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Time - A Multidimensional Concept

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Abstract. There exist a lot of studies about time, its interpretations, different features and structures from several scientific points of view. In our paper, we propose a multidimensional framework of time. The main idea of the paper is to present a synthesis of different dimensions of time. We discuss some parts of the framework to illustrate and highlight the multidimensional features of time. We also demonstrate an early-stage implementation of the framework as a “Time on Wall” course in the eEducation/Optima environment. By means of the “Time on Wall”, we are able to teach different dimensions of time across disciplines and faculties and to illustrate different time scales.

Keywords. Time, multidimensional framework of time, models of time, cultural sense of time, eEducation, Optima environment

Introduction

> *“Living on Earth may be expensive, but it includes an annual free trip around the Sun.” Anonymous in Singh, S. 2005. Big Bang: The Origin of the Universe.*

When we travel to a different country, we assume that a certain amount of cultural adjustment will be required, whether it's getting used to new food or negotiating a foreign language, or adapting to a different standard of living or another currency. We have to adapt to another culture's sense of time and the pace of life which both contributes also to our sense of disorientation. For example in Brazil, it is perfectly acceptable to be three hours late, and in Japan we can find a sense of the long-term that is often unheard of in the Western countries. Time is everywhere around us and, in a way, inside us.

Over the last two thousand years, philosophers have been interested in "What is time?" Different philosophical time conceptions have been proposed changing each other [1]. The concept of time is of great interest not only to philosophy but also to science. Humankind regards time as a universal phenomenon. We try to understand our world and the universe by means of time. It is difficult to find an object which wouldn't have a relation to time. Research of any process has a temporal context. Time has special characteristics, such as a rhythm and scale in each of these processes. Time is a term that aggregates temporal properties of our world. In the nature, several time scales exist, starting from the macro level - the estimated age of the universe (13.8×10^9 years or 4.4×10^{17} seconds) - and reaching to the very micro level in particle physics - Planck’s time (5.4×10^{-44} seconds) [2]. In today’s science we already are dealing with the concept of time at nanoscale in nature. These scales are very difficult for us to understand. We should be able to illustrate them, however. In science, several time categories have been proposed: for example, physical, geological or biological time [3].

The evolution of information and communication technologies has given us further extensions to the temporal context, such as time in databases, time in Web and XML applications and time in mobile computing. As time is an important parameter of all processes in nature, science, society and in our technological systems as well, we should be able to teach time.

Even if it is difficult to give an exact and right answer to a question "What is time?", we can still study time from different viewpoints. In our paper, we integrate different aspects of time into a global view and propose a multidimensional framework of time, which is presented in Figure 1. Our paper discusses some parts of the framework and highlights the multidimensionality of time by illustrating some multidimensional features of time. Finally, we demonstrate the early stage of the implementation of our framework, the "Time on Wall" course in the eEducation/Optima environment. "Time on Wall" is a multidisciplinary course on time based on the proposed framework. By means of the "Time on Wall", we are able to teach different dimensions of time and to illustrate different time scales across disciplines and faculties.

The rest of the paper is organized as follows. Section 1 provides different definitions of time. Models of time are presented in Section 2. In Section 3, cultural dimensions of time are discussed. Time in information systems is discussed in Section 4 and in other disciplines in Section 5. The early stage of implementation of our framework is introduced in Section 6. Section 7 is reserved for the conclusion and issues for further research.

