Learning Networks:
A first elaboration

connecting people, organizations,
autonomous agents and learning resources to establish
the emergence of effective lifelong learning

Framework for the
Learning Technology
Development Programme

Educational Technology Expertise Centre
Open University of the Netherlands

COLOPHON

Title:	Learning Networks: a first elaboration connecting people, organizations, autonomous agents and learning resources to establish the emergence of effective lifelong learning
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Report type:	Programme plan
Publication date:	17th December 2002
Document Reference	U2003-1880 MMO
Distribution	OUNL

Educational Technology Expertise Centre (OTEC)
Open University of the Netherlands

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Introduction

This report describes the intellectual framework for the Learning Technology Development Programme (Koper & Sloep, 2002) at large. The framework only is a first stab at a theoretical underpinning of the work to be undertaken. As a first priority, this framework will be expanded and further elaborated, a process which is likely to continue during the first half of the programme's life cycle. First a number of research fields and topics are discussed that have served to both constrain and inspire the programme. Building on these theoretical foundations, a synthesis is subsequently presented that represents the first elaboration of the programme.

Theoretical foundations

eLearning systems can be studied from a micro, meso or macro perspective. At the micro level one looks at the function of the smaller parts within the system, e.g. the relationship between instructional measures and learning processes within individuals. At the macro level one looks at the overall functionality of the eLearning system in relation with the environment, e.g. the effectiveness, efficiency, attractiveness, accessibility and adaptability of the eLearning system. For centuries philosophers and other theoreticians have wondered how, in general, the micro activities of the actors within some system relate to the macro behaviours of the system as a whole: how can human performance be explained from the activity of brain cells; how can the individual activities of ants explain the behaviour of ant colonies; how can the effectiveness of an educational institute relate to the activities of its individual students and staff members; formulated in more general terms, how may a collection of disparate actors create higher-level order under certain conditions? Only recently, new theories, models and approaches have been developed particularly in the natural sciences, biology, economical and organizational sciences that explain these aggregation relationships.

The LTD Programme focuses on a meso level of analysis of eLearning systems. The programme approaches learning of individuals in relation to the organization of the network environment in which they interact and it seeks to understand how macro phenomena occur as emergent behaviours from the activities of the subsystems at the micro level (see e.g. Prietula, Carley & Gasser, 1998, p. 14). The interaction behaviours and performance of the learners and other actors are the smallest elements in the analysis. Issues like interoperability, re-use, distributed actor interaction, emergent properties (co-ordination, grouping, quality, …), social-constraints and affordances, accessibility and network infrastructures are issues that are relevant in this perspective.

The theories underlying this approach to eLearning are elaborated in theories like complexity theory (see Waldrop, 1992; Kauffman, 1995), the study of emergence (e.g. Johnson, 2001), self-organization theory (Varela, Thompson & Rosch, 1991; Maturana & Varela, 1992), multi-agent approaches and distributed autonomous intelligence (e.g. Axelrod, 1997; Ferber, 1999; Jennings, 1998), computational organization theory (Carley, 1995; Lomi & Larsen, 2001); small-world network theory (e.g. Watts & Strogatz, 1998; Barabási, 2002), learning communities (Retallick, Cocklin & Kennece Coombe, 1999; Ison, 2000), new learning spaces (Peters, 1999), and technological approaches as peer-to-peer systems (Liber, Olivier & Britain, 2000; Barkai, 2002), pattern analysis (Gamma *et al*, 1995; Fowler, 1997; Larman, 2002), simulation approaches (e.g. Gilbert

& Troitzsch, 2002), formal learning theory (Jain, Osherson, Royer & Sharma, 1999; Zwaneveld, 1999), and the Grid (Foster, Kesselman & Tuecke, 2001).

Emergence is the effect that happens when an interconnected system of actors, interacting with each other and with resources, self-organizes to form more intelligent, more adaptive higher-level behaviour. The resulting organization in its turn puts constraints on and social objectives for the interactions of the actors/agents and resources (Figure 5).

