# The Application of Concepts for Learning and Teaching

*Christian Gütl, Victor Manuel García-Barrios*

Institute for Information Systems and Computer Media, Graz University of Technology, Austria

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## Abstract:

*Human-beings tend to simplify, unify and cluster characteristics in phenomena by concepts as well as interrelate them in order to build a knowledge structure for their thoughts and notions. In this paper we want to focus on the application of concepts in the field of learning and teaching. First, possible application fields as well as interesting research and development are represented. Second, we give an overview of our past and ongoing research and development work regarding the usage of conceptual spaces for e-learning. Thereby, we discuss experiences and results of user surveys about the application of concepts in the learning process.*

# 1 Introduction

In general, biological and artificial life-forms tend to build an own internal representation of their environment by means of the inputs of their sensory components. This 'internal view' is well modeled by neuronal networks for human-beings and can be well modeled by artificial intelligence methods such as logical agents, connectionism and logic-based knowledge bases. Taking a closer look at human-beings, they tend to simplify, unify and cluster characteristics in phenomena (such as observations from environment, complex systems and processes, and the like) as well as to interrelate them into semantic structures for their thoughts and notions. Considering the latter aspect and analysing research work in cognition science and social science, the idea of 'concepts' can be identified. According to [1] a concept is defined as "*[…] an abstract, universal idea, notion or entity, that serves to designate a category or class of entities, events or relations. […] Concepts are abstract in that they omit the differences of the things in their extension, treating them as if they were identical. Concepts are universal in that they apply equally to every thing in their extension.*" However, in general the term 'concepts' has several meanings [2] and there are several perceptions in different research areas, such as in semantic web [3], in knowledge management for knowledge generation, explanation and sharing [4], and in learning science [5, 6].
In this paper we want to focus on the idea of concepts in the field of teaching and learning applications. First of all, relevant research, possible application fields and developments are depicted. Secondly, we give an overview of our past and ongoing research and development activity regarding the use of concepts for e-learning. Thereby, we discuss experiences and results of a user survey about the application of concepts in the learning process.

# 2 The Concept of 'Concepts in Teaching and Learning'

## 2.1 Concepts in Learning and Teaching at a Glance

This section gives a brief overview over relevant research topics and terminology issues related to concepts in the context of teaching and learning processes.
*Concepts* represent thoughts, ideas, senses, notions, believes or entities in order to describe categories or classes of entities and events. A *symbol* or a *term* (one or several words) is used

to uniquely define a concept within a particular domain, which is given by individuals or domain experts. That given, we like to emphasise that symbols and terms for a concept may differ over various domains and individuals as well as one and the same symbol or term may address several concepts. Furthermore, one and the same concept may be logically related to 'regions' of different domains. [1, 7, 8, 9]

Concepts might be classified in *Concrete Concepts*, which address common objects or events, and *Abstract Concepts*, which are rules for the classification of concrete concepts. It might also be distinguished between *Fundamental Concepts* (or *Low-level Concepts*), which are formed directly from perceptual information, and *High-level Concepts*, which are defined through the process of abstracting and representing an advanced state of knowledge. Furthermore, it is understood that concepts are jointly described by their intensions and extensions: *Extension of a concept* is the sum of the instances, i.e. the set of entities or objects which form a concept, *Intention of a concept* is an abstract definition of common features shared by instances of the extension, i.e. all attributes that describe a concept. On the one hand we claim that attributes themselves are represented by concepts; e.g. one intention to define the concept 'summer' might be the attribute 'temperature', which in turn is itself a concept for example within the domain of physical sciences. On the other hand, concepts are not just sets of attributes; from our viewpoint, parts of these attributes or concepts address 'regions' in different domains, and build correlations among them. Thus, concrete or fundamental concepts can be referred by examples of instances or described by attributes; abstract concepts need to be defined by language description or codified rules. [7, 8, 10]