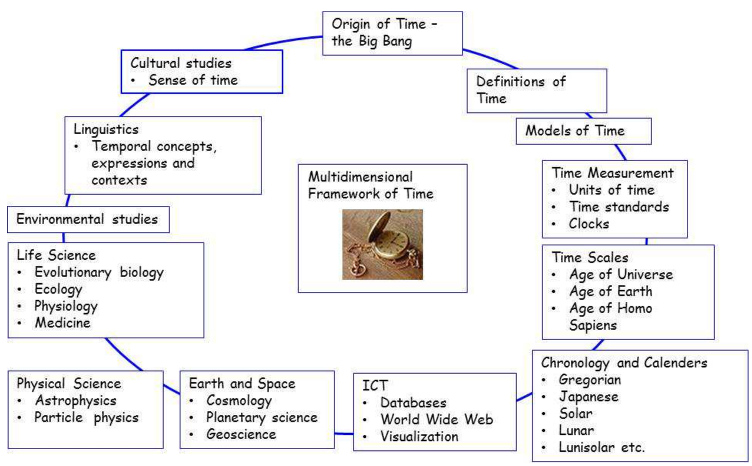

Figure 1. A multidimensional framework of time.

1. Definitions of Time

What is time? Several definitions can be found in the literature. Time is a measured or measurable period, a continuum that lacks spatial dimensions [4]. Time is the indefinite continued progress of existence and events in the past, present and future, regarded as a whole [5]. It is an observed phenomenon, by means of which human beings sense and record changes in the environment and in the universe [6]. Time is a basic component of the measuring system used to sequence events, to compare the durations of events and the intervals between them, and to quantify the motions of objects [7].

Time is a dimension in which we order events from the past through the present into the future. We can measure durations of events and intervals between them. We usually understand the passing of time by means of changes we observe occurring to objects in space, like their transformations over time and their movements in relation to one another. Scientific study of the spatial processes that have an effect on these changes is impossible without considering both space and time. Only by this way we are able to derive cause and effect relationships and reach ultimate understanding of nature and its structure. We can say that time has a structure as well as primitives. As a whole, time seems to be one of the ways we humans try to analyze and understand our world and universe. On Earth, the Sun has an essential role in our sense of time.

Most of these definitions mainly reflect the characteristic way humans understand time in terms of events. According to Giumale and Kahn [8], time, as an abstract concept, means a space of time points connected to each other by *before* and *after* -like operators. Some features in the structure of time reported by Schreiber [9] include absolute ordering (past, present and future), relative ordering (before, concurrent-with, after), finiteness and infinity, openness and closure, discreteness and continuity, objectivity and subjectivity, and linearity and circularity.

Temporal logic is any system of rules and symbolism for representing, and reasoning about, propositions qualified in terms of time. In the field of temporal logics, several researchers have presented the notion of branching time [10, 11]. In this notion, the model of time is a tree-like structure in which the future is not determined. There are different paths in the future, any one of which might be an actual path that is realized. It is used in formal verification of software or hardware artifacts.

Granularity, in general, is the extent to which a system is broken down into small parts, either the system itself or its description or observation [9]. It is the extent to which a larger entity is subdivided. For example, a day includes 24 hours, an hour 60 minutes and a minute 60 seconds.

Time can also be represented in terms of time primitives, that is, by durations, duration bounds, time points, time intervals, concurrency, coincidence, synchronicity and periodicity [12]. Duration is the absolute distance between two points in time. It is specified in terms of years, months, weeks, days, hours, minutes and seconds. Duration boundaries are defined by an upper and lower boundary such as a minimum duration of 2 minutes and a maximum duration of 20 minutes. Time points are used to represent specific instants along a timeline. Time intervals are sets of constraints between two points, a start and an end time. Concurrency is the closeness of two or more temporal events in time, in no particular order. Coincidence describes the intersection of several intervals. Synchronicity is the synchronous occurrence of two temporal events. Periodicity is the repetition of the same event with a constant period.

Many famous philosophers have argued over two contradictory aspects on time [2]. One aspect – the objective view - is that time is part of the fundamental structure of the universe in which events occur in sequence. Sir Isaac Newton supported this view, and hence it is sometimes referred to as Newtonian time. The other aspect is that time does not refer to any kind of "container" that events and objects "move through", nor to any entity that "flows". Instead, time is part of a fundamental intellectual structure within which humans sequence and compare events – the subjective view.

