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ABSTRACT

ADAPT[IT] (Advanced Design Approach for Personalized Training - Interactive Tools) is a European project within the Information Society Technologies program that is providing design methods and tools to guide a training designer according to the latest cognitive science and standardization principles. ADAPT[IT] addresses users in two significantly different domains within the aviation industry: aircraft maintenance training and air traffic control training. Because these two subject domains are quite different and because those who perform associated tasks also differ in significant ways, it is hypothesized that outcomes will generalize to other complex domains and users. The methods integrated into ADAPT[IT] are based on van Merrienboer's (1997) four-component instructional design model. The model provides guidelines for the design of training programs in highly complex domains and consists of four layers: (1) principled skill decomposition; (2) analysis of constituent skills and related knowledge; (3) selection of instructional methods; and (4) development of a learning environment. These layers prescribe and contextualize the activities that instructional designers should perform in order to produce effective training for complex cognitive skills. This paper reports the needs assessment procedures and outcomes associated with the effort and indicates how they are informing the evaluation plan. (Contains 10 references.) (Author/AEF)

Assessing Adaptive Instructional Design Tools and Methods in ADAPT[IT]

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Abstract

ADAPT[IT] is a European project within the Information Society Technologies programme that is providing design methods and tools to guide a training designer according to the latest cognitive science and standardisation principles. Adapt[IT] addresses users in two significantly different domains within the aviation industry: aircraft maintenance training and air traffic control training. Because these two subject domains are quite different and those who perform associated tasks also differ in significant ways, it is our hypothesis that outcomes will generalise to other complex domains and users. The methods integrated into ADAPT[IT] are based on van Merriënboer's (1997) four component instructional design model. This paper reports the needs assessment procedures and outcomes associated with the effort and indicates how they are informing the evaluation plan.

Introduction

ADAPT[IT] is a European project coordinated by the Dutch National Aerospace Laboratory (NLR). The effort falls with the European Commission's Information Society Technologies programme (IST; see http://www.cordis.lu/ist/ for additional details) and includes as partners: NLR, the Open University of the Netherlands, the University of Bergen, Seven Mountains AS, EuroControl, the Swedish Air Traffic Control Academy, and Piaggo Aerospace. The project began in January 2000 with an extensive needs assessment of training designers within the aviation industry and in other business and industry sectors that involved training of complex skills. The early literature review and training requirements analysis indicated that the most appropriate and relevant methodology was the four component instructional design model (van Merriënboer & Dijkstra, 1997). Before discussing the ADAPT[IT] needs assessment and its implications for implementation and evaluation, we would first like to orient the reader with a brief overview of the European Commission's research programmes and IST.

The European Commission's Fifth Framework research and development programme extends from 1998 through 2002. IST is a single, integrated research programme within that framework that builds on the convergence of information processing, communications and media technologies. IST has a budget of approximately 3.6 billion Euro, and is managed by the Information Society Directorate General of the European Commission (one of 20 commissioners in the EC). The strategic objective of the IST is to realise the benefits of the information society for Europe both by accelerating its emergence and by ensuring that the needs of individuals and enterprises are met. It is managed by the European Commission, with the assistance of the IST Committee consisting of representatives of each Member and Associated State. The Commission and the IST Committee are supported in their work by an IST Advisory Group of some 25 members who are highly experienced in this field. They provide independent expert advice concerning the content of the IST work programme, which includes research and development.

The IST Programme has four inter-related specific objectives concerning individuals, enterprises, multimedia technologies and enabling technologies. For the private individual, the objective is to meet the need and expectation of high-quality affordable general interest services. For Europe's enterprises, workers and consumers, the objective is to enable individuals and organisations to innovate and be more effective and efficient in their work, thereby providing the basis for sustainable growth and high added-value employment while also improving the quality of working life. In the sector of multimedia content, the key objective is to confirm Europe as a leading force, realising its full potential. For the enabling technologies, which are the foundations of the information society, the programme objective is to drive their development, enhance their applicability and accelerate their take-up in Europe.

ADAPT[IT] addresses all four objectives but is tightly focussed on instructional design methods and tools as a critical enabling technology. The next section contains a brief overview of the effort, the approach taken and the associated work plan.

