A Model for Optimizing Step Size of Learning Tasks in Competency-based Multimedia Practicals

☐ Rob J. Nadolski
Paul A. Kirschner
Jeroen J.G. van Merriënboer
Hans G.K. Hummel

Learners are often overwhelmed by the complexity of realistic learning tasks, but reducing this complexity through traditional Instructional Design (ID) methods jeopardizes the authenticity of the learning experience. To solve this apparent paradox, a two-phase ID model is presented. Phase 1 consists of cognitive task analysis, where a systematic approach to problem solving (SAP) is identified in conjunction with skill decomposition and determination of task complexity. In the subsequent design phase, inductive micro-level sequencing based on the four-component ID model (van Merriënboer, 1997) is applied where worked-out examples and problems accompanied by process worksheets assure the necessary variability of practice. Step size in a multiple-step whole-task approach—needed for the process worksheets—is determined on the basis of estimated part-task complexity. A developmental study of the model is illustrated with examples from the domain of law.

☐ In designing competency-based learning environments the challenge is to facilitate learning while providing authentic tasks. Authentic undecomposed tasks are often too complex for learners to deal with. In this article we present an instructional design (ID) model that focuses on optimizing step size in whole-task approaches to learning complex, mainly nonrecurrent, cognitive skills. The model consists of: (a) skill decomposition , (b) determination of task complexity, (c) identification of systematic approaches to problem solving (SAPs), (d) micro-level sequencing of problems, (e) choosing problem formats, and (f) choosing step size of SAPs to be presented to learners through process worksheets. All are important to facilitate learner task performance in competency-based learning environments. The model is, otherwise stated, concerned with task analysis and design of learning tasks for such environments.

Competency-based Multimedia Practicals (CMPs) provide realistic situations in which meaningful learning through contextualized practice takes place (Brown, Collins, & Duguid, 1989; Westera & Sloep, 1998). These practicals usually deal with complex skills consisting of an integrated set of constituent skills. Although some constituent skills may be recurrent from problem situation to problem situation (i.e., procedural), nonrecurrent constituent skills where the desired behavior is contextually dependent and where transfer to new problem situations should occur

ETR&D, Vol. 49, No. 3, 2001, pp. 87–103 ISSN 1042–1629

are most important. The total skill-set for CMPs is also referred to as the *goal competency*.

Problems within CMPs typically have a well-defined beginning state, many possible pathways, and usually not very well-defined end states, which are within well-defined constraints. Such problems can be extremely large. An example of such a problem is preparation to plead a case in court (Wöretshofer et al., 2000). Because learners are unfamiliar with the problems posed and thus do not know how to approach them (they do not possess the necessary SAP), the problem-task representing the goal competency is too complex to achieve in one try. In other words, the "step size" is too large. In contrast, provided that the necessary support is given to the learners, the problem-task itself is not so difficult that it cannot be practiced as a whole. Learners have most, if not all, of the essential prior knowledge and skills, but have never combined them in the prescribed manner (the SAP).

Our model prescribes six steps in two phases that provide the necessary support to learners. The first three steps form the cognitive task analysis phase; the final three steps constitute the design phase. Before describing this model, we first elaborate on learning in such practicals.

LEARNING IN COMPETENCY-BASED MULTIMEDIA PRACTICALS

CMPs are typically *simulated* task environments, modeled after realistic situations. The learning tasks that learners have to deal with involve complex cognitive skills. Situational learning (Brown et al., 1989) emphasizes that such environments need to offer realistic situations where learning through meaningful practice takes place; complex skills-learning occurs most effectively in a relevant context. This knowledge construction is context-dependent and cannot be isolated from situations in which it is learned (Anderson, 1982, 1993; Brown et al., 1989; Kirschner, van Vilsteren, Hummel, & Wigman, 1997; Kolb, 1984; Parreren, 1987). We assume that complex learning requires the mindful abstraction of cognitive schemata from concrete experiences. However, the full complexity of real-life tasks typically interferes with such effort-demanding inductive processing. In this it is important to stress that *realistic* situations are not necessarily the same as *real-life* situations. ID always involves translation from the real-life events into realistic instructional events.

In the CMP, *Preparing a Plea* (Wöretshofer et al., 2000), the learner is a trainee in a law firm (on CD-ROM), and must prepare pleas for various cases. The case files are available within an (electronic) office. As trainee, the learner receives support from a senior (electronic) employee of this firm, the coach. This coach introduces how to prepare a plea and comments on various activities (i.e., part-tasks of the whole task, to conduct a plea) that the trainee performs during the preparation phase. The trainee can make use of office equipment and can visit other places in the firm. The trainee can—for example—consult experts, observe and analyze other pleas using a "plea checker," attend staff meetings, and study legal backgrounds of different pleas. Finally, the trainee conducts the prepared pleas in real-life two-day role playing exercises and receives comments from tutors and fellow learners before conducting a final plea, the examination for this course.

Learning in CMPs typically involves acquiring a set of highly interrelated, nonrecurrent constituent skills (*goal competencies*) involving a high degree of transfer. Skill performance is based on schema-based behaviors after the training. Problem solving consists of first finding an appropriate problem schema in long-term-memory and then filling this schema with the specific parameters of the problem at hand (Chi, Feltovich, & Glaser, 1981; Chi, Glaser, & Farr, 1988). The problem schema that is retrieved in a particular case is a crucial determinant of how the problem is solved because it determines both the conceptual knowledge used to elaborate the problem statement and the approaches used to solve the problem (Gagné, Yekovich, & Yekovich, 1993). Complex cognitive skills involve both problem solving and skilled performance; the recurrent constituent skills are driven by automated schemata held in long-term memory.

CMPs anticipate novice problem-solving behavior by offering a process worksheet to guide learners through the problem-solving process instead of over-challenging them to induce their own SAP. SAPs are domain-specific problem-solving strategies with their associated heuristics. Learners in CMPs start as novices and act as apprentices since they have not encountered such problems before (Bedard & Chi, 1992). They, therefore, use certain "novice" strategies when solving those problems. Early research on human problem solving (e.g., Newell & Simon, 1972) has made clear that individuals performing complex tasks utilize heuristics that keep the information processing demands of the situation within the bounds of their limited working memory capacity. This, however, often leads to nonefficient learning, resulting in surface processing instead of deep, meaningful processing (Craik & Lockhart, 1972, Sternberg & Frensch, 1991).

Tasks in CMPs

Tasks in a CMP are performed using a SAP encompassing a sequence of phases with associated subgoals. Each phase is accompanied by a set of heuristics that may be used to reach the subgoals and thus to achieve the goal competency. SAPs represent the needed *strategic knowledge*. In our example, the goal competency is "pleading a case in court." The SAP is provided in Table 1. Note that this SAP is nonhierarchic and that the result of each phase is input for the next; iterations between phases are possible.

Transfer for pleading a case in court entails the learner's ability to plead a case in any domain of law (e.g., criminal law or civil law) and in any court (e.g., single judge or three judge).

Tasks in CMPs at the Open University of the Netherlands typically have a study load of about 30–50 hours. Despite the interrelatedness of constituent skills, they are easy enough to be dealt with using a whole-task approach. The available time in instruction (100–200 hours) is considered enough to master the task on a *basic* level while offering a variability of practice. Schemata for recurrent aspects of the skill are not automated at this basic level. Development of expertise is supposed to add at least a factor of ten to the required training time (Eraut, 1997).