In the International System of Units [13, 14], time is one of the seven fundamental physical quantities. Time is used to define other quantities such as velocity. Therefore, defining time in terms of such quantities would result in circularity of definition. An operational definition of time, wherein one says that observing a certain number of repetitions of one or another standard cyclical event (such as the passage of a free-swinging pendulum) constitutes one standard unit such as the second - the base unit of time. This definition is useful for both advanced experiments and everyday life.

Temporal measurement has occupied scientists and technologists. It also was a prime motivation in navigation and astronomy. Periodic events and periodic motion have long served as standards for units of time. Examples include the apparent motion of the sun across the sky, the phases of the moon, the swing of a pendulum and the beat of a heart. Currently, the international unit of time, the second, is defined in terms of radiation emitted by cesium atoms [14]. Time has also significant social importance. It has economic value and personal value, because we are aware of the limited time in each day and in human lifespans.

2. Models of Time

Modeling of time has two main traditions represented in the literature. One view of time is a set of points without duration [15]. In time-point data models, observations are associated with a specific point in time. The other model proposes that intervals should be considered as temporal individuals [16, 17].

According to Allen's interpretation [16], an interval is an undefined basic concept the meaning of which derives from the relations in which it stands with other intervals - relations such as "overlaps", "contains", "comes before" etc. Allen's temporal relationships between two time objects, X and Y, are given in Table 1.

Table 1. Allen's temporal relationships between two time objects X and Y.

Relations	Example	Inverse
X before Y	XXX YYY	YYY XXX
X equals Y	XXX YYY	YYY XXX
X meets Y	XXXYYY	YYYXXX

X overlaps Y	XXXX
	  YYYY
		YYYY
		  XXXX

X during Y	XXX YYYYYYY	YYY XXXXXXX
X starts with Y	XXX YYYYYY	YYY XXXXXX
X ends with Y	XXX YYYYY	YYY XXXXX

With temporal data models, one of the classic questions is how temporal data is represented. In time-point data models, observations are associated with a specific point in time. The most commonly employed concept is order or concurrency. In time-interval data models, observations are associated with the time between two time points. Most models focus on three temporal concepts: order, concurrency, and synchronicity. Time interval models are summarized in Table 2 [12, 15].

Table 2. Time interval models.

Time Interval Models	Definitions
Allen's interval relations	Thirteen relations, forming an algebra. Any two intervals have exactly one of the relations. Invented in AI for temporal … *Continues* …reasoning. Used also in data mining.
Freksa's semi-interval relations	Semi-interval means that one interval boundary is unknown. Two relations between start or end points of two intervals suffice to uniquely identify the relations. Representation of incomplete or coarse situations is easier than with Allen's relations.
Reich's interval/point relations	Extension of Allens's relations to points. Five more relations: point finishes and inverse, point starts and inverse, point equals.
Roddick's mid-point interval relations	Allen's relation extended by a relation of each interval midpoints to the other interval. For example: midpoints within other intervals (largely overlap) or not (overlap to some extent). Nine versions of overlaps, 49 relations in total.

3. Time in Information Systems

Basic models of time have been applied to information systems in several ways. In the open specifications developed by the W3C community, time can be found at least in the following specifications: Working with Time Zones [18], XML/HTML [19], EmotionML [20] and Time in OWL [21]. Working with Time Zones describes the guidelines and best practices for working well with geographically distributed applications with date and time values. The document also aims to provide a basic understanding and vocabulary for talking about time and time handling in software, a source of confusion for many developers and content authors on the Web. In HTML, the <time> element represents either a time on a 24 hour clock, or a precise date in the calendar, optionally with a time and a time-zone offset. In Emotion Markup Language, time is represented as four timestamps: absolute time, duration, relative time, and timing in media. Time in OWL presents an ontology of temporal concepts. The ontology provides a vocabulary for expressing facts about topological relations among instants and intervals, together with information about durations, date times and time zones. The main classes of the ontology are: TemporalEntity (subclasses: Instant and Interval), DurationDescription, DateTimeDescription, TemporalUnit, and DayOfWeek. Time in OWL has been proposed to be extended with the concept of temporal aggregates [22]. Temporal aggregates are collections of temporal entities. Examples of temporal aggregates are "every 3rd Thursday in 2008", and "3 consecutive Mondays".

