, an instrument that allows for better communication between the three worlds. Whether mental models or other theoretical constructs are the most fruitful elements of such a common language needs to be seen. In any event, the search for a common language itself will help us take multiple perspectives on the field of ID, further improve our insight into how to help people learn better, and develop more powerful ID models. □

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