Table 1 □ A systematic approach to problem solving (SAP) for "pleading a case *X* in court"

Subgoals (phase)	*Heuristics*
1. Order documents of file *X*	You might try to order chronologically, categorically (e.g. legal documents, letters, notes), or by relevance.
2. Get acquainted with file *X*	You might answer questions such as "Which subdomain of law is relevant for this case?" or "How do I estimate the chances for my client?"
3. Study file *X* thoroughly	You might provide answers to questions such as "What is the specific legal question in this case?", "What sections of the law are relevant in this case?" or "What legal consequence is most convenient for my client?"
4. Analyze the situation of the plea for *X*	You might answer questions such as "Which judge will try the case?", "Where?", "What time of the day?"
5. Determine the strategy for the plea for *X*	You might weigh the importance of the results of (3) and (4) and take your own capabilities (plea-style) into account when deciding about aspects to include in your plea.
6. Determine the way to proceed from strategy to pleading for *X*	You might write a concept plea-note in a certain format using results of (3) and (5) in spoken language, always keeping your goal in mind and using a certain style to express yourself.
7. Determine the way to proceed from pleading (a note) to plea for *X*	You might transform the plea-note into index cards containing the basic line in your plea and then practice this for your self paying attention to various presentation aspects (verbal and non-verbal behavior).
8. Make a plea for *X* and plead it in court	You might pay attention to the reactions of the various listeners.

AN ID MODEL FOR CMP-DEVELOPMENT

Because CMPs focus on nonrecurrent aspects of goal competencies using a whole-task approach, traditional ID theories using behavioral task analysis, which is restricted to the analysis of recurrent skills, have several design shortcomings (see e.g., Dehoney, 1995). Cognitive task analysis is more appropriate here because it can deal with nonrecurrent aspects of a complex skill (Merrill, 1987; Reigeluth, 1983; Reigeluth & Merrill, 1984; Tennyson, Elmore, & Snyder, 1991; van Merriënboer, 1997). Furthermore, it also allows the description of expert performance in complex problem-solving domains (Dehoney, 1995; Dubois, Shalin, Levi, & Borman, 1995; Gardner, 1985; Roth & Woods, 1989). It does so by illuminating the "covert heuristics" (Wilson & Cole, 1990) used by experts to solve problems.

An example of an ID-theory dealing with the analyis of nonrecurrent aspects of complex skills, as well as the teaching of heuristics or rules-of-thumb that help learners to perform such skills, is the four-component ID (4C/ID) model (van Merriënboer, 1997). The 4C/ID-model prescribes task-analytical techniques and design principles for four interrelated components: (a) learning tasks, which provide the backbone of any training program for complex learning; (b) supportive information, which helps learners to learn nonrecurrent aspects of learning tasks; (c) just-in-time information, which is prerequisite to learning recurrent aspects of learning tasks; and (d) part-task practice, which may provide additional practice in recurrent task aspects. The model presented in this article is best seen as a specification of the first component, that is, learning tasks and related support structures in CMPs.

Our six-step ID-model (Figure 1) deals with cognitive task analysis issues (Phase 1: Steps 1 through 3) and ID issues (Phase 2: Steps 4 through 6). It results in a detailed blueprint for the instructional material. The iterative steps in our model are:

Analysis phase

- Step 1: Skill decomposition based on task complexity through:
  —segmentation analysis
  —knowledge analysis
  —scenario analysis for identification of problem (in)dependent features
- Step 2: Objective determination of task complexity
- Step 3: SAP-analysis or strategy analysis

Design phase

- Step 4: Micro-level sequencing of problems (inductive)
- Step 5: Choice of problem formats for variability of practice (within the micro-level sequencing)
- Step 6: Choice of step size for the strategic approach to problem solving to be presented to learners via process worksheets

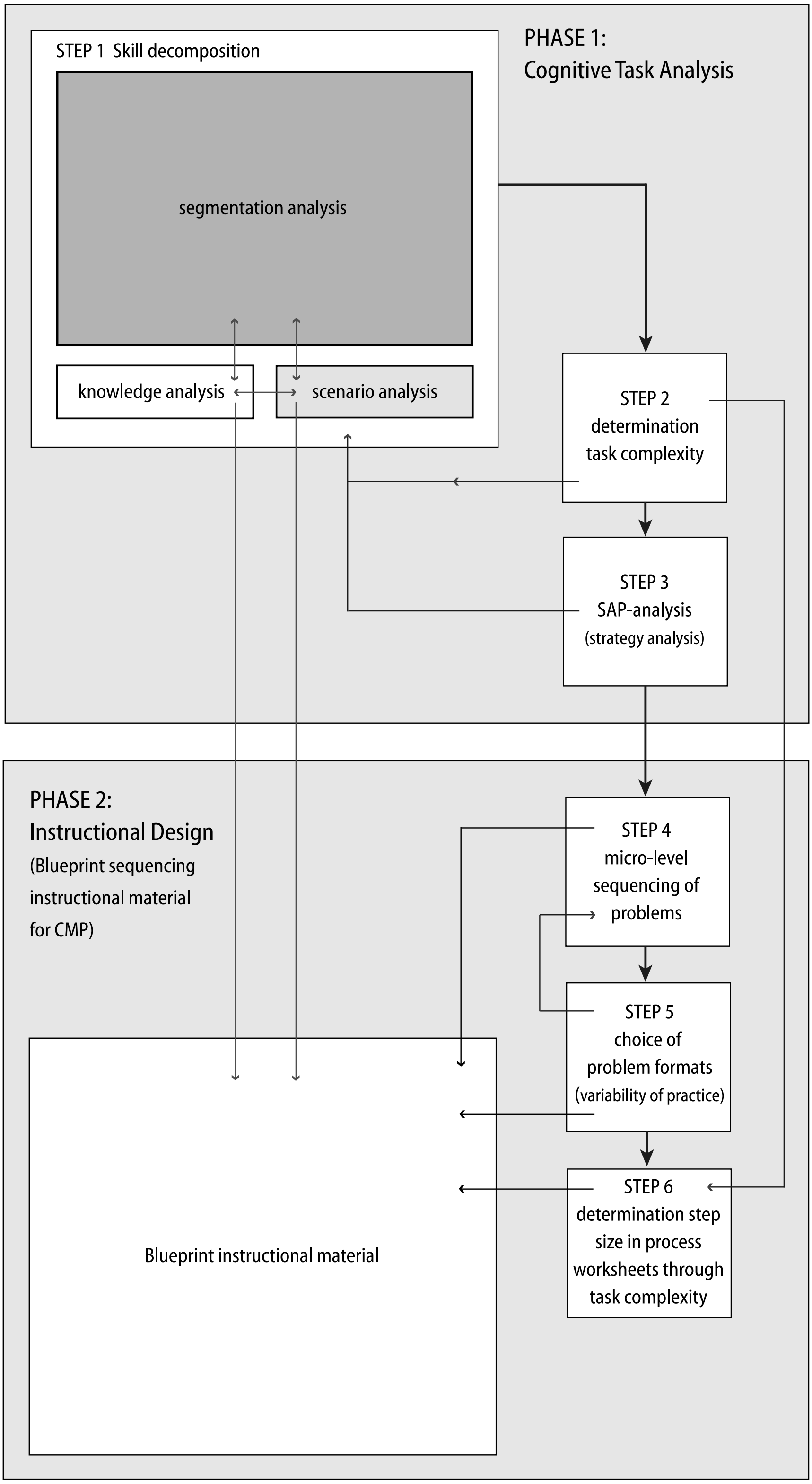
In the following sections we describe the ID activities within the separate steps. Since our model was applied in the development of the CMP, *Preparing a Plea* (Wöretshofer et al., 2000), examples for clarifying those six steps are taken primarily from this CMP.