Advanced Design Approach for Personalised Training-Interactive Tools (ADAPT^IT)

The overall goal of this effort is to create and validate effective training design methodologies, based on cognitive science and the integration of advanced technologies, so that Europe can better meet the many challenges of the information society of the 21st century. The aviation industry is targeted for this research and development effort as it is a key industry in which Europe has been an active leader. Two quite different training areas (air traffic control and aircraft maintenance) are involves so as to insure generalisability of the methodology and tools to other subject areas and industries.

This project bridges the gap between complex training problems and new technological possibilities by developing and validating a training design framework to guide the use of state-of-the-art cognitive approaches within advanced training systems. A central requirement for the design methodology is that it provide for development of a personalised training and education trajectory. This includes a specification of training models that account for and adapt to trainees' performances, attention strategies, and workload. Another important requirement for efficient training of flexible skills for complex tasks is to maintain a close and natural relationship between knowledge learning and skill acquisition activities for both individuals and teams (van Merriënboer, 1997; van Merriënboer & Dijkstra, 1997).

This project is developing a personalised training design methodology, providing associated design tools for efficient realisation of that methodology, and validating the methodology in different training domains and with different trainee-levels. The validation will be performed in the context of aircraft maintenance and air traffic control. Current challenges for aviation training relate to the increasing complexity of dynamic task environments, increasing time constraints, and increasing demands for cognitive and information-managing tasks. As technology takes over or automates many basic tasks and adds functionalities to operational systems, the result is that more demand is placed on humans to perform higher level and supervisory tasks. The problems within aviation training are exemplary of highly complex and automated task environments that require flexible skills and are likely to forecast training problems in other professional domains.

The project proposal is for 36 months beginning January 2000, with an estimated total of 175 person-months required for completion. The effort is broken into these 9 work packages:

1. Project management
2. Literature search
3. Design needs analysis
4. Specifications for method and tools
5. Development of method and tools
6. Validation of the design process
7. Validation of the learning process
8. Standardisation
9. Integration, final report and recommendations

Validation partners from the aviation industry (Piaggio, EuroControl, and the Swedish Air Traffic Control Academy) will directly benefit from the training design methodology and associated tools. These partners provide a real-world setting and associated support for testing the design, development, and validation of the design methodology and training developed according to that methodology. The design process is user-centered and involves the validation partners throughout the process. The process is iterative so that initial designs, methods, and tools can be refined in close association with the requirements and needs of the targeted industry users and beneficiaries. At the end of the effort, the validation partners will have in place validated training modules as well as a cadre of training design specialists knowledgeable and skilled in the use of the newly developed design methodology and tools.

Training Design for Complex Cognitive Skills

One of the major aims of ADAPT^IT is to create a harmonised training-design tool for dealing with tasks requiring complex cognitive skills, which can be defined as "skills for which the learner must invest considerable time and effort to acquire an acceptable mastery level and for which qualitative differences in performance exist between novices and experts" (van Merriënboer & Dijkstra, 1997, p.427). Training of complex cognitive skills are becoming increasingly important in today's society where routine tasks (recurrent skills) are mostly automated by machines. As a consequence, complex cognitive tasks, which cannot be taken over by machines, form the basis of training needs in industry. Examples of such complex cognitive skills are air traffic control skills, fault-management skills, and computer-programming skills. One of the main characteristics of such skills is that their acquisition is a lengthy and effortful process. In other words, they are hard to learn. There are many constituent skills involved and at least some of those constituent skills involve problem solving and qualitative reasoning, requiring a deep understanding of systems and processes. In addition, the ability to integrate and coordinate the constituent skills involved is critical to reaching acceptable performance. Traditional instructional design models (e.g., Dick and Carey, 1996; Gagné, Briggs, & Wager, 1992) are particularly weak when it comes to the design of training programs for the multidimensional, complex learning required in highly demanding technical domains (Schneider, 1985). Other alternative models, while useful at a high level, are typically too generic and fail to provide specific guidelines (e.g., Gustafson & Branch, 1997; Tennyson, 1995) or there haven't been validated in the aviation industry (e.g., Kieras & Polson, 1985). Therefore, the ADAPT[IT] methodology is based on van Merriënboer's Four-Component Instructional Design (4C/ID) model. The 4C/ID model involves a training design method that has been empirically validated in the aviation industry (van Blanken & van der Pal, 1999). This method is scenario-based and makes the acquisition of complex cognitive technical skills the primary target and foundation of the training analysis and design method.