XLinkTime [23, 25] is a time-sensitive linking structure and an extension of XML Linking Language (XLink) [25]. XLinkTime consists of resources and/or portions of resources and links between them. The links are functions of time, and they can be activated by a user when a certain temporal rule or a set of temporal rules is valid.

XLinkTime is realized by defining a timerule namespace xmlns:timerule with attributes timerule:start, timerule:end, timerule:status and timerule:title.

Temporal entities in content level are significant issues for temporal reasoning [26]. Temporal expressions can be explicit, implicit or relative. They can also include uncertainty of temporal durations. Examples of explicit temporal expressions are the token sequences “January 2014” or “September 14, 2014, 3.00 p.m.". Implicit temporal expressions include the token sequence “Ocean Day 2014 in Japan”, which can be mapped to the expression “July 21, 2014”, or the sequence “Midsummer Day 2014 in Finland”, which can be mapped to “June 21, 2014”. Implicit temporal expressions can also be collections of temporal entities such as “every other Wednesday in every second month”. Relative temporal expressions represent temporal entities that can only be anchored in a timeline in reference to another explicit or implicit, already anchored temporal expression (for example the starting time of a meeting). For example, the expression “3 p.m.” alone cannot be anchored in any timeline. However, it can be anchored if the date of the meeting is known. The date then can be used as a reference for that expression, which then can be mapped to a timeline. Uncertainty of temporal durations is interesting. Consider a news article title *Prof. A met with Prof. B in Tokyo.* How long did the meeting last? Our first inclination is to say we have no idea. But in fact we do have some idea. We know the meeting lasted more than ten seconds and less than one year. By guessing and narrowing the bounds, our chances of being correct will increase. Just how accurate can we make duration judgments like this? Will it be possible to extract this kind of information from text automatically? The uncertainty of temporal durations has been recognized as one of the significant issues for temporal reasoning.

A temporal database is a database with built-in supports for handling data involving time, for example a temporal data model or a temporal version of Structured Query Language (SQL) [27]. More specifically, the temporal aspects usually include *valid time* and *transaction time*. These attributes can be combined to form bitemporal data. Valid time is the time period during which a fact is true with respect to the real world. Transaction time is the time period during which a fact stored in the database is considered to be true. Bitemporal data combines both valid and transaction time. It is possible to have timelines other than valid time and transaction time, decision time in a database, for example. In that case, the database is called a multitemporal database as opposed to a bitemporal database.

The field of temporal data mining studies has ordered data streams with temporal dependencies and interdependencies. Over the last decade, many interesting techniques of temporal data mining have been proposed and shown to be useful in many applications [28, 29].

According to Zhezhnych and Peleschychyn [30], we can summarize different time dimensions in a context of information systems as follows: (1) time has an ordering feature, (b) time is discrete, (3) time orders unique individualized events, (4) in time, events are divided into past, present and future ones, (5) time flows (future events become present, events of present become past etc.), (6) time is universal, (7) time is irreversible, (8) alternative scenarios of future events are possible, but only one scenario will be realized and (9) time has a meta-moment structure (every present corresponds to its past and to a set of possible futures).