PHASE 1: COGNITIVE TASK ANALYSIS FOR CMP-DEVELOPMENT

Phase 1, consisting of three steps, makes extensive use of experts and focuses on SAP analysis because this is an important input for ID activities. The steps in the cognitive task analysis are iterative. Skill decomposition (Step 1) identifies part-tasks in a so-called segmentation analysis. Supportive knowledge (resulting from knowledge analysis), strategic knowledge (resulting from SAP analysis) and more or less problem-dependent features (resulting from scenario analysis) are identified for each part-task. SAP analysis or strategy analysis (Step 3) specifies the time relationships between the part-tasks (i.e., the nonrecurrent constituent skills). As an overarching tactic, we measure task complexity (Step 2) to guide the level of detail in the analyses.

Three different categories of experts are used for the different analyses. The first category is practitioners in the problem domain with a lot of experience (in our case lawyers with more than

Figure 1 ☐ The two-phase, six-step ID-model for CMP-development (CMP = competency-based multimedia practical).



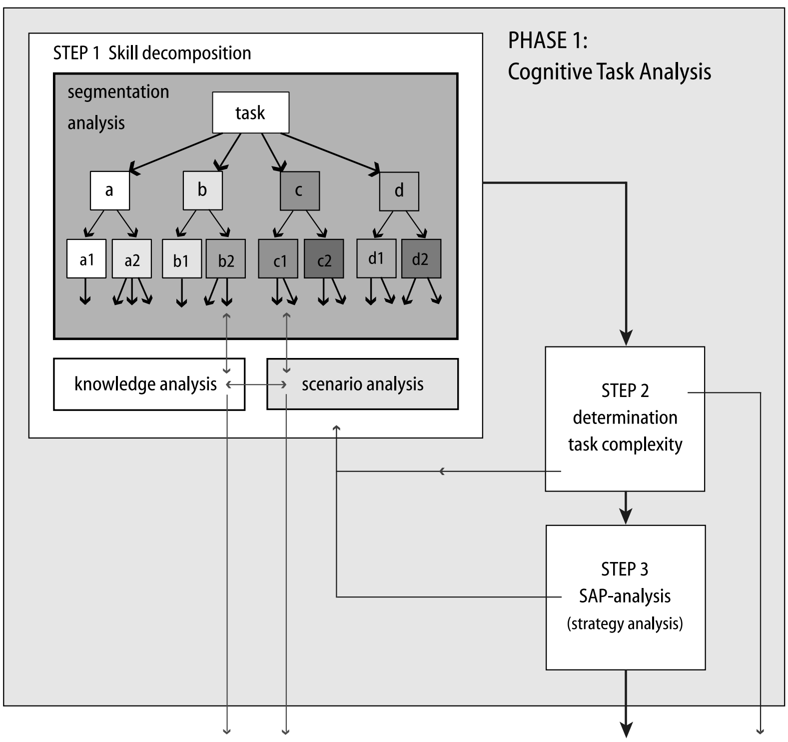
10 years of experience; the *nestors*). The second category is practitioners who are new in the domain, but who function as trainers in this domain (in our case fairly recent graduates who are practicing their profession; the *trainers*). The final category is teachers who are used to teaching in the problem domain, but who no longer practice (the *teachers*). Roth and Woods (1989) indicated that the choice of experts is a potential area of bias in a cognitive task analysis. We try to avoid this bias by using a reasonable number of experts with different backgrounds. They provide input for various analyses through standardized interviews that are analyzed by instructional designers. In their analyses they look for consensus while identifying (reasons for) observed differences.

Step 1: Skill Decomposition

In Step 1, the complex skill for the CMP is decomposed and analyzed. We make use here of three types of analysis, namely (a) segmentation analysis for determining relevant part-tasks, (b) knowledge analysis for determining relevant prior knowledge, and (c) scenario analysis for determining possible problem situations for the ID phase. These analyses are conducted, for the most part, in parallel and make use of data generated during Steps 2 and 3 (see Figure 2).

Segmentation analysis. Segmentation analysis results in segments (subtasks, subsubtasks, etc.) of differing step sizes. These segments must be both functional and nontrivial and must be of comparable complexity (complexity falls within a predetermined range). This determination makes use of an objective measure of task complexity to optimize task decomposition; that is, preventing too much or too little decomposition. Functional segments enable learners to build relevant schemata while nontrivial segments challenge them (cf. Clark, 1999). Using teachers (former practitioners) in this analysis prevents dysfunctional, trivial, or too complex segments because teachers have the pedagogical experience needed to determine this. For our goal com-

Figure 2 ☐ Cognitive Task Analysis phase (Phase 1) of the model.



petency, pleading a case in court, the task "order the documents of file *X*" can be further decomposed into (a) identify legal documents, (b) identify letters, (c) identify notes, and (d) order all three categories chronologically. The teachers identified this as trivial and therefore not to be included in the segmentation analysis. Since teachers use intuitive measures of task complexity to determine when to stop decomposition we needed to develop a task-complexity measurement instrument (see Step 2) for designing self-contained CMPs.

Knowledge analysis. Trainers and nestors identify—among other things—*supportive knowledge*; the declarative knowledge that supports the performance of nonrecurrent aspects of a skill (van Merriënboer, 1997). Supportive knowledge refers primarily to complex cognitive schemata such as conceptual models, goal-plan models, causal models, and functional models. Supportive knowledge for conducting a plea are models that link the consequences of the characteristics of certain plea-styles to actual plea-performance, link the impact of certain (non)verbal behavior on the way people react and describe the ways in which we can attract a person's attention. Supportive knowledge has a bidirectional relationship with strategic knowledge (which may be either procedurally or declaratively encoded in memory) in supporting the nonrecurrent aspects of a skill.

Scenario analysis. CMPs deal with situations that differ from each other, but that also have elements in common. Scenario analysis identifies these problem-dependent features for use in the ID phase; that is, When does a lawyer do this and when, that? All three categories of experts are involved in this analysis. In our example of pleading a case in court this entails a chronological and detailed description of how the plea was prepared and conducted. This task-analytical information guides the process of finding and describing problems or examples and enables designers to design and order problem-situations in the ID phase.

Step 2: Objective Determination of Task Complexity

In Step 2, the complexity of the tasks described in Step 1 is determined using a task-complexity measurement instrument in order to prevent using tasks that are either too complex or too simple. In this way, learners can be optimally challenged during their learning experience.