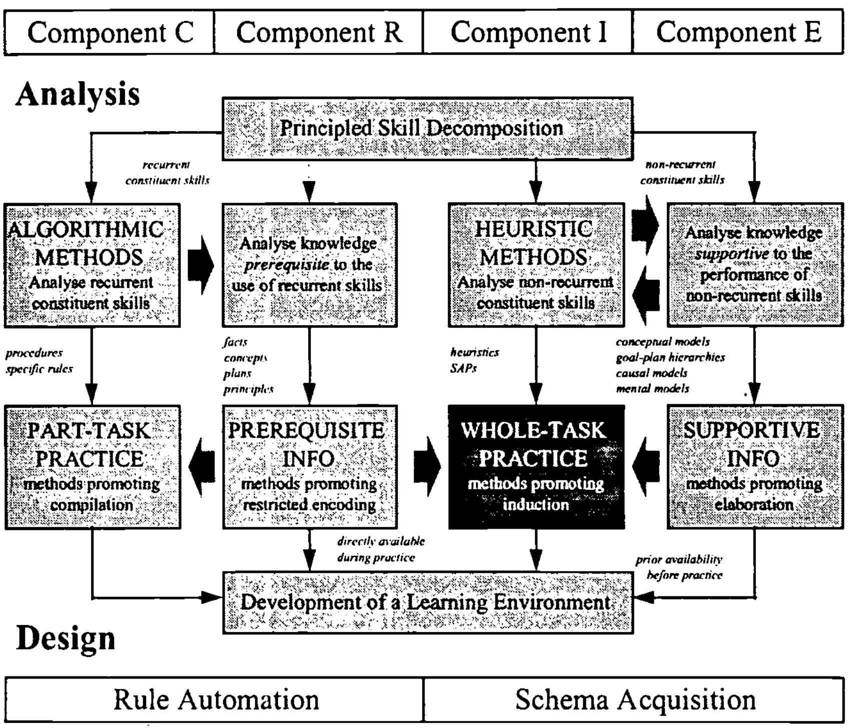

Figure 1. Overview of the 4C/ID-model, adapted from van Merriënboer (1997).

The model's systematic approach to the development of training is represented in Figure 1. The model provides guidelines for the design of training programs in highly complex domains and consists of four layers: (1) principled skill decomposition; (2) analysis of constituent skills and related knowledge; (3) selection of instructional methods; and, (4) development of a learning environment. These layers prescribe and contextualise the activities that instructional designers should perform in order to produce effective training for complex cognitive skills. Layers 1 and 2 involve the analysis of a complex cognitive skill; layers 3 and 4 involve the design of a training strategy and learning environment for that skill. It should be noted that although the layers are represented in a linear order, real world applications are much less well-ordered and often involve iterations. Tennyson (1995) also emphasizes this, as well as the associated contextualised activities of designers.

Ideally, the application of the model starts with principled skill decomposition, where the complex cognitive skill is decomposed into a hierarchy of its constituent skills and categorized according to their desired exit behaviours and related types of learning. This phase assumes that a proper needs analysis has been conducted and the general goal or terminal objective of the training has been identified. Briefly speaking, in the principled skill decomposition phase, this general goal is further decomposed into a skills hierarchy that reflects the more specific constituent skills that enable the performance of the whole skill. The general idea of such a skill hierarchy is that "learning the constituent skills lower in the hierarchy might facilitate the learning or performance of the skills higher in the hierarchy" (van Merriënboer, 1997, p.86). The creation of hierarchies has been a long-standing practice in many instructional models (Dick & Carey, 1996; Gagné et al., 1992), but this particular hierarchy is focussed entirely on complex cognitive skills.

