A Taxonomy for Interactive Educational Multimedia

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Abstract: Learning is more than knowledge acquisition; it often involves the active participation of the learner in a variety of knowledge- and skills-based learning and training activities. Interactive multimedia technology can support the variety of interaction channels and languages required to facilitate interactive learning and teaching. We will present a taxonomy for interactive educational multimedia that supports the classification, description and development of such systems. Such a taxonomy needs to embed multimedia technology into a coherent educational context. A conceptual framework based on an integrated interaction model is needed to capture learning and training activities in an online setting from an educational perspective, describe them in the human-computer context, and integrate them with mechanisms and principles of multimedia interaction.

Introduction

The development focus in computer-supported teaching and learning has shifted from early attempts to provide static resources to the provision of more interactive material (Northrup 2001). Platforms such as the Web are ideal to make learning resources constantly accessible, in particular to a distributed learner audience. Learning resources alone, however, do not constitute a pedagogical approach. *Interactivity* in its varied forms is central to teaching and learning (Moore 1992; Ohl 2001) – everybody involved in teaching will know that a learner's active participation is a prerequisite for successful learning (Sims 1997; Nardi 1997). We use the term *activity-based learning and training* to emphasise the duality between knowledge and skills. In many disciplines, skills training is equally important as learning of factual knowledge.

Multimedia has been widely used in educational technology (Okamoto et al. 2001; Trikic 2001); support frameworks for their development and evaluation exist (Heller et al. 2001). Interactive multimedia can enable activity-based learning and training. Central in a learner's interaction with the environment is the interaction with learning content – in particular in learning technology environments, the learner-content interaction is more central than the learner's interaction with instructors and peers (Ohl 2001). *Interactive educational multimedia* need to present the learning content in the most adequate form and need to provide the facilities to enable and process learner activities. The variety of learning and training activities is ideally supported by a variety of multimedia interaction channels and languages (Elsom-Cook 2001). The acquisition of, firstly, declarative knowledge and, secondly, of procedural knowledge and skills-based experience and expertise through learning and training needs to be integrated through a coherent channel and language design.

Our objective is to introduce a *taxonomy* for *interactive educational multimedia* supporting *activity-based learning and training*. The aim is to support the description, classification, comparison and development of educational multimedia environments. Such a taxonomy needs to be grounded in a conceptual model, which gives meaning to the terms of the taxonomy (Sowa, 2000). The conceptual model is based on an interaction and activity model and a multimedia interface language. A case study - a database learning environment called IDLE (Murray et al. 2003) - will illustrate the concepts and terminology of our framework.

Activity-based Learning and Training

Common to various forms of education is a strong reliance on active participation in learning and skills training. A *pedagogical model* captures the essentials of the different forms of interactions in learning and training processes. This model is part of the *conceptual model* for the *taxonomy*, but depends also on the particular context.

We will introduce a concrete model – the virtual apprenticeship approach – together with our case study. A number of concepts, however, are common to different models supporting activity-based learning and training.

The learning and training activities facilitated by educational multimedia interactions shall be captured in form of an *activity model*. Learner-content interaction, the dialogue of a learner with learning resources, is the primary form of interaction in computer-supported educational environments (Ohl 2001). We distinguish two aspects: the purpose of the learning activity and the degree influence of a learner on the environment through the activity.

Pedagogical theories determine the learning process design, i.e. the sequencing of learning content. The individual activities – the learner interaction with content – are often subject- or domain-specific. We can distinguish various *types* of *learner activities*. Learning in general is about the acquisition of knowledge or skills. The *purpose* of acquiring knowledge on the one hand and skills on the other differs:

- *Knowledge*. We refer here to what is often called *declarative knowledge*, i.e. facts. The objective of the learner is to be able to *reason* about knowledge. The style of learning is often classical studying. We usually use the term *learning* to refer to this activity.
- *Skills*. This shall denote here what is sometimes called *procedural knowledge*, i.e. instructions. The objective of the learner is to be able to *perform* instructions and procedures – in this case we speak about skills. The style of learning is often *training*.

This aspect describes the *meaning of the interaction* for the learner in terms of her/his *goals* and *tasks*.

- *Knowledge-level interaction*. This is interaction in terms of domain concepts and relationships. Meaningful communication with these elements is essential for declarative knowledge acquisition and production.
- *Activity-level interaction*. This is interaction in terms of domain-specific actions and activities. Meaningful activities are important for the acquisition and execution of skills, i.e. procedural knowledge and experience.

This distinction is necessary to reflect the different cognitive processes of knowledge and skills acquisition.