Task complexity can be objectively determined (Bonner, 1994; Campbell, 1988; Campbell & Gingrich, 1986; Wood, 1986). To determine task complexity objectively, teachers use a task-complexity measurement instrument that we developed using the Burtch, Lipscomb and Wissman procedure (1982). Burtch et al. used a benchmark scaling technique in which anchor tasks described each complexity level on a scale. This technique is easy to use and results in an instrument that can be quickly used for analogous tasks (i.e., domain-specific tasks). Expected prior knowledge of learners is stated in advance of the complexity determination. The effective use of experts in determining task complexity has been reported in various studies (Bonner, 1994; Burtch et al., 1982; Byström & Järvelin, 1995). Task complexity has proven to be both an effective predictor of task performance (see Bonner, 1994) and a relevant indicator of development costs.

Step 3: SAP Analysis

Step 3 of this cognitive task analysis identifies a domain-specific problem-solving strategy together with its associated heuristics. Trainers play a key role in identifying this SAP since they themselves, as beginning practitioners, are not far removed from the target population. Their SAPs, acquired through think-aloud protocols, can with relatively small changes be used for ID purposes. Nestors internalize, automate, or shorten their SAPs to such an extent that they leave out many steps, making it almost impossible to use them for instructional purposes. Practicing law is quite different from learning to practice law (see also Kirschner, 1991, for an example in the domain of the natural sciences). Trainers have not yet internalized, automated, or shortened their SAPs to the level that nestors have. An example of a SAP with its related heuristics for *Preparing a Plea* (Wöretshofer et al., 2000) has already been illustrated in Table 1.

A second problem with using the SAPs provided by experts (Kirschner, 1991) is that the way experts work in their domain (epistemology) is not equivalent to the way one learns in that area (pedagogy). A similar line of reasoning is followed by Dehoney (1995), who reasons that the mental models and strategies of experts have been developed through the slow process of accumulating experience in their domain areas. It is therefore not clear what happens if these models and strategies are imposed on learners. They may interfere in as yet unknown ways with the process of acquiring expertise. Dehoney (1995, p. 120), however, proposed that "some lower-level cognitive strategies can be taught. For example, experts' domain specific strategies for planning and reflecting on the problem solving process will emerge from a cognitive task analysis. These can be taught to novices through modeling." In our view, providing a domain-specific strategy in problem solving through a process worksheet supports the process of acquiring expertise, because this is an example of such a domain-specific planning strategy.

For achieving goal competency we advocate using a whole-task instead of a part-task approach because the learner quickly acquires a view of the whole skill (Reigeluth, 1987). A second advantage of a whole-task approach with a trainer SAP is that learners can use the output from one step as input for the following. In other words, the task is more authentic. Finally, whole-task practice aims at inductive processing in which complex cognitive skills are acquired by practicing them under different conditions (e.g. different problem formats, different sequencing principles, and fading of scaffolding). In this approach, *induction* of cognitive schema is promoted by concrete experiences that force the learner to work from given examples to more general and abstract knowledge and strategies. For example, in *Preparing a Plea* (Wöretshofer et al., 2000) important elements are presented via a "virtual video tape" containing examples and nonexamples of certain plea behaviors. Each concrete observable behavior in a plea is directed at the achievement of a certain subgoal (e.g., make information accessible, keep someone's attention).

PHASE 2: DESIGNING INSTRUCTION FOR CMPS

Phase 2 uses the results from the cognitive task analysis phase and focuses on micro-level sequencing of the tasks (Step 4), choosing relevant problem formats (Step 5), and choosing appropriate step size for process worksheets (Step 6). These steps are also conducted iteratively and result in a detailed blueprint for the CMP (see Figure 3). This leads to micro-level high-variability sequencing using worked-out examples and problems with process worksheets (with a certain step size for SAPs included). This approach both encourages schema construction and supports transfer, and corresponds with the earlier enumerated guidelines in the 4C/ID model.

Sequencing of learning tasks (Step 4) is pivotal in facilitating the learning process (e.g. Brown et al., 1989; Gagné et al., 1993; Merrill, 1987; Reigeluth, 1983). Although many design methods deal with sequencing instruction, few deal with doing this for complex cognitive skills (see van Merriënboer, 1997).

Working memory is limited. Since learning tasks differ in their taxing of the learner's working memory, we have chosen to use Sweller's cognitive load theory (1988) to guide us in the selection of problem formats (Step 5).

Process worksheets guide learners through the application of the (sub)SAPs needed for performing the task. The optimal step size of such process worksheets is determined (Step 6) through determining the task complexity.

Step 4: Micro-level Sequencing

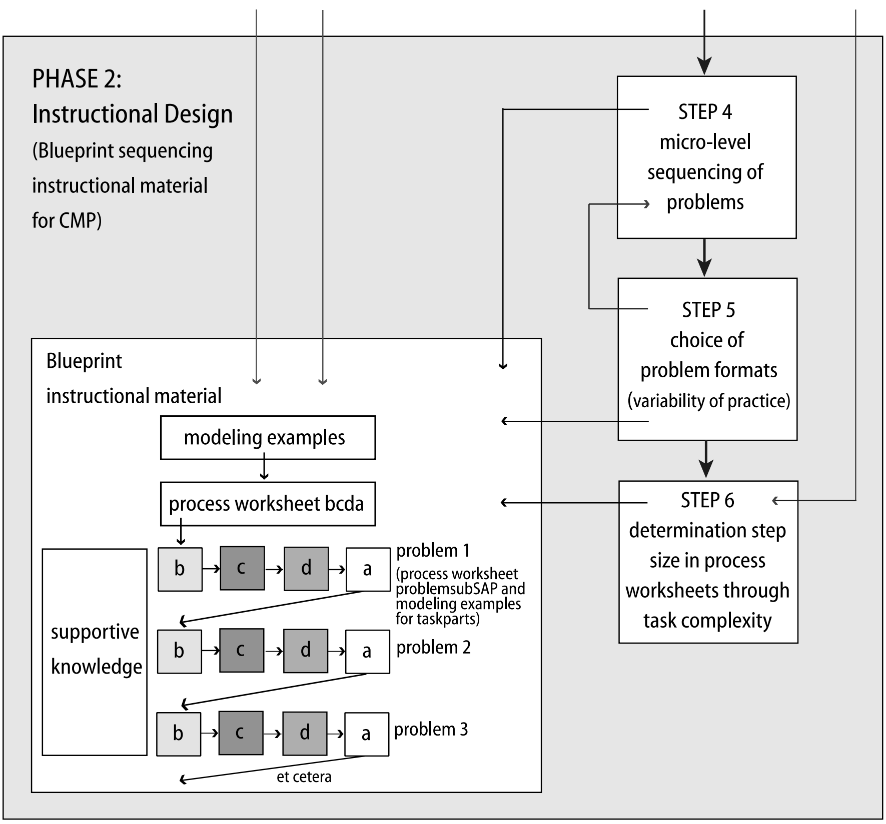
Micro-level sequencing establishes the order in which different problem formats will occur. Typical simple-to-complex ordering of problems is not the most effective approach to micro-level sequencing of the whole task because it tends to hamper schema acquisition (see Step 3). The interconnectedness of the various part-tasks is high, which results in increased cognitive load for the learner. High-variability sequencing, on the other hand, provokes inductive processing and improves transfer of training (Spiro, Coulson, Feltovich, & Anderson, 1988).