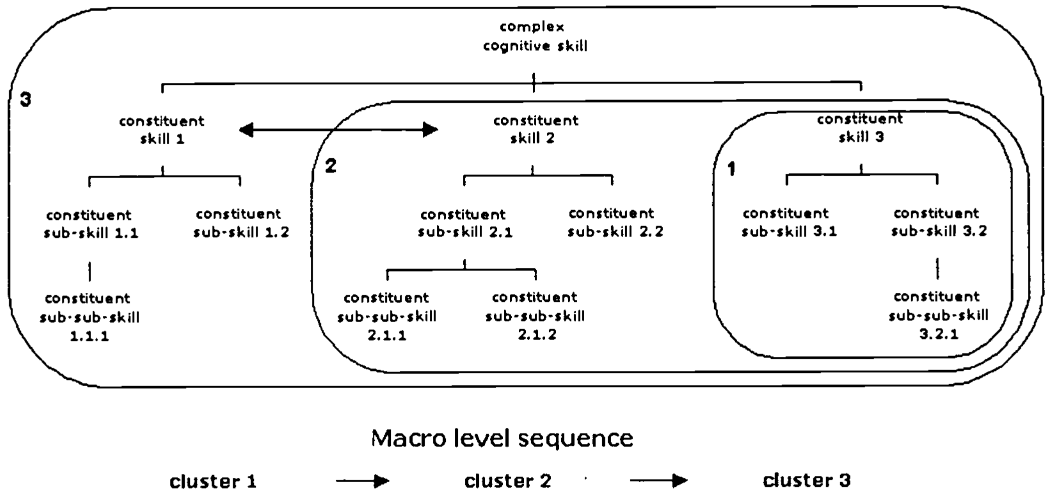

Figure 2. Generic example of a skills hierarchy and its division into skill clusters

For many tasks, all of the constituent skills of the complex cognitive skill cannot be trained simultaneously, so the skills hierarchy is divided into clusters. This clustering is called macro-level sequencing. The clusters may be seen as "parts" of the complex cognitive skill and each cluster contains a fairly large, meaningful set of interrelated constituent skills. Each cluster may require from 20 to 200 hours of training. Also, every cluster of subskills should represent an authentic task that an expert would perform in practice. Figure 2 shows an example of a skills hierarchy and how it used to form skill clusters. At the top of the hierarchy is the complete complex cognitive skill. The downward links represent the skills that are prerequisite for mastery of the skill above. For example, to be able to perform skill 2, one should be able to perform subskills 2.1 and 2.2. From left to right, a temporal order is depicted. For example, for the complete performance of skill 2, one first performs skill 2.1 and then skill 2.2. Skills on the same level that are connected with a double arrow are performed concurrently. In the example, a backward chaining approach is applied to order the skills clusters. This means that the cluster of skills that is trained first is the cluster that is usually performed last when an expert performs the complete complex skill.

Once the constituent skills are described along with performance objectives, categorized (recurrent, non-recurrent), and sequenced, the next layer in the model deals with the analysis of those identified constituent skills, relationships between them, and knowledge structures underlying the performance of the complex cognitive skill and its constituent skills. This analysis primarily refers to the procedures or rules that underlie expert knowledge. Briefly, in this phase four different analysis takes place: (1) analysis of recurrent constituent skills as strong methods; (2) analysis of non-recurrent constituent skills as weak methods; (3) analysis of prerequisite knowledge to perform recurrent skills; and, (4) analysis of supportive knowledge to perform non-recurrent constituent skills. Different task analytical techniques are prescribed by the model for each of these analyses (van Merriënboer, 1997). It is important to note that this layer translates into meso-level sequencing which specifies the order in which case types (i.e., categories of problems or worked-out examples) should be included in the training sequence for the skill clusters defined during macro–level sequencing. In other words, this sequencing provides a first global blueprint for the contents of a training program, providing a sound basis for the subsequent design of a learning environment. The outcomes of the analysis conducted in this second layer are heuristic methods - systematic approaches to problem solving (SAP charts). These charts that indicate: the sequence of non-recurrent skills; the supportive knowledge involved; rules and procedures for performing recurrent skills; prerequisite knowledge required to be able to perform procedures and apply rules; and sets of case types in a progression of simple to complex versions of the whole skill within the cluster.

After analysing the complex cognitive skill and each of its constituent skills, the training strategy should be composed. This coincides with the third layer in the model, where instructional methods for the design of whole-task and part-task practice as well as for different types of information presentation before and during practice are specified. Again four different activities take place depending on the category of the constituent skills at hand: whole-task practice, supportive information, prerequisite information, and part-task practice. The design of whole-task practice, in this layer, mainly refers to specifications of examples (problems and their solutions) and problems (incomplete examples) that the learners will be confronted with during training. This process should aim at promoting "a rapid development of highly situation-specific, automated rules by knowledge compilation. Instructional methods that are suitable for to reach this goal are often associated with repeated imitation and drill; learners are invited to mechanically and consistently repeat performance" (van Merriënboer & Dijkstra, 1997, p. 437). The key learning process to be promoted is induction - mindful abstractions of cognitive schemata that are useful to solving problems in the domain of interest. This is based on the premise that giving learners examples helps them construct mental frameworks that they can use when encountering similar problems in the future. The design of whole-task practice results in the first blueprint of the training program, describing what the learners will be required to do during the training. Figure 3 depicts the basic blueprint of a training program resulting from macro-level, meso-level, and micro-level sequencing. From the viewpoint of the designer, it is basically a hierarchy with the complex skill at the top followed by three sequencing levels: (1) skill clusters; (2) case types; and, (3) specific whole-task problems. This basic skeleton serves as the backbone for other design activities where additional practice for recurrent constituent skills and information is presented in order to support the acquisition of either non-recurrent or recurrent constituent skills. In other words, the training program blueprint is a hierarchy of:

- *skill clusters* ("whole tasks" - macro-level sequence);
- *case types* (the simple-to-complex cases of the whole task - meso-level sequence); and,
- *specific problems* (the problems or worked-out examples in each type of case and in each skill cluster - micro-level sequence).

This basic blueprint as presented in Figure 3, is then further elaborated to reach a complete description of the training program with the other activities in the third layer, which provide:

- additional part-task practice that may be necessary to reach the required exit behavior for particular recurrent constituent skills (part-task practice);
- information that is prerequisite to the performance of recurrent constituent skills, as performed either in a whole-task or part-task context (prerequisite info/JIT presentation); and,
- information that may be helpful to the performance of non-recurrent constituent skills, which are only performed in a whole-task context (supportive info for elaboration and understanding).

The model further provides detailed guidelines for instructional strategies and tactics for the presentation of information for each of the four components: whole-task practice, part-task practice, just-in-time information, and supportive and strategic information that need to be elaborated by the learners (van Merriënboer, 1997). Once, appropriate strategies and tactics are selected in the third layer, the designer moves to the fourth layer to compose a training strategy containing the selected instructional methods; this process results in a detailed blueprint for the learning environment. This layer prepares the designer for the transition from the design phase to the development phase. Since 4C/ID is an instructional design model, not an instructional development model, it does not provide detailed guidelines for the development of instructional materials. The model should be integrated with and embedded in an instructional development model during its implementation.

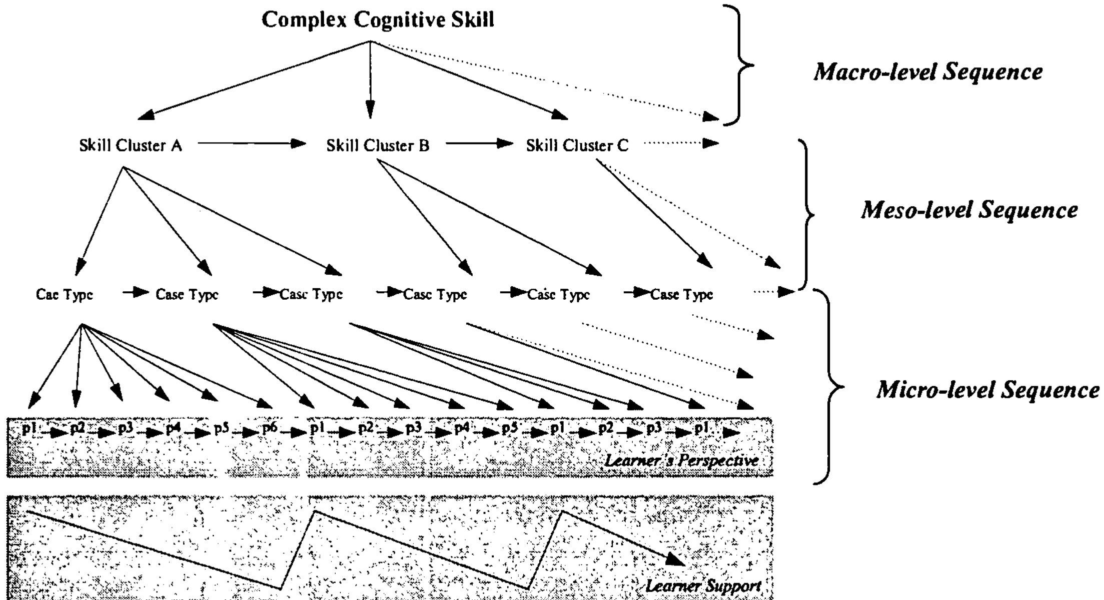

Figure 3. A generic blueprint for the training program showing the skills hierarchy, adapted from van Merriënboer (1997).