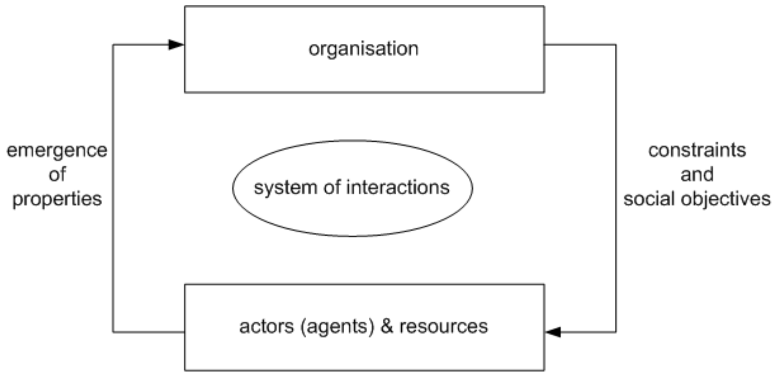


Figure 5. Relationship between emergent properties and organizational constraints (Ferber, 1999, p.14).

The conditions for emergence to occur (as seen from the perspective of the smallest reactive agents), can be summarised as follows (see Johnson, 2001):

1. More is different. A critical mass of micro level agents is necessary to invoke the macro level behaviours. This critical mass creates a kind of phase shift in the behaviour of the system: the macro behaviours occur and can put new organizational constraints on the lower level agents (e.g. the occurrence of traffic jams). The study of micro level behaviours (e.g. the behaviour of an individual ant in a colony) is not enough to be able to anticipate the macro level behaviour. In most current approaches to learning communities this factor of 'critical mass' is still ignored.
2. Simplicity of lower level agents. The individual agents can perform according to simple rules and only limited information. For the study of the macro behaviours, only a limited set of rules and behaviours are accountable at the lower level. All other complexity can be ignored. Aggregations of lower level agents can be perceived as more complex, more intelligent agents within a higher level of organization. This accounts for the difference between so-called reactive agents and cognitive/intentional agents (e.g. Ferber, 1999).
3. Random encounters and explorative behaviour. The adaptive behaviour of the system is dependent on random interactions of the agents with the environment, exploring a given environment without any predefined order. Parenthetically, this does not preclude the possibility of planned or even institution led activities in the network. Here, however, we want to underscore the importance of random, explorative behaviour, even though that obviously may act in concert with staged behaviours.
4. Perception of patterns. The agents must be able to detect patterns in the input signs. The knack for pattern detection allows meta-information to circulate through the network: signs about signs. The major difference between human societies and animal societies is attributed to the existence of so-called second-order emergence patterns. Human agents can distinguish patterns of collective action, which in turn effects their actions and the function of the system as a whole (Gilbert, 1995).

5. Feedback from the direct neighbours. The provision of feedback from the direct neighbour agents is an essential condition for the higher-order network behaviour to occur, specifically its learning and adaptation mechanisms.

The higher-order emergence phenomena that are of interest to us here are the emergence of learning, knowledge and communities in networks of learners and organizations. An interesting corollary is: how can we create a distributed network of agents that optimise the emergence of effective, efficient and attractive learning in its participants and the network as a whole. The essence of this approach is that the learning processes and the learning or knowledge communities are not designed, but emerge, i.e. arise bottom-up through mechanisms that operate under certain, favourable conditions. Studies in other domains show that these types of inductively created artifacts can be as effective and efficient as top-down designed approaches. The emergent behaviours of a system evolve over longer periods of time (Gordon, 1999) and influence individual agents.

These theories, models and approaches can now be applied to the eLearning field, because of two reasons. First, because the conditions for emergent behaviours can be met by eLearning infrastructures: these connect a large number of individuals, learning artifacts and organizations into a learning network that is capable of inducing emergent behaviours. Second, because recently the approach has shifted from understanding emergent behaviours to intentionally creating systems, like learning networks, that exhibit emergent behaviours. It is expected that new approaches towards learning, like inductive learning design based on the patterns of learners in learning networks will be feasible and will stimulate new ways of learning and knowledge handling. Because of the ubiquitous nature of learning networks available at home, at workplaces, and at formal educational institutions, it is expected that these are specifically suitable for lifelong learning purposes.