Nestors, teachers and trainers identify salient features of problems during the scenario analysis (Step 1). Varying tasks and practice with respect to problem situations or conditions (presentation mode, saliency of defining characteristics, task performance contexts) encourages learners to develop meaningful schemata by increasing both the chances that similar features are identified and the chances that relevant features can be distinguished from irrelevant ones. This consistently results in beneficial effects on transfer of training (Cormier & Hagman, 1987; Shapiro & Schmidt, 1982; Singley & Anderson, 1989). A negative aspect is that variability of practice also increases cognitive load. In our opinion, this disadvantage is outweighed by the fact that the alternative—simple-to-complex ordering—seldom has beneficial effects on transfer.

Step 5: Choosing Problem Formats

We use problem formats that avoid cognitive overload. Cognitive load theory (Sweller, 1988; Sweller & Chandler, 1994; Sweller, van Merriënboer, & Paas, 1998) can be used to guide the selection of problem formats. Cognitive load theory, with respect to schema learning, prescribes that instruction should be designed such that working memory is capable of processing the instruction. Appropriate problem formats for schema acquisition are (a) real-life conventional problems, (b) product-oriented problems such as worked out-examples and completion problems where learners have to complete a partially given solution, or (c) process-oriented

Figure 3 ☐ Instructional design phase (Phase 2) of the model.



problems such as modeling examples and problems with performance constraints. This theory can be summarized in two basic principles, namely, (a) prevent cognitive overload, and (b) redirect attention. Preventing cognitive overload entails posing problems that are not significantly beyond the learner's level of competence. Redirecting attention shifts learner attention from cognitive processes not directly relevant for learning (e.g., searching information, weak-method problem solving) to processes relevant for learning (in particular, schema construction by induction from concrete cases). We augment Sweller's approach through using different problem formats and fading support as the learner gains more expertise (and thus increasing authenticity). Of the problem formats suitable for achieving nonrecurrent skills, worked-out examples and problems with performance constraints combined with process worksheets typically meet the criterion of preventing cognitive overload (van Merriënboer, 1997, p. 187).

Learners using our CMPs receive a process worksheet based on a domain-specific problem solving strategy (SAP) to solve the problem tasks presented. This approach is beneficial in that it encourages the development of schemata (Bedard & Chi, 1992; Gagné et al., 1993; Sternberg & Frensch, 1991).

Cognitive load theory predicts an interaction between problem formats and sequencing (Paas & van Merriënboer, 1994). For problem formats with high cognitive load, changes in variability of the sequence have little or no effect on inductive processing and transfer due to the possibility of cognitive overload. For problem formats with relatively low cognitive load, increasing the variability of the problem sequence will substantially enhance inductive processing and transfer (Paas & van Merriënboer, 1994; van Merriënboer, Schuurman, de Croock, & Paas, in press). High variability sequencing may have positive effects on transfer, but it also has negative effects on the number of problems or training time needed to reach a certain performance level. Thus, in the same training time, fewer problems can be solved; otherwise, more training time is needed to reach a predefined performance level. This is called the *transfer paradox* (de Croock, 1999; Jelsma, 1989; van Merriënboer, de Croock, & Jelsma, 1997).

Table 2 contains the sequence and problem formats constituting the blueprint we identified for our example, *Preparing a Plea* (Wöretshofer et al., 2000). The design prescription used here entails first designing whole-task practice aimed at inductive processing through using a high variability sequence, followed by fading as learners gain more expertise, proceeding from

Table 2 ☐ Blueprint of instruction within competency-based multimedia practical (CMP), *Preparing a Plea*

1. Modeling example(s) (video-registration of persons conducting a plea)
2. Presentation of process worksheet containing Steps 1–8 to proceed from file to plea
3. File Bosmans (civil law) (Problem 1 consisting of *i* steps)
   - Step 1 Order documents in categories (practice-files for Step 1) (problem with process worksheet subSAP for Step 1)
   - Step 2 Get acquainted with file using guiding questions (practice-files for Step 2) (problem with process worksheet subSAP for Step 2, including worked example for Step 1)
   - Step *i* Activity for Step i (practice-files for Step *i*) (problem with process worksheet subSAP for Step *i*, including worked example for Step *i*-1)
4. File Ter Zijde (criminal law) (Problem 2 consisting of *i* steps)
   (No practice files and less in-step cueing as compared to File Bosmans; i.e., fading)
   - Step 1 Order documents in categories (problem with process worksheet subSAP for Step 1)
   - Step 2 Get acquainted with file using guiding questions (problem with process worksheet subSAP for Step 2)
   - Step *i* Activity for Step *i* (problem with process worksheet subSAP for Step *i*)

Note: SAP = systematic approach to problem solving concrete modeling examples to problems with process worksheets to enhance inductive processing and transfer. This is a specification of the box, "Blueprint instructional material," in Figure 3.

Step 6: Determination of Step Size in Process Worksheets

The final step—before actual development of the instructional material—is determining the step size in the process worksheet to be presented to learners, which will guide them through the application of (sub)SAPs and the associated heuristics. The complexity of the part-tasks and the prior knowledge of the learners primarily influence step size.

Determining step size is an optimization problem (Clark, 1999). The amount of work in ID and development activities (and thus also the cost) is inversely related to step size. The smaller the step size, the more steps and thus, the higher the cost. Instructional design theorists agree that *designers* should decompose tasks in the analysis phase to a greater level of detail than that which is presented to the *learner* (Jonassen & Hannum, 1995; Jonassen, Hannum, & Tessmer, 1989; Merrill, 1983). However, little is known about what step size should be used for learners with a particular level of prior knowledge, given a certain task decomposition and a specified task complexity. As soon as content and learning goals are determined, the optimal step size is mainly influenced by prior knowledge and skills (Chang, Ho, & Liao, 1997; Kalyuga, Chandler, & Sweller, 1998).

In the analysis phase we stressed the importance of determining objective task complexity for task decomposition and identification of a SAP by trainers. This task complexity also guides the process of determining step size for process worksheets in CMPs.

Tasks used in instruction should preferably have sufficient and comparable complexity to challenge learner capacity. Too detailed a decomposition results in tasks that are too simple. Too global a decomposition results in tasks that are too difficult. Suppose that trainers identify a SAP containing the tasks "bcda" during a cognitive task analysis, where each step can be further decomposed into smaller steps (part-tasks a, b, c, d, a_1, a_2, b_1, b_2 et cetera). Theoretically, then, "bcda" can be presented in a process worksheet as $(b_1b_2)(c_1c_2)(d_1d_2)(a_1a_2)$ or $b(c_1c_2)da$ or $(b_1b_2)c(d_1d_2)(a_1a_2)$ et cetera (see Figure 2). For each of those part-tasks, task complexity needs to be determined using an instrument for measuring task complexity. In the example in Figure 3 it has been decided to present "bcda" (not further decomposed) in a process worksheet since tasks "a," "b," "c" and "d" have sufficient and comparable complexity.

