

Toward Learning Grid Infrastructures: An Overview of Research on Grid Learning Services

Roger Nkambou¹, Guy Gouardères² and Beverly P. Woolf³

¹Département d'Informatique, Université du Québec à Montréal, Montréal(PQ), H3C 3P8, Canada

²Equipe ISIHM – LIUPPA, IUT de Bayonne, 64100 Bayonne, France

³Department of Computer Science, University of Massachusetts, Amherst, MA. 01003, USA

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Mailing address (for proofs):

Roger Nkambou
Département d'informatique
Université du Québec à Montréal
201, avenue du Président-Kennedy
Montréal (Québec)
H2X 3Y7
Canada

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Roger Nkambou¹, Guy Gouardères² and Beverly P. Woolf³

¹Département d'Informatique, Université du Québec à Montréal, Montréal(PQ), H3C 3P8, Canada
Nkambou.roger@uqam.ca

²Equipe ISIHM – LIUPPA, IUT de Bayonne, 64100 Bayonne, France
Guy.Gouarderes@iutbayonne.univ-pau.fr

³Department of Computer Science, University of Massachusetts, Amherst, MA. 01003, USA
bev@cs.umass.edu

Abstract. The ‘Learning Grid’ refers to the promise of projects that pool together instructional materials on distant computers. The Grid provides a wide range of available and potential learning services and resources and does not simply refer to taking advantage of the multiplying effects of connectivity. It supports the personalized use of the collective intelligence provided by networked computers and supports the exchange, negotiation and dialogue within and among virtual, evolutionary and pervasive learning communities. This article provides an overview of papers from the first workshop on Grid Learning Services, which brought together researchers discussing their views of infrastructure, services and resources. It also addresses several research questions, including: What are the relevant resources and services and how can they be identified or built? How do they rely on the basic open Grid service architecture? How can intelligent tutoring systems be built on the Grid? How do the performance, efficiency, usability and the global ability of those services meet individual and collective users’ expectations?

1 Introduction

New software and network capabilities have suggested the possibility of ubiquitous and customized instruction for all students with a connection to the Internet. Both the construction of content and the availability of virtual assistance have been substantially improved, enabling students to move towards network-mediated learning, and replacing classical tutoring based on a single microprocessor. In this context, the ‘Learning Grid’ paradigm aims to support the personalized use of a collective intelligence provided by a wide range of available and potential learning services and resources on the Grid.

The underlying universal driving mechanism of the ‘Learning Grid’ is learning. It does not refer to simply taking advantage of the performance capabilities and the multiplying effects of connectivity, rather the resources and services are significantly centered on the exchange, the negotiation, the dialogue within and among virtual, evolutionary and pervasive learning communities.

The ‘Learning Grid’ refers to the promise of projects that pool together distant computers, possibly distributed across the globe for the benefit of learners everywhere. Grid computing combs through numerous computers in search of the appropriate learning resource or service.

It addresses the rapid proliferation of network resources, by tying together distributed resources to form a single virtual computer, with benefits provided in accelerated learning, increased resources and effective services.

Grid computing differs from cluster computing or peer-to-peer (P2P) computing (Haynos, 2004). Cluster computing usually contains a static number of processors and resources, perhaps a single type of processor and operating system, physically contained in the same or fixed locations, which can be interconnected together. On the other hand, Grid computing consists of heterogeneous resources, integrating storage, networking, services and resources. Resources may include machines from different vendors, running various operating systems, and including the ability to manage the workload. The advantage and challenge of Grid computing is that it is dynamic (resources appear and disappear on the net), inherently distributed, can be located anywhere and offers increased scalability.

Peer-to-Peer (P2P) computing lacks a central form of management, thus providing the user with anonymity and some protection from being traced. P2P is far more scalable and much more dynamic than Grid computing. One key to building Grid computing systems is to find a balance between decentralization and manageability.

Networking capability, based on optical fiber, doubles every nine months, whereas microprocessor capability, based on memory capacity and processor speed, doubles only every 18 months. Thus, the advances of networking technology far outstrip the advances in desktop computers, which is limited to the capability and number of its transistors.