This approach towards the creation of learning networks provides a new view on the organization of learning. Briefly, it holds that learning is organized or patterned in an inductive way. The autonomy of the learner is taken as the starting point, rather than a design based on particular instructional principles. Through the users' learning behaviour, inductively learning 'principles' emerge. What type of emergent behaviours (e.g. emergent knowledge, learning, tracks, patterns, etc.) occur in a learning network, by what rules are they governed, what is their efficiency and economy, and how can they be influenced, are still open questions. Answering them is the subject of study and experimentation in this programme.

It should be noted that we use the term learning networks in a stipulative way. There are a number of other contexts of use of the term in which the term has a somewhat different meaning. Examples are Harasim, Hiltz, Teles & Turoff (1995, p.4), who define learning networks as 'groups of people who use CMC [computer-mediated-communication] networks to learn together, at the time, place, or pace that best suit them and is appropriate to the task'. And there is an online journal called Asynchronous Learning Networks (www.aln.org) that mainly refers to work at the group level using computer conferencing or other networked collaborative tools. A related term is networked learning, which focuses on the experiences of students and teachers with the use of computers in learning. (see e.g. the programme at Lancaster University at csalt.lancs.ac.uk/jisc/). Each of these conceptions bears similarity to the one espoused here, particularly in that they all involve the use of networked computers to support learning. However, there are also significant differences, the most important one being that the present programme seeks a deeper understanding of what networked learning is about. It does so by contrasting the informal to the formal, the emergent to the proscribed, and the self-directed to the institutional, which is evidenced by the explicit incorporation of self-organizational aspects, based on the interactions between actors and learning artifacts, in the conception discussed here.

What can we expect from the application of these connection theories into the eLearning field? A provisional list:

- A better understanding, perhaps explanation, of learning phenomena in networks, providing justified decisions for educational institutions that create multiple levels of collaboration and want to use eLearning in an effective, efficient and attractive way.

- A better insight into how to set up and manage collaboration, and especially collaborative development of learning resources and content in the eLearning field: consortia of digital universities, public-private sector partnerships, libraries, partnerships between traditional and open university systems, international collaborations, relations with publishers, etc.

- A better approach to, and instrumentation of lifelong learning; since e.g. dossiers are not global, but remain under the custody of the education provider, genuine lifelong learning still remains an unfulfilled dream.

- Ultimately a seamless integration of knowledge creation, sharing and use for learning purposes, that possibly opens the doors to complete new ways of learning, teaching and knowledge creation, sharing and transfer.

- A test bed through which institutions can experiment with alternate means of both providing and assessing flexible learning opportunities for accreditation and certification of learning accomplishments.

- A visible means to operationalize the move from nebulous accreditation practices to outcomes based learning models.

A first elaboration

The programme focuses on research and technology development into learning networks. Learning networks are provisionally defined as: self-organized, distributed eLearning systems, designed to facilitate life long learning in particular knowledge domains.

The concept of a learning network refers to the connection of a large number of actors and learning artifacts into an organization, as well as to the physical ICT network and facilities that are responsible for the technical connections. The following sections elaborate this concept to a first approximation. They provide a preliminary analysis of the functional, organizational and technical aspects of learning networks.

Use case model

Figure 6 provides a first elaboration of the learning network use case, specified in UML (OMG, Booch, Jacobson & Rumbaugh, 1999). A use case specifies the different functions that different (UML) actors can perform with the learning network. The use case specifies four different actors: learners, providers, autonomous agents and learning network facilitators. A learner actor can be an individual person or a group of persons. A further specialization of learners can be given in terms of workers, citizen and students (in educational settings). Different kinds of providers may be distinguished, such as network providers responsible for the technical facilities, and content providers responsible for the provision of (high quality) content, e.g. publishers, libraries. Furthermore, learning service providers can be distinguished responsible for tutoring, mentoring, assessment and other learning support functions. The learning network facilitators manage the operation of the network, they are for instance moderators and webmasters.

Autonomous agents, finally, are automated processes (a kind of small robot) that may perform a variety of activities ordinarily performed by human actors. An autonomous agent may thus fulfil the role of a learner, a provider and/or learning network facilitator.