FIRST EXPERIENCES WITH THE MODEL IN DEVELOPING THE CMP, *PREPARING A PLEA*

In the development of *Preparing a Plea* (see Appendix, Wöretshofer et al., 2000) Steps 1, 3, 4, and 5 of the six-step model were applied. The instrument for objectively measuring task complexity (Steps 2 and 6) was not yet available during development but tested afterwards. This developmental study was intended to determine (a) if an objective task complexity measurement really was necessary, and (b) the instructional effectiveness of the material developed according to our model.

Method

Participants, materials and procedure

Twenty experts from three different backgrounds participated in the cognitive task analysis: 8 practicing lawyers (nestors), 6 trainers of starting lawyers who also practice as lawyers themselves (trainers), and 6 law teachers familiar with teaching students to conduct a plea (teachers). A structured interview technique was used in order to get an impression of the experts' ideas about how to prepare a plea (cf. Cooke, 1994).

The CMP, *Preparing a Plea* (Wöretshofer et al., 2000), was developed according to the instructional blueprint resulting from Steps 4 through 6. The six teachers were asked to determine task complexity *subjectively*, on a 4-point rating scale (i.e., without anchor tasks). Together with three instructional developers, those law teachers were also involved in the actual development of the CMP. After development, a second group of 20 teachers was asked to determine task complexity *objectively*, using a task-complexity measurement instrument. This instrument was developed according to the procedure of Burtch et al. (1982), and used a benchmark scale with four anchor tasks, each describing one complexity level.

The CMP was studied by a small group of sophomore law students (N = 12). Six of them had no plea experience at all; the other six had some limited plea experience as members of a debating club. The CMP was developed for use by students without plea experience. A jury consisting of three persons (two teachers and one trainer) scored student results on the pleas. Data were collected on subjective perception of task complexity (using a 9-point rating scale; Paas & van Merriënboer, 1994), student motivation, confidence to plea without a process worksheet, and appropriateness of step size.

Results and Discussion

The qualitative data gathered in the structured interviews demonstrated an interesting difference between trainers' and nestors' SAPs, namely that trainers gave more elaborate descriptions of how to prepare a plea and thus had probably not internalized and automated SAPs to the level that nestors had. We asked the development group of six law teachers to determine task complexity subjectively for the nine part-tasks to be included in *Preparing a Plea* (Wöretshofer et al., 2000) on a 4-point rating scale. The subjective task complexity of the nine part-tasks ranged from M = 1.2 (for the part-task "ordering the file," SD = 0.4) to M = 3.3 (for "setting up a plea strategy," SD = 0.8). A satisfactory interobserver agreement for the judged complexity of part-tasks was found, Kendall's W = .53, X^2 = 25.56, $p < .01$.

In the retrospective analysis of task complexity by the second group of 20 teachers, the judged objective task complexity of the nine part-tasks ranged from M = 1.3 (for the part-task "ordering the file," SD = 0.7) to M = 3.5 (for "setting up a plea strategy," SD = 0.8). Again, a satisfactory interobserver agreement for the judged complexity of part-tasks was found, Kendall's W = 0.32, X^2 = 50.59, $p < .01$. Whereas the subjective and objective judgments show agreement on what is the simplest task ("ordering the file") and what is the most complex task ("setting up a plea strategy"), there is a difference in the overall rating of task complexity. The mean subjective complexity over the nine part-tasks (M = 2.4, SD = 0.3) is significantly higher than the mean objective complexity (M = 2.1, SD = 0.4; $t(24)$ = 2.1, $p < .05$). In other words, if objective instead of subjective measures had been used during the CMP development process, this would have yielded larger step sizes.

Table 3 ☐ Learner Results with competency-based multimedia practical (CMP), *Preparing a Plea*

Results	*No Plea Experience (n = 6)* *M*	*SD*	*Limited Plea Experience (n = 6)* *M*	*SD*
Subjective Task Complexity[a] [1–9]	3.7	0.8	3.2	0.8
Motivation [1–4 (very high)]	3.5	0.5	3.25	0.7
Confidence [1–4 (very high)]	1.8	1.0	2.75	1.0
Too big step size [1–4 (complete agree)]	2.6	0.5	1.72*	0.8

[a] Using the instrument described by Paas & Van Merriënboer (1994)
* $p < .05$

All 12 sophomore law students who studied the CMP completed it successfully and were, according to the jury, able to conduct a plea in court. Table 3 presents the results on subjective task complexity, motivation, confidence, and step size for the subgroups with no and limited plea experience. Students reported a mean subjective task complexity of 3.45 on a 9-point scale, indicating a rather low subjective complexity; a mean motivation of 3.38 on a 4-point scale, indicating a high motivation, and a mean confidence in their ability to plea without a process worksheet of 2.28 on a 4-point scale, indicating medium confidence. For subjective task complexity, motivation and confidence, there were no significant differences between subgroups. However, with respect to the appropriateness of step size, students without plea experience agreed significantly more with the number of steps ($M = 2.6$, $SD = 0.5$) than did students with limited experience, who reported that the number of steps could be fewer ($M = 1.72$, $SD = 0.75$; $t(10) = 4.94$, $p < .05$).

Concluding, the subjective task complexity data of both teachers and students show that the part-tasks were not too difficult. The objective task complexity measured by teachers indicates that the step size could have been somewhat larger, especially for those students with some prior plea experience. Students reported a high motivation, confirming that the step size was not far too small and that part-tasks were experienced as functional and nontrivial. The findings show that the instructional materials developed according to our model are effective and they give tentative support for the use of an objective task-complexity measurement instrument in ID.

GENERAL DISCUSSION

Our two-phase, six-step model has proven to result in a detailed blueprint for effective CMP development. The cognitive task analysis phase results in detailed input for the design phase which is largely based on the 4C/ID-model (van Merriënboer, 1997) and insights from cognitive load theory. Objective measurement of task complexity determines optimal step size for the SAP through a process worksheet to learners.

The benefit of cognitive task analysis is clearly its rich and thorough description of task performance. This approach, however, is not without drawbacks. The largest problem is resource intensity for both data gathering and data analysis. A second problem is that it is susceptible to bias and error and should be used by experienced instructional designers because it is mainly heuristic in nature (Jonassen & Hannum, 1995). In fact, our model has been described in this article by giving a SAP and associated rules-of-thumb or heuristics for its use. Our research and development work is directed toward a further specification and articulation of the model, which is necessary to make it directly useful for less experienced designers or teachers. This is in line with formative research on the simplifying conditions method (Reigeluth, Lee, Peterson, & Chavez, 1999). At this moment, however, no other less costly and less error prone methods are available.

In defense of our model, we are convinced that it will save costs on ID and development and result in reusable, high-quality materials. The present costs for designing and developing computer assisted multimedia instruction greatly exceed the costs incurred by cognitive task analysis. Beyond this, the use of various types of experts (nestors, trainers and teachers) also prevents serious mistakes in the analysis and design phases especially if this is accompanied by an instrument for determining task complexity. In this, our model clearly differs from other task-analytical methods which almost always include the use of one particular category of experts and which do not consider measuring task complexity. An important critical success factor for developing instruction is that the instructional designer needs, to a certain extent, to be familiar with the subject domain (Dehoney, 1995).