We can define *activity types* now based on the *purpose of the learning process*. However, we introduce three types, see (Tab. 1). The second category is important in particular in the sciences and engineering domain where a deep understanding of the subject activities is required for a learner.

Activity Type	Description
knowledge acquisition activities	the aim is the acquisition of declarative knowledge in order to reason about it
procedural knowledge acquisition activities	the aim is the acquisition of procedural knowledge, but here to reason about it
skills acquisition activities	the aim is the acquisition of procedural knowledge in order to perform the instructions

Table 1: Activity Types based on Learning Purpose

The *style of the activity execution* can be based on the *degree of involvement and influence* of the learner on the environment, see (Tab. 2). We can distinguish types ranging from system-controlled to learner-controlled environments. We can explain these three forms in terms of a computational model – the object-based model. Observation is pure object inspection without any state change. Controlling would allow the object state to be influenced. Creation involves the generation of objects themselves that are sent to the target object.

Activity Type	Description
observation	a form of knowledge acquisition with no influence on the environment activities by the here passive learner
controlling	a form of knowledge acquisition mixed with knowledge production elements, based on observational elements, but allowing the learner to influence the environment activities to control their ordering
creation	a form of activity where knowledge or skills are created by producing some form of artefact that can be processed by the learning environment

Table 2: Activity Types based on Degree of Involvement

Often the two aspects based on purpose and environment influence are related. Declarative knowledge is often acquired through observation, procedural knowledge for reasoning purposes through controlled animations, and skills through artefact creation and processing. We discuss some examples in our case study.

Interaction

Interaction is central in the implementation of learning activity. An *interaction model* focussing on learner-content interaction shall capture and relate meaningful activities and interactions with educational multimedia. This will seamlessly embed interactive multimedia into an educational framework.

The notion of interaction has a meaning in different contexts. Clarifying these meanings in a terminological framework is essential. We distinguish three perspectives on interaction – presented in three layers: learning and training interaction, human-computer interaction, and interactive educational multimedia.

Learning and Training Interaction

Learning should be an active process in which interactivity is central (Northrup 2001). The aim of interaction models is to support the design of learning activity and knowledge representations. Moore (1992) distinguishes three types – learner-learner, learner-instructor, and learner-content interactions. It is often argued (Sims 1997; Ohl 2001) that *content* has a more *central function* in computer-based education than interaction with peers or instructors. Ohl defines interaction as an internal dialogue of reflective thought that occurs between learner and the content – how the learner interacts with what has to be learned or trained. We have provided a context for an educational notion of interaction through our activity model.

Human-Computer Interaction

The notion of learning as a dialogue between learner and content needs to be adapted to the human-computer environment (Dix et al. 1993). Models for this context formulate these interactive dialogues as cycles consisting of computer-based executions and human evaluations (Norman 1998). Three models are essential:

- *Cognitive models* represent the user's knowledge, intentions, and abilities. Acquisition and production of plans of activities are central. A *cognitive architecture* addresses the cognitive learning processes as interactions in the human-computer environment. The architecture provided by an educational computer system defines a problem or learning space in which a learner should be able to accomplish a learning goal. The architecture is defined by the actions that allow the learner to traverse the space, i.e. to learn, and by the desirable states that represent the successful accomplishment of the goal, i.e. to find a solution for the learning goal.
- A hierarchical *task and goal model* structures the learner goals and the corresponding tasks that have to be executed to accomplish the goals. A task is an operation to manipulate concepts of the domain, i.e. a goal is the desired output from a task. A hierarchy is defined by dividing goals into subgoals and tasks. A learning strategy defines how learning goals on the same level are connected and scheduled. The formulation of goals and tasks for the learner is based on knowledge-level or activity-level attributes relevant in the educational context. The tasks, however, have to be mapped onto the actions supported by the architecture.
- *Linguistic models* constrain the interaction through a user-system grammar. Different interaction styles and activities, e.g. different pedagogical activities, can be described. Style examples include commands, direct manipulation, menus, or form fill. The purpose of a language capturing the interaction processes is usually the specification of learner dialogues, including the legal user actions and the system responses.

Interactive Multimedia

Learner-content interaction in computer-supported learning and training actually occurs as interaction with the *interactive multimedia features* that implement the *cognitive architecture* and the *linguistic model* and that enable the *tasks* to be executed and the learning *goals* to be accomplished. This multimedia interaction implements the dialogue of reflection and activity with various content features that a learner engages in.