Different use cases (or activities, represented by the oval boxes) can be performed, like: perform learning activity, create/read/update (CRU) learning activities, select activity, rate activity, and etcetera. A key notion in the learning network is that it should support learners to perform all learning related use cases, also the ones that traditionally are only available for content and learning service providers. In traditional eLearning systems there are fixed roles in the system. These systems are organized as a waterfall, or pipeline: first learning content is created, courses are designed, delivered and evaluated. Participation of learners in content creation or course design is limited, they are the primary responsibility of the providers. In a learning network fixed, planned processes are not the only or even preferred means of building knowledge. Learners can make their own learning artifacts, build their own curriculum; can provide ratings for the quality of learning artifacts, etcetera. But this does not impede others, like providers, to use other processes, e.g. the waterfall approach. All the approaches can be mixed and the resulting learning artifacts are all part of the learning network. Organizational principles governing the overall process in the learning network stem from self-organization theory, organization is considered an emergent behaviour of the learning network. There are no central control actors; the control is expected to emerge under favourable conditions (local feedback, pattern detection, etc.). Students, teachers, administrators and technical experts will all be asked to help create and validate the use cases developed at this stage of the research.

A similar argument holds true for quality control. There is no central quality control. It is expected that the network will uphold a variety of different qualities, but that the feedback mechanisms (like ratings and paths, see below) will assure that on the average a satisfactory quality level will be maintained. Thus factors like development costs, frequency of use, incentives, price, and satisfaction may be dynamically balanced. Again this is an emergent behaviour, which, as indicated above, will only occur at a certain scale (more is different). Hence, specifically at the start of a learning network, or in experimental situations, it may be hard to fulfil these scale conditions. We will look for the possibility to use autonomous agents in different roles to artificially increase the scale. Real actors and autonomous agents will than both be part of the network. The development of autonomous agents will also provide the possibility to study the behaviours of learning networks with multi-agent simulation runs.