Because our model has not yet been broadly applied, research should be conducted to further justify our assertions. The most important question to be addressed at this moment is that of optimizing step size within process worksheets by using a task-complexity measurement instrument. As far as we know, no studies examine the impact of step size on task performance and learning. We are presently conducting experiments on task complexity and step size within process worksheets to gain more insight into this matter. □

Rob J. Nadolski [rob.nadolski@ou.nl], Paul A. Kirschner, Jeroen J.G. van Merriënboer, and Hans G.K. Hummel are with the Open University of the Netherlands. Correspondence concerning this article should be addressed to Rob J. Nadolski, Educational Technology Expertise Center, Open University of the Netherlands, Valkenburgerweg 177, 6419 AT Heerlen, The Netherlands.

REFERENCES

Anderson, J.R. (1982). Acquisition of cognitive skill. *Psychological Review, 89,* 369–406.

Anderson, J.R. (1993). *Rules of the mind.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Bedard, J., & Chi, M.T.H. (1992). Expertise. Current directions. *Psychological Science, 1,* 135–139.

Bonner, S. (1994). A model of the effects of audit task complexity. *Accounting, Organizations and Society, 19*(3), 213–234.

Brown, J.S., Collins, A., & Duguid, S. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18,* 32–42.

Burtch, L.D., Lipscomb, M.S., & Wissman, D.J. (1982). *Aptitude Requirements Based on Task difficulty* (Report No. AFHRL-TR-81-34). Brooks AFB, TX: Air Force Human Resources Laboratory, Manpower and Personnel Division.

Byström, K., & Järvelin, K. (1995). Task complexity affects information seeking and use. *Information Processing & Management, 31,* 191–213.

Campbell, D.J. (1988). Task complexity: a review and analysis. *Academy of Management Review, 13,* 40–52.

Campbell, D.J., & Gingrich, K. (1986). The interactive effects of task complexity and participation on task performance: A field experiment. *Organizational Behaviour and Human Decision Processes, 38,* 162–180.

Chang, C.J., Ho, J.L.Y., & Liao, W.M. (1997). The effects of justification, task complexity and experience/training on problem-solving performance. *Behavioral Research in Accounting, 9,* 98–116.

Chi, M.T.H., Feltovich, P.J., & Glaser, R. (1981). Categorization and representation of physics knowledge by experts and novices. *Cognitive Science, 5,* 121–152.

Chi, M.T.H., Glaser, R., & Farr, M.J. (Eds.). (1988). *The nature of expertise.* Hillsdale, NJ: Lawrence Erlbaum.

Clark, R.E. (1999). Yin and Yang cognitive motivational processes in operating multimedia learning environments. In J.J.G. van Merriënboer (Ed.), *Cognition and multimedia design* (pp. 73–107). Heerlen, The Netherlands: Open University of the Netherlands.

Cooke, N.J. (1994). Varieties of knowledge elicitation techniques. *International Journal of Human-Computer Studies, 41(6),* 801–849.

Cormier, S.M., & Hagman, J.D. (Eds.). (1987). *Transfer of learning: Contemporary research and applications.* San Diego, CA: Academic Press.

Craik, F.I.M., & Lockhart, R.S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11,* 671–684.

de Croock, M.B.M. (1999). *The transfer paradox: Training design for troubleshooting skills.* Thesis. Enschede, The Netherlands: Twente University.

Dehoney, J. (1995). Cognitive task analysis: Implications for the theory and practice of instructional design. *Proceedings of the annual national convention of the association for Educational Communications and technology (AECT), Anaheim, CA,* 113–123. (ERIC Document Reproduction Service No. ED 383 294)

DuBois, D.A., Shalin, V.L., Levi, K.R., & Borman, W.C. (1995). *A cognitively-oriented approach to task analysis and test development.* Minneapolis, MN: Personal Decisions Research Institute, Inc. .

Eraut, M. (1997). *Developing professional knowledge and competence .* London: The Falmer Press.

Gagné, E., Yekovich, C., & Yekovich, F. (1993). *The cognitive psychology of school learning.* New York: Harper Collins.

Gardner, M.K., (1985), Cognitive psychological approaches to instructional task analysis. In E.W. Gordon (Ed.), *Review of Research in Education,12.* Washington, D.C.: American Educational Research Association.

Jelsma, O. (1989). *Instructional control of tranfer.* Enschede, The Netherlands: Bijlstra & van Merriënboer.

Jonassen, D.H., & Hannum, W.H. (1995). Analysis of task analysis procedures. In: G.J. Anglin (Ed.), *Instructional technology, past, present, and future* (pp.197–214). Englewood, Colorado: Libraries Unlimited Inc.

Jonassen, D.H., Hannum, W.H., & Tessmer, M. (1989). *Handbook of task analysis procedures.* New York: Preager.

Kalyuga, S., Chandler, P., & Sweller, J. (1998). Levels of expertise and instructional design. *Human factors, 40*(1), 1–17.

Kirschner, P.A. (1991). *Practicals in Higher Education.* Thesis. Heerlen, The Netherlands: Open University of the Netherlands.

Kirschner, P.A., Vilsteren, P.P.M. van, Hummel, H.G.K., & Wigman, M.C.S. (1997). The design of a study environment for acquiring academic and professional competence. *Studies in Higher Education, 22*(2), 151–171.

Kolb, D.A. (1984). *Experiential learning.* NJ: Prentice Hall.

Merrill, M.D. (1983). Component display theory. In C.M. Reigeluth (Ed.), *Instructional design theories and models: An overview of their current status* (pp. 278–333). Hillsdale, NJ: Lawrence Erlbaum.

Merrill, P. (1987). Job and task analysis. In R.M. Gagné

(Ed.), *Instructional technology: Foundations* (pp. 141–173). Hillsdale, NJ: Lawrence Erlbaum.

Newell, A., & Simon, H.A. (1972). *Human problem solving.* Englewood Cliffs, NJ: Prentice-Hall.

Paas, F.G.W.C., & van Merriënboer, J.J.G. (1994). Variability of worked examples and transfer of geometrical problem solving skills: A cognitive load approach. *Journal of Educational Psychology, 86,* 122–133.

Parreren, C.F. van, (1987). *Ontwikkelend onderwijs* [Developing education]. Amersfoort. The Netherlands: ACCO.

Reigeluth, C.M. (Ed.). (1983). *Instructional theories and models. An overview of their current status.* Hillsdale, NJ: Lawrence Erlbaum.

Reigeluth, C.M. (Ed.) (1987). *Instructional theories in action. Lessons illustrating selected theories and models.* Hillsdale, NJ: Lawrence Erlbaum.

Reigeluth, C.M., Lee, J.Y., Peterson, B., & Chavez (1999). *Formative Research on the Heuristic Task Analysis Process* [On line]. Available: http://www.indiana.edu/idtheory/hta.html

Reigeluth, C.M., & Merrill, M.D. (1984). *Extended task analysis procedures (ETAP): User's manual.* Lanham, MD: University Press of America.

Roth, E.M., & Woods, D.D. (1989). Cognitive task analysis: An approach to knowledge acquisition for intelligent system design. In G. Guida & C. Tasso, (Eds.), *Topics in expert system design* (pp. 233–264). New York: Elsevier Publishers.

Shapiro, D.C., & Schmidt, R.A. (1982). The schema theory: Recent evidence and developmental implications. In J.A.S. Kelso & J.E. Clark, (Eds.), *The development of movement control and coordination* (pp. 113–150). New York: John Wiley & Sons.