Computer-supported learning and training is characterised by a variety of different learning activities and strategies. The term *interactive educational multimedia* emphasises the interactive nature of learning and training and the variety of media often required or used to facilitate learning and training. Understanding *learning and*

training software as *interactive multimedia* is paramount if learner interaction, usability and cognitive processes involving knowledge and activities have to be considered.

Multimedia systems (Elsom-Cook 2001) are characterised by the channels provided to access and communicate knowledge and to enable activities.

- A *channel* is considered as an abstraction of a connection device used to communicate encoded information.
- Specific *languages* are used to communicate along the channels between the user and the multimedia system.
- A *medium* is a set of co-ordinated channels.

In computer-supported learning and training, content- or instruction-related information is communicated, usually through text and spatial position (mouse) channels.

Communication needs to be *meaningful*. Technically, a communication is meaningful, called an *interaction*, if it results in a change of state for either the user or the system. An internal state, the ability to communicate in a common language, and goals and intentions that guide the activities are assumed for both learner and medium – both called *agents*. The user interacts with the system in form of *dialogues* to access knowledge and engage in activities.

Interactive Educational Multimedia

Interactive multimedia for activity-based learning and training can be distinguished into interaction with knowledge media and with activity media. A taxonomy-based characterisation and classification of knowledge and activity media is a central aspect of our framework. Crucial for educational multimedia description are the multimedia interface and the interaction dialogues a multimedia system allows through channels and languages.

Interaction with Knowledge and Activity Media

In order to support activity-based learning and training involving skills-based activities, interactive multimedia support is needed. Multimedia systems for education are usually hypermedia systems providing structure through hierarchy and guidance for learning tasks through navigation topologies (Jonassen and Mandl 1990). Different media supporting different activities are connected through hypermedia structures.

Activity-based training focuses on skills-oriented activities, but needs to be integrated with knowledge learning aspects. *Knowledge media* focus on knowledge information to be communicated. *Activity media* focus on artefacts that are produced and processed in activities. Domain-specific activities aiming at skills development are usually more varied and more complex than knowledge acquisition activities. The purpose of interactive educational multimedia is twofold:

- The domain-specific activities need to be facilitated, i.e. activity-level interaction with the educational multimedia feature through artefacts and instructions has to be enabled.
- The instructor needs to be replaced by a virtual form of an educational multimedia feature that provides advice and feedback in relation to activities, thus adding more meaning to the interaction.

Interactive multimedia are considered as agents (like the learner) with knowledge, an internal state, and intentions – the prerequisite to implement a master through an intelligent agent.

Facet	Type	Description
channel	general	the abstraction of a communication device, characterised by modality
language	general	information is encoded in common language for communication over a channel
activity purpose	education	this distinguishes whether declarative knowledge reasoning, procedural knowledge reasoning, or skills acquisition is aimed at
activity style	education	this is the classification of activities into observation, controlling, and creation that describes the degree of influence of a learner on the environment
content topic	education	the topic or domain within which activities or knowledge-level access is provided

Table 3: Educational Multimedia Facets

Educational Media Taxonomy

We can classify educational multimedia through different *metadata facets* – see (Tab. 3) – essentially different dimensions that allow us to describe educational multimedia characteristics.

- *General multimedia facets* cover multimedia aspects such as channel and language. These facets together describe a medium as a co-ordinated set of channels and their languages.
- *Education-specific facets* cover aspects specific to learning and training such as the activity purpose, the activity style, and the content topic.

The aim of this *taxonomy* is to describe, distinguish, and classify educational multimedia.

The two general facets of multimedia – channel and language – shall be revisited in the context of education. In comparison with classical uses of multimedia for knowledge-oriented learning (Heller et al. 2001), here the interaction between learner and content in the context of activities, which is determined by the channels and their languages, is more central.

Educational Multimedia Channels

Multimedia is about channels and meaningful communication along these channels. Often, a natural language such as English, written or spoken, constitutes a channel. For our context, we will identify a number of specific channels – based on partly more formal languages, partly languages specific to the subject or instruction context – determined by the underlying educational model, the virtual apprenticeship model. Therefore, we define *interactive educational multimedia* as a set of *co-ordinated educational channels* – see (Tab. 4). We distinguish two types of channels – those that support *core* content-oriented learning activities and those that are part of the *meta*-context of instruction, the latter including instruction-related learner actions and coaching actions by the master or instructor.