4. Cultural Dimensions of Time

Time is seen in a different way by eastern and western cultures, and even within these groupings temporal culture differs from country to country. Also temporal identities of different organizations and teams in organizations may vary. In cultural context, there exist two general time models: linear and cyclic [31]. In the linear time model (Figure 1a), past time is over, present time can be seized and parceled and made to work for the immediate future. One task is carried out at a time. For example, Scandinavian people are essentially linear-active, time-dominated and monochronic. They prefer to do one thing at a time, concentrate on it and do it within a scheduled timetable. Southern Europeans are more multi-active and polychronic. Monochronic cultures differ from polychronic cultures in that the former encourage a highly structured, time-ordered approach to life and the latter a more flexible, indirect approach, based more upon personal relationships than scheduled commitments.

Cyclic time sees time as circular, not necessarily leading towards something but repeating itself in a cycle of events. Each day the sun rises and sets, the seasons follow one another, people grow old and die, but their children reconstitute the process. In many Asian countries, time has traditionally been considered as cyclic. For example, the Japanese traditional temporal culture can be presented by the Makimono model of time (Figure 2) [7]. In Makimono time, the future flows into the present, just as the past does. The present is a period that links the region of the past with the world of the future. Nowadays, linear time model has also been integrated into Japanese society. At present, Japan uses the Gregorian calendar, together with year designations stating the year of the reign of the current emperor [32].

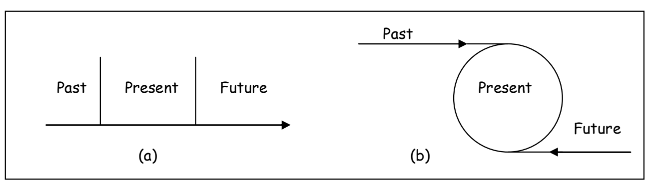

Figure 2. Linear time model (a) and cyclic time model according to Makimono time pattern (b). Makimono takes its name from *makimono*, a picture story or writing mounted on paper and usually rolled into a scroll.

Linear time is believed to be the closest depiction of our experience of time. However, for many centuries the Eastern world has used a cyclical view of time which supports the way nature behaves.

Western linear type action chains and Asian reflection are compared in Figure 3 [31]. The western model contains tasks A-F to be sequentially completed during the day. In Asian reflection, instead of tackling problems immediately in sequential fashion, to circle round them for some time is preferred. After a suitable period of reflection, A, D and F may seem worth pursuing. B, C and E may be quietly dropped. Contemplation of the whole scene has indicated however that task G might be the most significant of all.

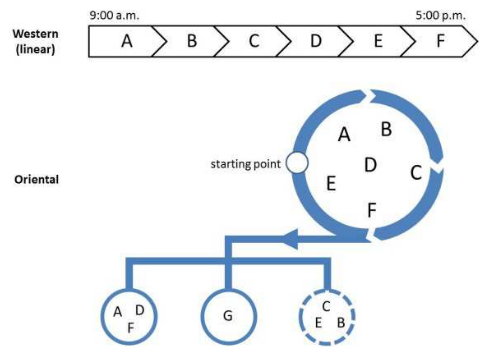

Figure 3. Western action chains versus Asian reflection.

When travelling, we are not only moving over time zones but also moving to a different kind of temporal culture. We can move in the opposite temporal direction, from fast to slow (or from slow to fast) [33]. From a temporal point of view, there are several things to be taken into account. We can consider these as temporal rules or temporal norms in cultural context (Table 3).

Table 3. Examples of temporal rules in cultural context.

Temporal expressions	Time has several meanings in different language. For example in Japanese, which is a very semantic, context sensitive and context rich language, there are around nine different time expressions that can be used in different contexts.
Punctuality	We should learn to translate – by cultural mapping of time frames from our own culture to another – our appointment time to the accepted range of punctuality for a particular situation in another culture.
The line between work time and social time	We should understand the separating line between work time and social time. In Japan, the distinction between work and social time can be meaningless. There the workday has a large social element and social time is very much a part of the work. The crucial goal that overrides both of these types of time is the *wa* of the work group. *Wa* is a Japanese cultural concept usually translated into English as "harmony". It implies a peaceful unity and conformity within a social group, in which members prefer the maintenance of a harmonious community over their personal interests.
Waiting for another person	We should also study the rules of the waiting game: who is expected to wait for whom and for how long?
Spaces between events	How your hosts treat pauses, silences or doing nothing at all. For Japanese people, the spaces between events are as significant as the events themselves: for example, the length of time of a silence that must be endured before a "yes" means "no".
Asking about accepted sequences	Each culture sets rules about the sequences of events. Is it work before play or vice versa? Do people take all sleep at night, or is there a siesta in the mid-afternoon? Is one expected to have coffee or tea and socialize before getting down to serious business, and if so, for how long? Etc. *Continues…*