Singley, M.K., & Anderson, J.R. (Eds.). (1989). *The transfer of cognitive skill.* Cambridge, MA: Harvard University Press.

Spiro, R.J., Coulson, R.L., Feltovich, P.J., & Anderson, D.K. (1988). *Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains* (Tech. Rep. No. 441). Champaign, IL: University of Illinois, Center for study of reading.

Sternberg, R.J., & Frensch, P.A. (Eds.). (1991). *Complex problem solving: principles and mechanisms.* Hillsdale, NJ: Lawrence Erlbaum.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12,* 257–285.

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. *Cognition and Instruction, 12,* 185–233

Sweller, J., van Merriënboer, J.J.G., & Paas, F.G.W.C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10,* 251–296.

Tennyson, R.D., Elmore, R.L., & Snyder, C. (1991, april). Advancements in Instructional Design theory: Contextual module analysis and integrated instructional strategies. In M. Rausch (Chair), *Instructional design theory contributions to the cognitive science.* Symposium conducted at the annual meeting of the American Educational Research Association, Chicago, IL. (ERIC Document Reproduction Service No. ED 336 080)

van Merriënboer, J.J.G. (1997). *Training complex cognitive skills.* Educational Technology Publications: Englewood Cliffs, New Jersey.

van Merriënboer, J.J.G., de Croock, M.B.M., & Jelsma, O. (1997). The transfer paradox: Effects of contextual interference on retention and transfer performance of a complex cognitive skill. *Perceptual and Motor Skills, 84,* 784–786.

van Merriënboer, J.J.G., Schuurman, J.G. , de Croock, M.B.M., & Paas, F.G.W.C. (in press). Redirecting learners attention during training: Effects on cognitive load, transfer test performance and training efficiency. *Learning and Instruction.*

Westera, W., & Sloep, P.B. (1998). The Virtual Company: Toward a self-directed, competence-based learning environment in distance education. *Educational Technology, 38,* 32–37.

Wilson, B., & Cole, P. (1990). A review of cognitive teaching models. *Educational Technology Research and Development, 39,* 47–64.

Wood, R.E. (1986). Task complexity: Definition of the construct. *Organizational behaviour and human decision processes, 37,* 60–82.

Wöretshofer, J., Nadolski, R.J., Starren-Weijenberg, A.M.A.G., Quanjel-Schreurs, R.A.M., Aretz, C.C.W.M., Meer, N.H.W. van der, Martyn, G., Brink, H.J. van den, Slootmaker, A., & Berkhout, J. (2000). *Pleit voorbereid* [Preparing a plea] (version 1.0) [multimedia CD-ROM]. Heerlen, The Netherlands: CIHO.

Appendix ☐ Activities and outcomes when applying the six-step instructional design model

Step-description	*Activities (by instructional designer)*	*Outcomes*
Step 1—CTA-phase *Skill decomposition*	Start an introductory reading or research in the task field. Determine expected task behavior and expected prior knowledge and skills for the inexperienced task-performer during (written & oral) communication with teacher experts.	Formulation of the global competency to be achieved after finishing instruction. Formulation of prior knowledge and skills for the task-doer.
Step 1a—CTA-phase Skill decomposition: Segmentation analysis	Identify part-tasks for the task at hand by: —observations of expected task behavior by juveniles and experts (reality, taped); if possible, discuss those observations afterwards —(if available) further readings about task (to become more familiar with the field) —structured interviews asking experts (with different backgrounds) how they (mentally) perform the task, how they did learn to perform the task (how long did it take them to learn it), what does their preparation consist of, to describe some case studies they encountered, what in their opinion are easy/complex part-tasks, if there are part-tasks that are not always encountered (and why so), does a simplest version of the task exist and how representative is it, et cetera. (in these interviews it is advised to start with a juvenile expert which does not have internalized too much so the instructional designer can become more familiar with the task and can further develop his interview-technique) —structured interviews to (further) identify a possible order in which part-tasks are conducted and check this order with different experts —report on temporary identified part-tasks to teacher-experts and check these and ask teachers to identify trivial segments —ask teachers to estimate task complexity of part-tasks for an inexperienced task-performer (with pre-specified prior knowledge) preferably by using an objective measurement instrument (following the procedure from Burtch et al.).	Identified functional part-tasks.
Step 1b—CTA-phase Skill decomposition: Knowledge analysis	Identify for all part-tasks the supportive knowledge; declarative knowledge that supports the performance of the nonrecurrent aspects of the task. Again structured interviews are used to identify conceptual models, goal-plan models, causal models, and functional models. This is conducted parallel with other analysis. Only supportive knowledge identified for functional part-tasks will be included. However during this analysis, functional parts are not yet known. The analysis results should again be checked by reporting them to experts.	Identified supportive knowledge for functional part-tasks.

Continued

Appendix ☐ (continued)

Step-description	*Activities (by instructional designer)*	*Outcomes*
Step 1c—CTA-phase Skill decomposition: Scenario analysis	Identify more or less problem-dependent features in analyzing the various case studies gathered in the interviews. Report these features and cases to experts and ask teachers to order those cases on dimensions "complexity" and "representativeness."	Identification of possible problem situations for the instructional design phase.
Step 2—CTA-phase *Determination of task complexity*	Teachers use an instrument to measure the complexity for the part-tasks. Trivial tasks are excluded. Too simple tasks are also excluded for the further analysis.	Identification of the complexity for the functional part-tasks.
Step 3—CTA-phase *SAP-analysis*	Identify from the interviews a juvenile expert's (i.e., trainer) systematic approach to solve the task at hand and identify the heuristics in this approach. These can be several approaches and subset of them can be used in conjunction with functional part-tasks. Report those SAPs and heuristics to experts and ask them about the "representativeness" of the SAPs. Finally ask teachers about the dimension "complexity" of identified SAPs.	Identified SAP and heuristics in which functional part-tasks play a role.
Step 4—ID-phase *Micro-level sequencing*	Problem situations can be derived from case studies gathered in earlier steps. Look for variability along dimensions such as "the context in which the task has to be performed," "the way of presenting the task," "the saliency of the task," "the amount of support given when performing the task."	Identification of cases that adhere to variability of practice, working from examples to more general and abstract parts of knowledge and strategies.
Step 5—ID-phase *Choosing problem formats*	The cognitive load theory and various other studies suggest to use "worked out examples" and problems with performance constraints combined with process worksheets (i.e., "problems with process worksheets" for instruction of ill-structured tasks such as in CMPs).	Problem formats for the problem situations in Step 4.
Step 6—ID-phase *Determination of step size in process worksheets*	Take prior knowledge and skills of learners into account, the complexity of the part-tasks included in the SAP to be chosen should be comparable and neither too difficult nor too easy. This complexity is determined in earlier steps. Summarize the outcomes from Steps 4, 5 and 6 in a blueprint and ask experts to verify this overall outcome and agreement before actual development of the instructional material takes place.	Step size for SAP to be presented in a process worksheet. Blueprint for CMP development combining outcomes from Steps 4, 5 and 6.

Note: ID = instructional design
SAP = systematic approaches to problem solving
CMP = competency-based multimedia practicals
CTA = cognitive task analysis