For the sake of completeness let us also state that concepts are not isolated entities. Concepts have relationships and are linked together, which allows building knowledge structures. *Knowledge in a domain*, or in general knowledge, can be described, modelled and codified by a set of concepts and their relations. *Relations* are statements and assertions that describe a particular situation or a knowledge domain. [4, 11, 12] Further, relationships among concepts and terms may also form ontologies, classification systems, thesauri and lexica. [13, 14] In literature, the process of identifying concepts and relations is defined as *Concept Mapping* and is technologically supported by *concept map* tools that allow capturing, organising, communicating, transforming and assessing knowledge. [10, 11, 12, 17]

From the learning viewpoint new concepts and relations are built and integrated into prior knowledge, and existing concepts and relations are adapted. This might be induced by stimuli and information in every day life as well as initiated by an active knowledge transfer process applying different styles, such as declarative and constructivistic approaches. [9, 10, 15, 16] From the teaching perspective, the use of concept modelling support the identification and description of syllabi, topics and main subjects within courses and lectures. In addition, course content itself can be modelled through concepts and relations, which in turn might also help to identify the logical order to be taught. Finally, concept structures and their linked extensions can be used to transform knowledge from teachers to students. In the context of this paper and for the purpose of simplification, we use the terms *concept structures* and *conceptual spaces* as synonyms, although we know that a conceptual space is a representational framework for information structures. [11, 12, 17, 18]

Following the insights stated so far, Concepts represent a powerful tool in a wide range of application domains. For example, they allow humans to symbolise simple and complex ideas, they enable concepts' instances to be linked (original objects or multimedia representations), and they provide a framework for modelling by attributes, language descriptions and codified rules. Concept Modelling enables applications to refer from concepts to illustrative examples or descriptions, and to build (automatically) further concepts and their attribute representation from training instances. Further, concepts' relations have the power to structure perceptions and insights, allow expressing knowledge about a specific situation, and make possible to detect and explain dependences to and influences by other concepts. This latter observation enables applications e.g. to codify pre-knowledge and to modify or adapt knowledge through concept map tools, and to (re-)discover or generate knowledge from unknown or hidden relations by using co-occurrence analysis.

### 2.2 A First Approach to a Classification for Concept Application in Learning and Teaching

Based on our experiences in the application of concepts in our research activities (see also Chapter 3) accompanied by an extensive literature survey and the insight gained in the previous section, we propose *a classification for concept application in the field of learning and teaching, the CALT classification,* as depicted in the reminder of this section. A selection of interesting and illustrative examples complements this section.

(1) *Knowledge Expression and Organisation* encompass applications that support the management of (a) concepts and their relations, (b) links to examples of concept instances, and (c) concept representations through attributes, language description and codified rules.

The 'ADEPT Digital Learning Environment' implements a digital knowledge base of information about concepts and their interrelations for the utilisation in organising learning material. [17] The 'Concept Indexing Tool' the definition of instances of concepts by marking sections of text documents in a browser frame and linking them to a conceptual space. [19] The IMKA system maps different multimedia representations (i.e. sample instances of concepts) to a concept structure. [20] The 'CmapTools' supports a collaborative construction of knowledge models through the management of concept maps and their links to multimedia resources. [12] 'NavEx' parses C code, extracts automatically relevant concepts and links them to the example code. [21] The authors of [22] introduce 'Two-Phase Concept Map Construction (TP-CMC)', an approach for automatically constructing concepts and their relations from an underlying course by evaluating the learners' historical testing records.

(2) *Knowledge Retrieval* supports students and teachers in accessing and exploring concepts and their relations as well as examples of concept instances (e.g. original objects or multimedia representations).

Applications mentioned in the last section (a) support browsing and searching at the level of concepts and their structural space, or (b) enable the access to sample instances. The 'Concept Indexing Tool' (see [19]) also refers from specific concept instances to underlying concepts.

(3) *Knowledge Discovery* enables students and teachers to detect or reassemble a-priori unknown or unfamiliar knowledge, which was previously already codified in concepts and relations as well as in example instances or descriptions.