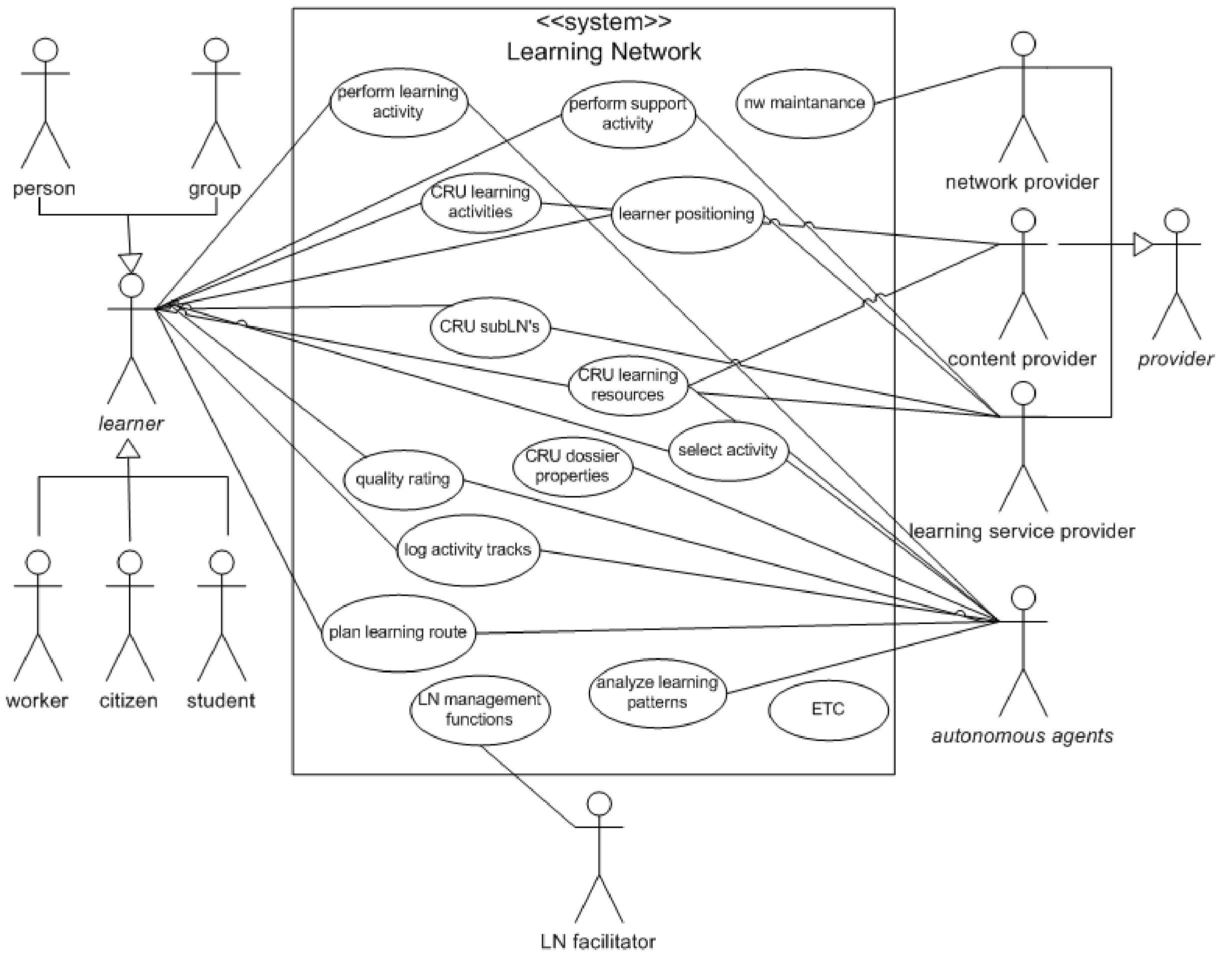


Figure 6. A first elaboration of the general use case for learning networks

Physical network

The organizational network is driven by the innovations in the technological network, and the technological network affords particular types of interactions and drives the development of technological networks, as organizational innovation makes demands on the technology. Figure 7 provides a view of the physical network with its connections. A learning network connects:

1. Actors (learners, providers, facilitators and autonomous agents).
2. Organizations (institutions, companies, associations, etc.).
3. Learning artifacts (activities, learning objects, units of learning, etc.).
4. Connected physical learning networks.