Clock time or event time	Are people on clock time or event time? In monochromic cultures, one activity is scheduled at a time; in polychronic cultures, people prefer to switch back and forth from one activity to another in a very flexible way.
Practice	An intellectual understanding of temporal norms does not in itself insure a successful transition. Practice is needed.
Criticism	We should not criticize what we do not understand. This concerns also our temporal norms. We can always ask our host to explain.

To summarize the main difference between western and eastern sense of time, we can say that the western time orientation emphasizes objectivity, absoluteness and fixation of time. The Asian traditional cultural time orientation conceives time as subjective, relative and flexible. The understanding of a cultural concept of time is an issue for successful cross-cultural communication and cross-cultural collaboration.

5. Examples of Time Dimensions in Natural Sciences

Many scientists, including Galileo and Newton, up until the 20th century thought that time was the same for everyone everywhere. In classical, non-relativistic physics, time is a scalar quantity and, like length, mass, and charge, is usually described as a fundamental quantity. Our modern conception of time is based on Einstein's theory of relativity, in which rates of time run differently, depending on relative motion, and space and time are merged into space-time. We live on a world line rather than a timeline. The world line of an object is the unique path of that object as it travels through 4-dimensional space-time. Thus time is a part of a coordinate, in this view.

Astrophysicists believe the entire Universe and therefore time itself began about 13.8×10^9 years ago in the Big Bang. The Big Bang theory [34] is the prevailing cosmological model that describes the early development of the Universe. The age of the Earth is calculated to be 4.54×10^9 years. Homo sapiens originated in Africa about 200,000 years ago.

In biology, evolution is any change across successive generations in the heritable characteristics of biological populations. Evolutionary processes give rise to diversity at every level of biological organization. The similarities between all present-day organisms indicate the presence of a common ancestor from which all known species, living and extinct, have diverged through the process of evolution.

Chronobiology is a field of biology that examines periodic (cyclic) phenomena in living organisms and their adaptation to solar- and lunar-related rhythms. These cycles are known as biological rhythms. The variations of the timing and duration of biological activity in living organisms occur in many essential biological processes. The most important rhythm in chronobiology is the circadian rhythm, a roughly 24-hour cycle shown by physiological processes in all these organisms.

Environmental science provides an integrated, quantitative, and interdisciplinary approach to the study of environmental systems [35]. Environmental issues almost always include an interaction of physical, chemical, and biological processes. The key characteristics of an effective environmental scientist include the ability to relate space and time relationships as well as quantitative analysis. In natural disasters resulting from the Earth's natural processes, including floods, volcanic eruptions, earthquakes and tsunamis, time has an essential role from short-term, alarm scale to long-term scale for estimating environmental effects locally and globally. Time geography was originally developed by human geographers. Hägerstrand's earliest time geography formulation that uses a physical approach informally described the workings of large socio-environmental mechanisms [36]. Hägerstrand's approach involved the study of how events occur in a time-space framework, and he illustrated it by means of a graphical notation. Today, time geography is applied in multiple fields related for example to transportation, regional planning, geography, time use research, environmental science and virtual spaces [37]. Time geography is an evolving multidisciplinary perspective on spatial and temporal processes and events such as social interaction, ecological interaction, social change and environmental change. Time geography is an integrative ontological framework and visual language in which space and time are basic dimensions of analysis of dynamic processes.