Overall, the ADAPT system aims at this integration. The result be a more time-effective instructional design process that increases the possibilities for re-usability of intermediate design products. Within the system, the ADAPT method that will guide the design phase will be based on the 4C/ID model just described but also integrate models of workload for aviation training development. In order to reach sufficient levels of standardisation and generality, designers will be supported in the proper and efficient use of the methodology by means of an interactive computer-based tool - automated instructional design support - ADAPT[IT]. One of the innovative aspects of ADAPT[IT] is that it will assist designers and design teams in decomposing and analysing a complex skill to-be-taught in such a way that alternative learning tasks can be developed that vary on the degree of cognitive load imposed on the learner. The ADAPT method will address the whole range of training design while including the aspects of 'intelligent tutoring' that relate to cognitive load theory.

Training Designer's Needs

Although the ADAPT methodology will be mainly based on the 4C/ID model it will be different from the 4C/ID method in two ways. First, it will be tailored to the needs of actual designers or design teams in a variety of training domains, economical sectors, and company sizes. Second, it will be extended to become a personalised training approach. In order to achieve the former, current practice in designing training for complex cognitive skills had to be identified. The project team realised this through three different data sources. First, the literature on training designer's needs was reviewed. Training designer's needs are defined as the requirements that have to be met in order to change and improve current design practice. These requirements refer primarily to instructional design practitioner's perceived needs for support to use and apply instructional design theories and models. In addition to the literature review, designer's needs were identified by means of questionnaires and interviews. The design of the questionnaire was a collective effort based on focus groups with project and subject experts. It consisted of the following sections:

1. Background information (information on the company and the responding designer);
2. Outcomes of training (the tasks, skills, knowledge and attitudes for which training is designed);
3. Training design method (the products of the training design process, both intermediate and final);
4. Instructional design tools (the tools that are used to design training); and,
5. Desired tool characteristics (the ideal characteristics and functionality that respondents would like to have).

A total of 150 questionnaires were sent out by targeted e-mail, and 18 were returned. The respondents came from different sectors: education, transport, business, and manufacturing. In addition to the questionnaires, extensive interviews with training designers were also conducted in order to gather more detailed information on current training design practices, the problems that are encountered and the desired support and specific needs during the training design process. The interview consisted of the following sections:

1. General information (information on the company and the interviewee);
2. Training design process (the training design process in general and the products of the training design process - both intermediate and final products);
3. Training design characteristics (the content of the training, the instructional principles used, etc.);
4. Co-operative design and design teams (the structure of a design team, the disciplines involved in a typical design team, the way in which a typical design team works, etc.); and,
5. Instructional design tools (the tools that are used and ideal characteristics of an instructional design tool).

Each interview took at least three hours. The target group was training designers who are actively involved in the design of training for complex domains. The interviews were conducted by two people, one to provide direct eye contact and ask questions and one to record answers and prompt for specific questions if needed. A structured interview instrument guided the interview process to insure that all respondents were asked similar questions. In total 11 interviews were conducted in the following sectors: 1 naval college, 3 air traffic control centres, 2 aircraft maintenance organisations, 1 telecommunications organisation, 1 information technology company, 1 training consultancy organisation and 1 distance education company. Unlike the questionnaires that produced data in one format, the more in-depth interviews were intended to provide detailed and rich information about company design practices. As interviewee background and companies differ substantially, the interviews were loosely structured in the sense that questions were open and no pre-defined answer categories were supplied. This was intended to stimulate the interviewer towards more natural, personal and company-specific responses, and this aspect was a complete success. Nevertheless, some structure was provided for the interviewer by a list of questions and themes to be addressed. Interviewer instructions were also provided since there were multiple interviewing pairs. This was intended to increase the compatibility between the interviews and over the variety of questions asked. The interviews not only yielded more detailed information, but, more importantly, they yielded an impression or feeling of current design practice, which did not emerge from the questionnaires.

The emphases during these data gathering efforts was on the difference between current and ideal training design practice, on the problems experienced during the design process, and on the ideal characteristics of an instructional design tool. In analysing the results, our interest was on the common themes that arose. In general, it can be concluded that current training design practice differs from that what is described in most instructional design models (e.g., Gustafson & Branch, 1997). Activities are carried out selectively and often partly and are characterised by implicit and intuitive methods as suggested by Tennyson (1995). The analysis phase is not carried out explicitly and in detail, mostly due to constraints involving time and resources. The design phase appears often to be combined with the development phase and often happens implicitly as part of the development and implementation of training.