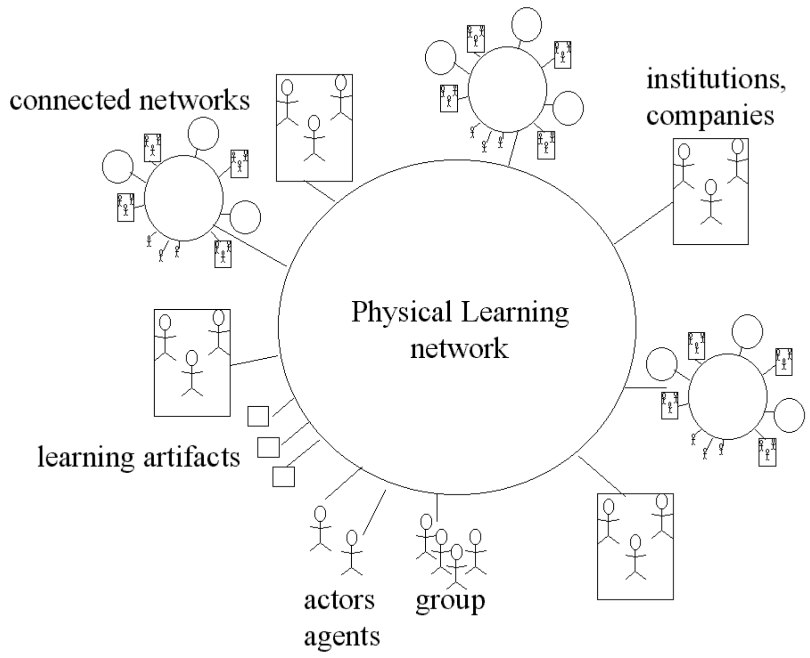


Figure 7: A physical view on the network

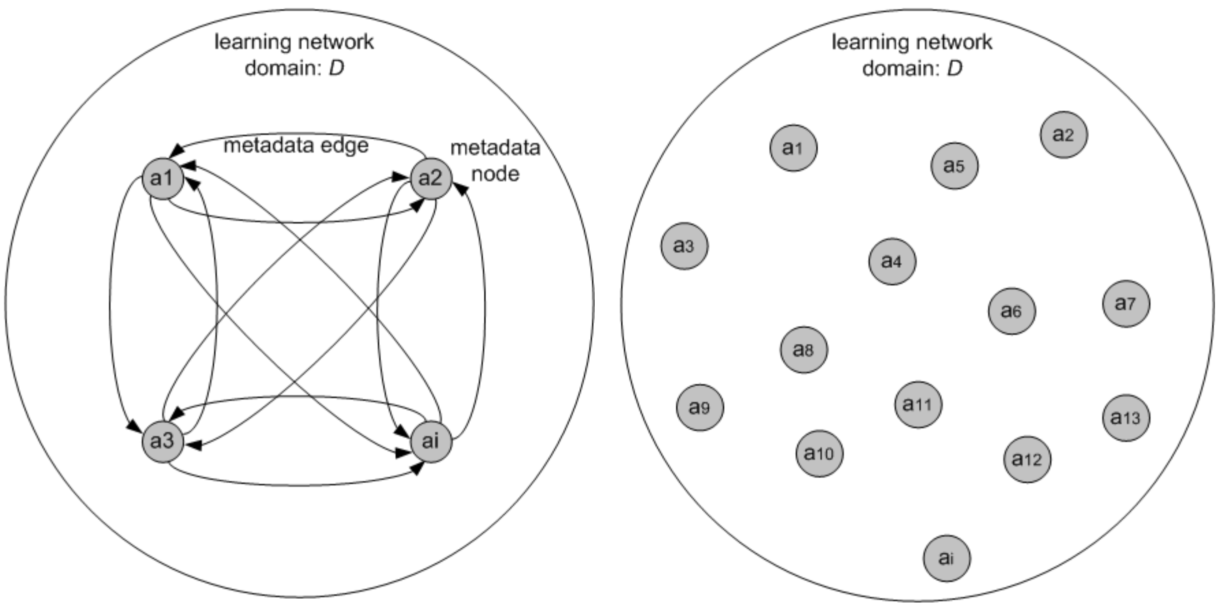
There are several approaches to realize these types of networks. One possible approach is with Peer-to-Peer (P2P) technology. P2P technologies represent a network-based computing model for applications in which computers share resources and communicate via direct exchange. P2P models allow users to form self-organized communities that collaborate through resource sharing. According to Barkai (2002) its major characteristics are: online identity that is not attached to a device; community framework with associated user profile definition; mechanisms for maintaining local autonomy while entrusting others with one's own resources; applications that are interoperable, or integrate, with each other. Another, similar approach is known as the Grid. The term Grid is introduced about five years ago to denote a proposed distributed network for advanced science and engineering. According to Foster, Kesselman & Tuecke (2001) the real and specific problem that underlies the Grid concept is co-ordinated resource sharing and problem solving in dynamic, multi-institutional virtual organizations. The sharing is not only one of file exchange but includes direct access to data, software, computers and other resources needed for collaboration. In a grid the sharing is controlled by rules of access and use. A virtual organization is the set of individuals or institutions that are defined by such sharing rules. Most current internet techniques do not support the functionality that the Grid requires, specifically the large-scale interoperability of computers in different organizations. Both P2P and the Grid support scalable, self-organized learning networks.

Another technological aspect is the architecture of the autonomous agents. Autonomous agents are computational systems that inhabit some complex, dynamic environment, sense and act autonomously in this environment, and in doing so realise a set of goals or tasks that they are designed for. Multi-agent systems are loosely coupled networks of entities that have the following characteristics: each agent has incomplete capabilities to solve a problem, there is no global system control, data is decentralized and computation is asynchronous. These systems have skills in social organization, co-operation, co-ordination, negotiation and communication (see De Croock *et al,* 2002, p. 106).

All network approaches are dependent on standards that are responsible for the connectivity and interoperability of systems. For example, without TCP/IP, HTTP, SMTP, HTML etcetera, the internet would not exist. It does exist because these interoperability specifications provide the foundation of the interoperable connections. In the eLearning field the interoperability issue has been identified and for several years now efforts have been put into place to develop and specify interoperability specifications for eLearning. What is true for the internet is true for eLearning systems in general and learning networks in particular: without interoperability specifications for learning artifacts, learner properties and agents there will be no learning networks. In the past Technology Development Programme into Electronic Learning Environments of OTEC, we defined EML and have put efforts in turning it into a standard in the IMS consortium. The outcome is the IMS Learning Design specification (IMSLD, 2002) that is a necessary condition for learning networks to function, along with other specifications. Further networks developed during this research programme will be used as validation examples of specifications developed by ourselves and other partners working in this area. In this programme we will strictly conform to interoperability standards where available and suitable. Furthermore we will continue to put efforts in the international standardisation communities by identifying missing interoperability specifications, developing proposals and participating in the different standardisation bodies that are of interest in this field. We see these contributions to standards as one of the primary type of outcomes of the programme, besides publications and prototypes.