The European Learning Grid Infrastructure, a 2004-2008 project launched by the European Union within the 6th Framework Program, places particular emphasis on a synergic approach, sometimes called ‘human centered design,’ to replace the classic, applicative approach to learning. Nevertheless, this ethno-centric vision must be followed with a techno-centric evolution of services, semantics and standards as a new class of components play a prominent key role in meeting pedagogical goals of novel learning situations.

The emergence of on-demand services for virtual communities has become a strategic goal. However, some pitfalls of this approach remain, including how to achieve pervasive, persisting and effective dialogues among users along with individual or collective personalization on the Grid. Other open issues include how to dynamically generate the open share of the Grid services and maintain their performance, their efficiency, their usability and their global ability to satisfy the individual and collective users’ expectations.

To address some of these issues and provide a technical foundation for an innovative design of the Learning Grid infrastructure, the first Workshop on Grid Learning Services (GLS’04) was convened on August 30, 2004 at the International Conference on Intelligent Tutoring Systems at Maceio, Brazil. This paper reports some of the ideas presented at that workshop and describes early attempts to sketch a Learning Grid infrastructure.

2 A Conceptual Framework for the Learning Grid

The concept of the Learning Grid originates in research aimed at the development of infrastructure for distributed high performance computing. Associated technologies were developed with the goal of sharing the latent calculation power of connected computers. So, the Grid appeared as a complex set of interconnected computers comparable to a virtual macro-computer (Foster and Kesselman, 1999).

Many strands have emerged with the current interest in Grid computing and a variety of approaches exist about its definition. Meanwhile, Rob Bjornson and Andrew Sherman (2004) propose a pragmatic definition, stating that Grid computing supports widespread and diverse collections of:

- CPU resources organized into a virtual supercomputer,
- Data resources organized into a virtual file system,
- Applications organized into standardized, reusable libraries of components; (virtual applications).
-

Simultaneously, the Grid enables users to:

- Collect and organize disparate, valuable, but hard-to-use resources into a more uniform, manageable, visual whole;
- Make this virtual Grid of resources accessible to multiple users simultaneously.

One of the objectives of this technology is the dynamic and secure creation of communities, or groups of coordinated individuals and institutions. The aggregation of computers representing relations between the nodes makes it possible to compare the grid to a social organizer allowing different groups to collaborate and then to form a new collaboration for common interests. The users share a set of computer resources (materials, software, data or services) distributed on a local or wide area network independent of technological choices.

With the Open Grid System Architecture (OGSA), many approaches to a Grid have been designed and many services considered (Foster et al., 2001; 2002). However several issues remain to be addressed to transform the Grid into a mirror of knowledge (Berners-Lee, 1996). Some issues relate to the Semantic Grid, the ontological grid and the identification and aggregation of autonomous communities from P2P networking.

The macro-analysis of such a structure reveals that members of the organization can be geographically dispersed, yet will reach resources for which they are authorized. So the virtual communities will only be created according to poles of interest that unite human users or software agents (Aberer, 2001). In an educational context, we observe that registration is generally the means by which one adheres to a group (be it relevant or not for what the person wishes to do) and each person must trust the hosting community. With the infinite number of virtual organizations that can exist on the grid, changes of state for a group (birth, growth, disappearance) must be considered.

The trend of current research is the transition to the Grid model network where many more computers are connected into a more complex system than Internet. Using the Grid for electronic learning can be considered a major innovation that will transform the Internet into a gigantic high-speed bus of structured data. This evolutionary new world should adapt its structure to the dynamic state of computers entering or leaving the grid. In such a system, the nature of several learning services offered by the Internet should evolve, taking into consideration the multiplicity of controls that may take place on the Grid. Therefore, appropriate learning services for the grid can be developed. The idea of grid learning services (GLS) has been introduced by a collective of researchers as part of the EleGI project objectives (Gouardères, 2004) to study all these transformations brought by the new open distributed network.

Grid Learning Services have been developed to satisfy these constraints with particular goals in mind: access and find relevant educational material, detect changes and trends in resources and services, provide pedagogical support and reflect changes in sharing knowledge. Additional learning issues must be considered especially for users who are geographically dispersed, such as cognitive overload and transactional distance.