Looking at the background of training designers, most designers have an operational background and are not specifically trained or educated in instructional design or training systems. Specific instructional design models or principles are rarely explicitly used by designers with an operational background. However, many basic ideas and some instructional design principles seem to be intuitively understood and used. These principles are not explicitly or systematically applied to a training plan or design blueprint.

In general, training is not designed in formally structured design teams. The most important actors in a team are subject matter experts and instructors, who typically design the training. Collaborative design does not seem to take place explicitly.

In answering the survey questionnaires and extended interviews, respondents indicated that the most significant and desired characteristics of an ideal instructional design tool are related to:

- targeting actual designers with an operational background;
- using non-academic language;
- providing practical worked-out examples;
- supporting an explicit, structured and systematic design process (especially for the analysis, design and evaluation phases);
- providing guidance in bridging the gap between current and ideal design practice;
- addressing the relational aspect during the training design process (setting up teams, involving users, teamwork, communication, etc.);

- providing support/guidance in applying educational design principles;
- providing methods for file management and version control;
- linking together the diffcrent training design products;
- making information easily re-usable and retrievable; and,
- allowing different degrees of freedom (e.g., from structured to non-sequential design).

The interest in structure, reusability, and relevant examples is consistent with the literature search conducted for this project and with the experience of project experts. Some respondents questioned the merit of such a tool as opposed to current design practice; these respondents are most probably the most experienced of those interviewed and are justifiably concerned with regard to the a tool constraining the application of their advanced knowledge and skills. ADAPT^{IT} should therefore be set up in such a way that designers quickly become aware of and are convinced of the additional value of ADAPT^{IT}, while allowing advanced users to integrate their own knowledge and skills. In addition, designers must be able to design training more quickly (increased efficiency) and to design better training (increased effectiveness) with ADAPT^{IT}.

Assessment within ADAPT^{IT}

The project is addressing two additional kinds of assessment issues: (1) validating the tool against the theoretically-based design methodology upon which it is based; and, (2) demonstrating the effectiveness of the tool and the method in terms of learning outcomes. The outcomes of the needs assessment phase described above have led to specific method and tool requirements that are being integrated into the first prototype. Field tryouts with users in real-world settings will then lead to a second iteration and refinement of the method and tool. The project will assess the usability and utility of the refined method and tool by aviation industry practitioners. In addition, the project will content a quality assessment of the design blueprints produced as well as an effectiveness assessment of the training developed according to those design blueprints. As was the case with the Experimental Advanced Instructional Design Advisor cffort (Spector, 1995), ADAPT^{IT} intends to improve both efficiency and effectiveness.

Additional requirements for ADAPT^{IT} have not been emphasised in this paper since the focus has been on the assessment methods and their implications. However, it is the intent to include a number of design advisors, customised to the appropriate enterprise setting. In the aviation industry, safety requirements are paramount and these must be emphasised in all training, both for maintenance technicians as well as for air traffic controllers. Moreover, there are aviation industry standards for the portability of training set by the Aviation Industry Computing Consortium (AICC) in addition to the IEEE standards being developed for meta-data in technology-based training. Finally, there are generic instructional design standards established independently by the International Board of Standards for Training, Performance and Instruction (ibstpi - see http://www.ibstpi.org) that ADAPT^{IT} is committed to include. The overall assessment of ADAPT^{IT} will include an external evaluation of how well the method and tool adhere to these various sets of standards.

Conclusions

While there have becn efforts in the area of automated support for instructional design (Spector, Polson, & Muraida, 1993), what has bcen missing in this area are sufficiently elaborated design models with associated guidance and frameworks that are appropriate for the design of training for complex cognitive skills. The ADAPT^{IT} project is intended to fill this gap in the set of methods and tools available to instructional designers. The outcome of the needs assessment phase strongly suggests that the demand for such an integrated method-tool combination is highly desired by business and industry. The user-centred process adopted for this project insure that these real world needs will be addressed in the project and its products. The assessment of European designers described in this paper has resulted in a set of design requirements that will also be used for evaluating the final outcomes of the effort.

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