Channel	Type	Description
declarative knowledge	core	declarative knowledge usually communicated in a domain-specific natural or formal language
procedural knowledge	core	procedural knowledge usually communicated in a domain-specific natural or formal language
skills	core	artefacts to be processed in form of activities are communicated with the corresponding execution instructions
actions	meta	instruction-related actions executed (communicated) by the learner such as navigation or location of learning units
coaching	meta	meta-level information capturing a master's advice and feedback regarding knowledge, activity, and other learning actions is communicated

Table 4: Educational Channels

Multimedia interface languages can capture the different channel communications. Such a language constrains the interaction between agents. The language defines the interaction dialogues; it describes the legal actions, how a learner can engage in an activity or how a learner can perform a task towards a learning goal.

Educational Multimedia Interface Language

The purpose of an interface language for educational multimedia is to specify learning behaviour and media interaction dialogues. The difficulty in defining an adequate language is to capture all three interaction model layers. The learning and training interaction model provides the conceptual model in which the language semantics is to be defined. Human-computer interaction models contribute to the design of activities represented in the language.

An interface language needs to define the vocabulary of communication and the grammar that constrains the interaction. The *linguistic model*, based on an underlying pedagogical model, provides the semantical framework in which an interface language is developed. It is based on the domain-specific aspects captured in the pedagogic model: (i) *knowledge-level* and *activity-level interaction* involving knowledge, artefacts and instructions, and (ii) *meta-level pedagogical interaction* involving feedback and advice. The *cognitive model* and *cognitive architecture* define the *learning space* and, therefore, determine the learning processes enabled by the language. The *task model* is about abstract educational multimedia interaction sequencing and usage, i.e. it determines the *interaction patterns*.

We have outlined five education-specific channels for learning and training activities. In principle, each channel is supported by a separate language. However, in practice, a number of channels or languages can be supported by a single educational medium. The interaction is often described by a single language incorporating all channels. Channels act only as a logical, but not physical mechanism of structuring interaction aspects. The

understanding of multimedia as a seamless integration of different media, for instance achieved through a language integration, is crucial (Heller et al. 2001).

The learner input is part of activities that are meaningful in the context of learning and training for a particular content domain. On the most basic level the learner interacts with multimedia usually through keyboard- and mouse-based input; output can be static visual (text, graphics), dynamic visual (animations, video), and/or involving other modalities such as audio. The basic inputs are part of low-level activities such as navigation (knowledge acquisition request) or text input/submission (knowledge generation) that constitute basic learning activities. A learning activity can be composed of more basic activities. Composition operators such as sequence, iteration, or choice can be provided. We can define a simple *interaction language* that illustrates the main ideas. This language shall consists of

- basic activities: `select` (knowledge acquisition by learner), `submit` (knowledge generation by learner), `reply` (response to knowledge acquisition/generation) ;
- activity combinators: `;` (sequence), `!` (iteration), `|` (choice) .

A language needs to facilitate declarative and procedural knowledge communication, skills-oriented activity execution, learner actions, and meta-level pedagogical interactions (coaching). `select` denotes a learner action; `submit` and `reply` support skills-oriented activities; `reply` could also convey meta-level feedback and coaching.

Technically, an interaction language describes information flow and processing between learner and educational medium. The language grammar constrains this information flow on an *interaction topology*, based on the learner and possibly several educational multimedia agents. The interaction topology consists of nodes (states of the agents) and arcs (transitions between the states). The transitions are caused by learner activities and multimedia responses. A state represents the delivered response. Nodes and arcs are described by attributes such as the modality and the language of the channel, activity type, or object/entity involved. The interaction topology and the constraints imposed by the language grammar form an implementation of the *learning space* described in the cognitive model.

Educational Multimedia Case Study

Our case study – the Interactive Databases Learning Environment IDLE – is a Web-based virtual undergraduate introduction to databases (Murray et al. 2003). This system has been gradually developed over a period of more than ten years. In its current form it supports learning and training activities such as design, implementation, and analysis of database applications.

A Pedagogical Framework

The learning-by-doing idea is part of the active learning theory. It captures the interplay of knowledge acquisition and knowledge creation by the learner in an interactive process with the learning environment (Nardi 1997). We have widened this focus by considering *knowledge acquisition* on the one hand and *skills and experience acquisition* on the other hand as two dual sides of learning and training.