The 'Concept Indexing Tool' (see [19]) provides concept occurrence detection for textual documents based on manually predefined concept descriptions. Furthermore, it statistically detects concurrence of concepts, and thus enables students and teachers to discover candidates of new concept relations for further exploration and validation. Quite similar, the authors of [23] build an associative conceptual space from a repository of text documents in order to find out new hypotheses for further investigations. 'NavEx' (see [21]) creates automatically concepts and 'TP-CMC' (see [21]) automatically creates concept maps, allowing students and teachers to grasp the underlying content or the course content on a higher abstraction level.

(4) *Knowledge Exchange and Transfer* support the exchange of personalised views on knowledge either at the level of concept structures or at the level of concept representations.

The 'ADEPT Digital Learning Environment' (see [17]) is applied for the knowledge transfer in face-to-face lectures by simultaneously projecting concept structures, lecture note slides and example instances. The authors of [12] report about 'Quorum': students can collaboratively create their concept maps in a knowledge domain and underlying propositions are extracted and stored in a central database. Thus, students can explore a common conceptual space and learn from each other, but they can only see those others' propositions that are linked to their own contributions.

(5) *Knowledge Assessment* provides a powerful mechanism for assessing pre-knowledge and knowledge acquired (learned) either at the level of concepts and their structure as well as at the level of concepts and their representations.
The AEG ('automated essay grading') tool extracts concepts from model answers, compares them to the concepts given by student answers, and automatically processes grades. In addition, the concepts contained in model answers and student answers are visualised in order to provide feedback for teachers and students. [24]

# 3 Past and Ongoing Research Activities at IICM

Being aware of the power of concepts in learning and teaching applications, our past and ongoing research and development work in the field of e-learning successfully builds on the 'concept' idea. In this context, some interesting applications and evaluation results are depicted in the following sections.

## *3.1 Dynamic Background Library*

The *Dynamic Background Library* (see [25]), for short *DBL*, builds on the idea that people besides lecture notes or books tend to use additional information at their learning activities, such as information about underlying theories and definitions, illustrative examples, state-of-the-art research or real-life applications, and so forth. Unlike pre-compiled and therefore static background repositories in other research works and implementations within the field of e-learning systems, we follow the approach of delivering topical and knowledge-level-based relevant background information through the application of conceptual spaces. Our prototype implementation was developed as a module of Hyperwave's e-Learning Suite. To follow students' various levels of expertise on the course subject, the DBL distinguishes among three different knowledge levels: beginner, advanced, and expert.
From the teachers' viewpoint, the DBL enables to define and manage course-relevant (domain-relevant) concepts as well as textual representations (matching patterns), and maps concepts to course chapters or lessons (concept context). In order to deliver background information (example instances of concepts) dynamically, search queries have to be defined for each concept and its corresponding level of expertise. Teachers are supported to specify their queries either for Google or the xFIND search system by testing, refining and storing their results into the DBL.
From the learners' perspective, the DBL helps to identify relevant concepts in learning content by highlighting them within the content or by attaching them at the end of the page, the lesson or the course. Furthermore, students can follow hyperlinks assigned to concepts in order to activate the predefined search queries, and thus, obtain relevant additional information based on their pre-knowledge.
Our findings from a user evaluation show that for most of the test subjects the concept-based access to background knowledge can improve their learning activities. In terms of the CALT classification, the DBL contributes to classes (1) to (4).