6. How to Teach Time? - Implementation in Optima Environment

Imagine that the entire history of the universe is compressed into one year - with the Big Bang corresponding to the first second of the New Year's Day and the present time to the last second of December 31st (midnight). Using this scale of time, each month would equal a little over a billion years. By means of this scaling and our Time on Wall –system, we can illustrate the times of occurrence of important events in our imaginary one-year universe. The same kind of scaling can be realized at a micro level, in particle physics and cell biology, for example.

Our early stage implementation of the multidimensional framework of time is realized in the Optima system [38]. The Optima system is widely used in universities in Finland as a Web-based learning environment. The University of Jyväskylä is divided into 15 individual Optima environments, each faculty having its individual Optima environment. Each of these environments has hundreds of workspaces. If a user has access to more than one Optima environment, he/she can change the environment easily. It is easy to create courses across faculties. Technical support for Optima is working well, and the system contains built-in tools and functions for e-learning. Wiki environments are also of considerable interest in this context. However, they need more customization for our purpose.

The users of workspaces are divided by the status of their profile: supervisors (teachers, lecturers and owners of the workspace) and users (students). Both profiles have different permissions and actions available. The profiles are workspace-specific: a person can be a supervisor in one workspace and a user in another.

A material repository is a variant of workspace. Workspaces are recommended to be set as material repositories when the same material is to be used in multiple different workspaces. Materials are linked to different workspaces from the originals which reside in a material repository. Using a material repository has its benefits: when there is a need to update some material, only the material in the material repository needs to be updated - workspaces that have the materials linked in them are automatically updated from the source.

A workspace is a closed working area created for a single online course. Access to it is always restricted. Material is normally organized in folders. In a workspace, various tasks such as distributing course materials, group work, discussions, completing assignments etc. can be performed. Objects are documents and functions (e.g., a page made with a light web editor, a discussion list, a link, an imported pdf file and a return box) in the workspace. These objects can be organized into folders. The screen print of our preliminary version of the Time on Wall course implementation is shown in Figure 4.

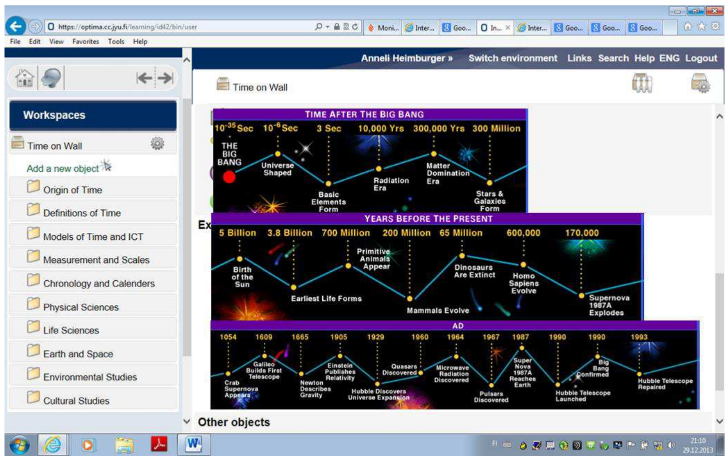

Figure 4. “Time on Wall” course prototype in Optima environment.

7. Conclusions

In our paper, we have studied time from different viewpoints and integrated different aspects of time into a global view. We proposed a multidimensional framework of time and demonstrated an early-stage implementation of the framework, the “Time on Wall” course in the eEducation/Optima environment. By means of the “Time on Wall”, we are able to teach different dimensions of time and to illustrate different time scales.

Time is a “connecting language” between different scientific disciplines. For the next phase of our research, we will organize a multidisciplinary scientific seminar around the concept of time. Its main aim is to specify the requirements for the final design of the Time on Wall course before establishing it as a part of international activities of the eEducation/Digital Campus programme at the Faculty of Information Technology of the University of Jyväskylä.

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