The *virtual apprenticeship model* (Murray et al. 2003) is a pedagogical theory – based on terminology defined in the activity model – that defines a framework for activity-based and skills-oriented learning and training, that integrates these activities with knowledge-oriented learning, and that explains the role of educational multimedia technology in this context. Two well-established theories form the pillars of our pedagogical framework:

- The *cognitive apprenticeship theory* formulates a pedagogical framework for knowledge acquisition based on an apprenticeship approach to learning (Guzdial & Kehoe 1998). An apprentice is a learner who is coached by a master to perform a specific task. In a Web-supported environment, the master's role of the apprenticeship model is often replaced by an intelligent agent.
- *Activity theory* is a framework that focuses on agents, or tools, as the mediators between learners and the learning resources (Nardi 1997). Tools reflect the experience people, such as the apprentice's master or the instructor, have made in trying to solve a particular problem. Here, IDLE is the tool that mediates the learner's interaction with learning content. Activity theory provides a framework to structure and develop educational activities in a Web-based environment. The role of mediating tools can be played by interactive educational media. These facilitate activities and guide the learning process through specific interaction channels.

The apprenticeship model can serve as the IDLE-specific pedagogical model for our learning and training taxonony.

One of the skills-training activities in the IDLE system is SQL (database) programming. The SQL tutorial and lab support is based on the apprenticeship philosophy. Integrated with a database system, the student – a virtual apprentice – works through guided material covering a range of individual problems. Each problem is based on a

submission- and execution-cycle. The virtual master provides scaffolding in form of advice and feedback. Advice reflects the instructor's experience over a period of several years. Each solution attempt is analysed and, based on an individual activity history and integrated assessments, personal feedback is given.

Classification and Description

The multimedia taxonomy as well as the education-specific channels and interaction languages shall be illustrated using IDLE. IDLE supports the classical forms of third-level teaching – lectures, tutorials, and labs – in a virtual form. These three forms can be described using the educational multimedia classification scheme – see (Tab. 5) which describes some selected activities for particular topics.

Facet / Activity	Channel	Language	Purpose	Type	Topic
Lecture	text and audio	natural language	declarative knowledge	observation	introduction to databases
Tutorial	dynamic animation	simulation	procedural knowledge	controlling	relational algebra
Lab	text	formal language	skills-oriented activities	creation	SQL

Table 5: Sample Multimedia Classification

The channel and language characterisation using the taxonomy in (Tab. 5) is abstract. These two aspects can be described in more detail. (Tab. 6) provides a channel-oriented view on IDLE; it lists the educational channel types and some sample features that are based on these channels.

Channel	Feature	Activity	Language
declarative knowledge	database introduction lecture	HMTL and audio-based synchronised virtual lecture	natural language (written and spoken)
procedural knowledge	relational algebra animation	interactive simulation of algebra operator execution	formal language (interaction – animation control)
skills	SQL programming lab	submission of query solutions and dynamic page update by system	formal language – SQL (solution and result)
action	SQL tutorial navigation	guided tour through a series of connected exercises	formal language (interaction – navigation)
coaching	self-assessment	multiple choice questions and virtual master's feedback	natural language (written)

Table 6: Sample Multimedia Channels

An example shall illustrate the interaction language. The expression `! ( select(exercise); submit(solution); reply(result) )` is the specification of an *exercise activity* in the interaction language – it combines the tutorial navigation with lab programming activities, see (Tab. 6). '`select`' is a navigation action through which the learner selects a particular exercise. The learner then submits a solution, i.e. generates knowledge. The system replies with a result.

Conclusions

Activity-based learning and training based on interactive educational multimedia might provide an answer for the current need to support not only knowledge acquisition, but also skills and experience acquisition in educational environments. Interactive educational multimedia is a platform to implement activity-based learning and training. We have developed a taxonomy based on a conceptual framework for the development, description, and evaluation of interactive educational multimedia. Taxonomies based on conceptual models allow us to describe activities,

interactions, and multimedia objects and their channels and languages. They can support the comparison between different systems and their effectiveness evaluation.

One of the central lessons we have learned over the years of developing, managing, and maintaining educational multimedia systems is that there are a number of reasons that ask for a domain-specific, systematic approach to activity-based learning and training. Firstly, interactivity is central and especially complex in the educational domain. The learning and training activities need to be embedded into a pedagogical framework in order to achieve a high quality learning experience. A domain-specific approach is therefore needed. Secondly, the need for activity-based education is increasing. Consequently, the integration and maintenance of educational multimedia is becoming increasingly a problem. Only a systematic approach to development and maintenance can provide a solution. Thirdly, learning and training are multi-channel and multi-language activities. Seamlessly integrated interactive multimedia is therefore an ideal support approach.

One of our objectives was to provide a central element for such an approach and to guide educational system design, implementation, and evaluation through our framework. Interactive multimedia has the potential to support innovative approaches to teaching and learning, but in order to be successful, it needs to be embedded into a systematic framework for development and management.

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