## *3.2 Concept-based Modeller*

The *Concept-based Modeller* (CBM) is our 'next generation' implementation for the DBL described previously. In general, the CBM aims at the same goals as the DBL, but in a more application-independent manner. Conceptual spaces are built with the CBM as context-dependent sets of concepts within a specific (but arbitrarily generated) domain space.
After specifying an own domain, which is just defined by a name and a description, a context structure has to be built. The context structure is a set of terms describing the divisions and subdivisions of a domain, i.e. it defines a flat or hierarchical ordering of topics and reflects one possible semantic view over a domain or domain region. Thereafter, DBL-concepts are

constructed and interrelated to the context items. To exemplify the multi-purpose usage of this technique, consider a concept-based context being (a) the structure of a course, e.g. divided in chapters and sub-chapters, (b) the result of a clustering process over an un-structured information space, e.g. a classification, taxonomy or ontology output, (c) the set of profiles in user modelling systems, (d) an arbitrarily defined set of topics defined by a user, (e) the organisational schema of a company, or (f) a set of interrelated tasks for a given purpose, such as tasks and sub-tasks within a project definition, the items in a meeting agenda or the steps through a workflow definition. Concepts, matching patterns and queries in the CBM are generated and managed in a very similar way as in the DBL. Just the functional specification of DBL-queries was extended in order to work also for other information retrieval systems, as for example online dictionaries, glossaries or search engines.

Considering the context of this paper, the CBM represents a very flexible, extensible and multi-purpose version of a DBL, which enables its usage for various systems that manage different kinds of semantic spaces. An evaluation of the CBM from the viewpoint of learners and teachers is in planning and will encompass not only semantic but also pragmatic and cognitive issues. In terms of the CALT classification and in accordance to the DBL, the CBM contributes to classes (1) to (4).

### 3.3 AdeLE

Within the *AdeLE* research project (see [26] for details), for which an adaptive e-learning environment has been implemented for monitoring user behaviour on real-time through the use of an eye-tracking system, concepts are applied for modelling and profiling purposes. Learning assets of the course content, which were visited, scanned, read, learned or searched by learners, are automatically linked to concepts within a context model generated by a CBM. Internal information in the conceptual spaces is used then for updating the user profile. In concrete, conceptual spaces are applied within AdeLE for the following purposes: (a) to implement a DBL, which is defined by a CBM, (b) to define the structure of courseware, i.e. learning paths through learning repositories, (c) to extract semantic data from real-time user behaviour, and (d) to develop profiles for the user modeling system.

From the didactical viewpoint, constructivistic and explorative learning is supported by just defining and using a Dynamic Background Library for a given course. From the learners' viewpoint, individual conceptual spaces are mapped to the user profiles, and consequently, not only semantic but also pragmatic advantages can be offered, i.e. personal views on conceptual spaces can be determined through the definition of individual extensions and intensions of concepts. Finally, the application of concepts for user profiles enables a flexible interchange of personal information in different standardised ways; for example, through mapping mechanisms of the internal conceptual space, user profile data can be transferred in IMS LIP or PAPI format.

The usability evaluation of conceptual spaces within AdeLE has not been finalised and will give insights into the application of concepts for different systems (DBL, user models, courseware, etc.). In terms of the CALT classification, the utilisation of concepts within the AdeLE system contributes to classes (1) to (4). AdeLE comprises also class (5) of CALT, Knowledge Assessment, in that the overall system can deal with the SCORM standard. However, the problem of SCORM is that it provides metadata to describe assessment goals, but in essence these are only 'arbitrary' metadata without a concrete didactical meaning.

### 3.4 MISTRAL's Semantic Application

The 'semantic application' within the *MISTRAL* research project (see details in [27]) enables access to annotated semantic features of multi-modal meeting data streams. The idea behind this application is to provide different context-dependent views on conceptual spaces as well as to merge them into personalised structures according to the notion of concept connotation