Logical structure

In this section we will represent the logical structure of a Learning Network as a connected, directed graph of *activities* in some knowledge or application domain (Figure 8). According to IMS Learning Design an activity is modelled as a simple unit of learning containing only one learning activity and zero or more support activities. A series of activity nodes in a learning network are the equivalents of a single traditional course. The metadata of an activity are dynamically updated according to certain characteristics of use, e.g. frequency of use, user ratings, and average completion time. An important feature of any one activity is the set of rules that govern the lifetime of that activity, specifically its extinction ('fading out') and maintenance ('staying alive') behaviour.



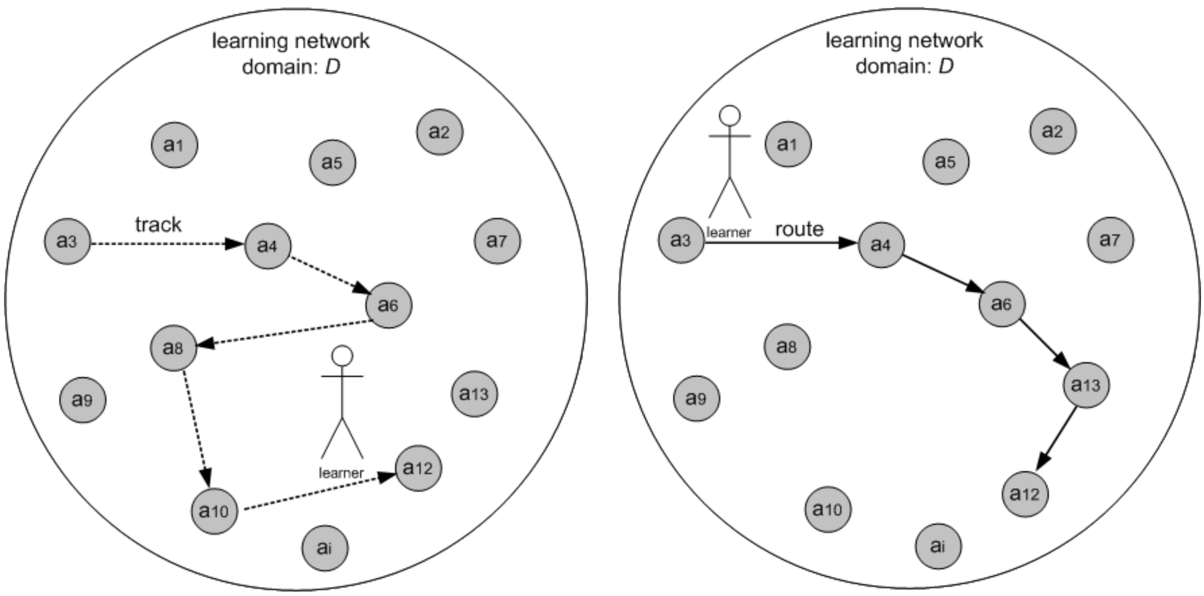
(a) connected, directed graph *(b) edges are implied*

Figure 8. A learning network represented as a graph with activity nodes. In (a) all the directed edges are drawn and in (b) they are implied (this is the default).

Figure 8 takes as its starting point the set of activities {a1, …, ai} in some domain *D.* Figure 8a represents the full connected graph, Figure 8b implies that all the arrows that connect all points are available, but are not drawn.
Actors can create, update, share, perform and rate activities in the learning network. Each activity has metadata with information about its creation, frequency of use, perceived quality, usage number (number of visits to it), completion number (number of times a visit resulted in completion of the activity), and indicators like completion time (time it took to complete said activity).