and denotation (respectively, something very similar to intension and extension as already described in Section 2.1). As the prototyping phase of Mistral's semantic application has just started, it can be said in summary that it is mainly intended to utilise conceptual maps as follows: first, the implementation of the CBM will be enhanced by defining concepts as 'molecular units' within a 'self-organising magnetic field'. In concrete, denotations and connotations of concepts will be modeled as 'molecules', for which single 'atoms' reflect synonyms, antonyms, meronyms, holonyms, hypernyms and hyponyms. It is expected to compare semantic and pragmatic interpretations of personal conceptualisations. Also, existing tools will be used for finding out positive and negative arguments (i.e. 'pros' and 'cons' based on subjective statements during meetings) within a specific context and domain. This pros and cons can be then integrated into the intensions of concepts and enrich its pragmatic meaning.
In terms of the CALT classification, the 'semantic application' within the *MISTRAL* research project contributes to classes (1) to (4), but the focus is set on (3) and (4). One of the main targets of Mistral comprises also the field of *Knowledge Visualisation*, but in the context of this paper, this field is incorporated in the CALT class (1), Knowledge Expression.

### 3.5 E-Tester and Game-based E-Learning

The *E-Tester* (see [28]) is inspired by the AEG tool (see [24]) and automatically extracts the main concepts from learning content in natural language. Based on these concepts, the system compiles simple questions, such as 'What is <concept 1>?' and 'Explain <concept 2>'. In the second step, the E-Tester assesses natural language answers from students against the learning content, and finally provides users with results on a conceptual level.
First evaluations about the quality of concept extraction and automatic grading compared to teachers' grading are promising, field tests and user evaluations will be future work. Applying the E-Tester in *Game-based E-Learning Environments*, as discussed in [29], allows quiz-based games to use the same idea of concepts as stated before. In terms of the CALT classification, the E-Tester contributes to class (5), and the E-Tester in Game-based Learning contributes to the classes (4) and (5).

### 3.6 Virtual Tutor

The *Virtual Tutor* (VT), as described in [30], aims at complementing more traditional learning activities through dialog-based learning and experiments on main concepts and their relations based on a course or a lecture. These main concepts and their attributes or sub-concepts or related concepts are modelled in the knowledge base of an expert system (ES). Following the dialog initiated by the ES, students have to answer questions about the attributes of the main concepts. Based on the answers, the ES infers concept candidates and their probabilities.
In such dialog sessions, students can learn about concepts' attributes and are encouraged to experiment, e.g. to answer questions about terms to address a specific concept. Further, the VT dialog component allows, as usual by expert systems, to request explanations about questions and results. In this explanation component, important concepts are highlighted and linked to static information (course content) and to a DBL (see Section 3.1).
A user evaluation has shown that in order to solve concrete tasks or questions, students found the usage of the VT and knowledge access by concepts significantly more helpful than using the lecture notes. The VT covers the classes (2) and (4) of the CALT classification.

## 4 Conclusions and Further Work

This paper has introduced into the field of Concept Modelling and into the application of Conceptual Spaces within the scope of teaching and learning. In summary, it can be concluded that there exist a variety of application fields and techniques where the use of concepts (as defined in this paper) can improve the efficiency of knowledge transfer procedures. According to our evaluations, students and teachers recognise the didactical potential of conceptual spaces, and moreover, they advocate the adoption of tools based on this idea. The main reason for this fact is that conceptual spaces are very flexible but accurate enough to give users the feeling of individual reasoning, and thus, it fosters explorative and constructivistic learning in a 'logical ordered' manner.

To give an example of our future efforts in context, we are working on the development of a Collaborative Concept Manager, which enables users to define, manage and share concept structures in a collaborative, distributed environment.

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## Author(s):

Christian Gütl, Dipl.-Ing. Dr.techn.
Institute for Information Systems and Computer Media (IICM) - Faculty of Computer Science at Graz University of Technology, Infodelio Information Systems, Internet Studio-Isser and GÜTL IT Research & Consulting
Graz, Austria
cguetl@iicm.edu and cguetl@acm.org

Victor Manuel García-Barrios, Wiss.-Ass. Dipl.-Ing.
IICM - Faculty of Computer Science at Graz University of Technology
and CAMPUS 02 - University of Applied Sciences Degree Program in IT and IT-Marketing
Graz, Austria
vgarcia@iicm.edu and victor.garcia-barrios@campus02.at