Learning networks are expected to consist of complex organizations of sub-networks and themselves to be part of interconnected networks. They thus reflect the complexity of the structure of knowledge and of application domains, and the collaborative efforts of actors that form temporary groups. However, we don't consider this organizational structure of learning networks necessarily to be the result of a design and planning process; rather, we assume it to result from a self-organization phenomenon. This occurs in virtue of a variety of measures, such as facilities to see who is performing the same activities in the same domain and the domain labels used in the metadata description of the activities, including the rules that govern the communication and use of these domain labels. In fact we expect actors only to create, label and use activities according to a set of rules. We will look, however, for other conditions and rules that invoke the self-organization of activities into learning networks.

Actors travel in a learning network from activity to activity, leaving their tracks in it. The sequence of activities that learners have completed may be called a *learning track* (Figure 9a). Learning tracks are made explicit in learning networks and can be shared. Different types of tracks can be distinguished. Actors who explore different kinds of activities in the network, whether they only read them, adapt them or study them, all leave their tracks. E.g. a learning track as defined above represents the sequence of *completed* activities of a learner.



(a) track *(b) route*

Figure 9. tracks (a) and routes (b) in a learning network

Tracks are trails that are left behind when actors, like learners, navigate through the learning network. Learning *routes* are paths that are planned beforehand, for instance by a teacher, an instructional designer or a learner. Such a path may be called a '*learning route' or a 'learning plan'* (Figure 9b). A route may be planned for a single individual to follow, representing a personalized learning route, or for a group, as in regular courses and curricula.

The directed path between two activities will be designed to hold metadata about the frequency of use, perceived quality of users, profile of the users that followed the path, etc. Extending the notion of a track, we may define a *learning road* as a frequency labelled directed path between two activities, where the frequency represents the number of times an individual has completed the two activities in the order given by the direction of the path. A learning road thus is a statistical concept, as it reflects the generalized behaviour of many actors. This provides, for instance, the possibility to create *learning road maps*, representing a learning network with all its nodes and roads (e.g. with frequency > 0; see Figure 10). A roadmap can help actors to navigate in the network, specifically when additional maps and facilities are created, like the possibility to match the currents user profile with the average profile of users that followed a certain track.

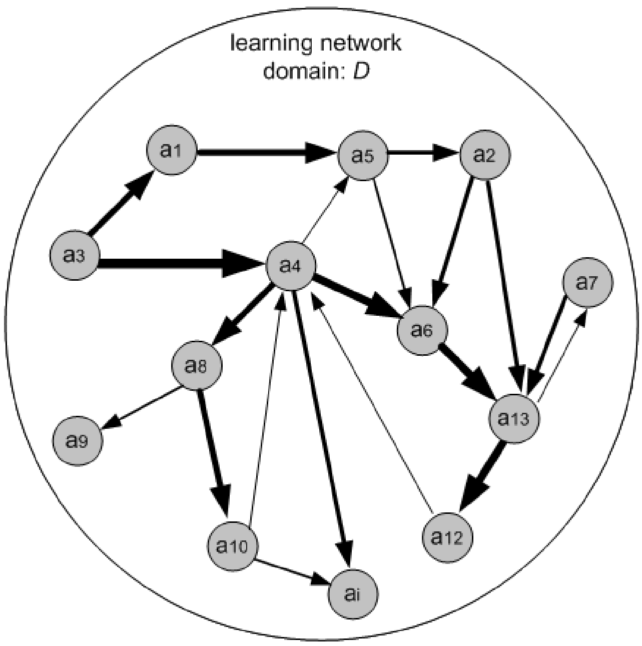


Figure 10. A learning road map (line thickness reflects frequency).

We may take this exercise yet one step further and define a *learning pattern.* A learning pattern is the set of rules that describes the learning path that maximizes the sum of the transition frequencies, in a generic way. A learning pattern may be abstracted from the specific learning network to be applied in other learning networks. The notion of a learning path may be used for the planning of courses and curricula in an inductive way, through generalizing user behaviour. A approach is to use finite automata and their probabilistic counterpart Markov chains for recognizing patterns in data. Also in the UML world there is a lot of attention for pattern capturing mechanisms (e.g. Gamma *et* al, 1995; Fowler, 1997; Larman, 2002). Some initiatives are known to search for pedagogical patterns (e.g. Sharp, 1999).

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