3 Grid Learning Services at ITS2004

Many approaches have been used to develop a technological infrastructure for the Learning Grid, as shown by the Proceedings of the First Workshop on Grid Learning Services. Contributions made by participants may be classified into in three categories: i) a semantic and ontological view of the Grid; ii) agents and networking; and iii) real-world content-rich environments. This section provides a synthesis of these ideas.

3.1 A Semantic and Ontological View of the Grid

Contributions regarding the semantic and ontological aspects of the grid generally assume one of three viewpoints. The first viewpoint supports a service-oriented model of the Grid and is deeply intertwined with the use of semantic tagging, required for the recognition of and service to individual users (personalization). An example of this approach is found in Allison et al., 2004. Through identification of the features that should be provided to learners, services are compared to interactive resources which are not products. Authors recognize that semantic tagging and profiling may be difficult to design and implement in terms of machine representation.

The second viewpoint relates the vision of the Grid to semantic web technologies. An example the CoAKTinG¹ project (Bachler et al., 2004), which presented a human centered approach to e-learning. Similarities can be made with the Grid when deploying hypertext and knowledge-based tools to augment the capacities of existing collaborative mediated spaces. Additionally, the ontology is used to “exchange structure, promote enhanced process tracking and aid navigation of resources before, after, and while collaboration occurs.” Therefore, the

¹ Collaborative Advanced Knowledge Technologies in the Grid project: <http://www.aktors.org/coacting/>.

semantic grid is defined as a process of creating structured knowledge from information and the capacity to share and reuse knowledge among tools and agents in the Grid.

The third viewpoint suggests that Grid Learning can be customized to an individual learner by using semantic web techniques applied to resources, students' characteristics and content categorization along dimensions that are important to learners and teachers. The semantic Grid is also seen as a means to support user-centered, personalized, contextualized and experiential approaches (Gouardères et al., 2002). This approach defines Semantic Web as "a mesh of instructional resources linked in such a way as to be easily computable by machines on a global scale" (Woolf and Eliot, 2004).

Another feature of a semantic or ontological approach to Grid Learning includes viewing the Semantic Grid as a basis for e-learning that also augments collaboration in existing collaborative environments (Allison et al., 2004). In addition, ontologies play several prominent roles: support the exchange of instructional structure and promoting enhanced process tracking; represent domain knowledge for dissemination or retrieval (Allison et al., 2004; Lefebvre et al., 2004); and customize instruction and personalize learning services for individual students according to a learner's knowledge from an ontology based user modeling approach (Razmerita, Angehrn and Maedche, 2003). The perspectives on which ontologies have been proposed focused on the need to define a methodology for knowledge representation and modeling through adequate knowledge structures. Ontologies are the most suitable representation mechanism for achieving the semantic vision of the Grid.

3.2 Agents and networking issues

The second approach to developing technological infrastructures for the Learning Grid is to focus on the role of agents and networks. Autonomous and intelligent agents can carry out sophisticated tasks for the students: they can diagnose errors and misconceptions, propose different types of learning objects with different characteristics or train students to acquire new concepts. In multi-agent systems, different types of specialized agents can cooperate to achieve different goals (Woolf and Eliot, 2004; Roda et al., 2003). An agent has the capacity to respond to dynamic aspects of the environment thus flexibly supporting for the next generation of services on the Grid. Three possibly overlapping viewpoints have emerged from these contributions.

The first viewpoint is of a multi-agent system performing training and cognitive monitoring through a network distributed training system (ASIMIL) (Gouardères et al., 2000). A multi-agent system architecture called ASITS (Actor Specification for Intelligent Tutoring Systems) uses agents interacting separately with actors (human, intelligent agents, physical disposals) through a common stream of messages. They provide a given community of users (instructors, learners, moderators, etc.) with diagnoses, advice and help among actors in the community.

The second viewpoint is an agent representation and agent communication model based on a social approach to realize the interactive, dynamic generation of services. In this approach, two types of agents are considered: humans as Human Agents (HA) and computers as Artificial Agents (AA). The goal is to improve HA-learning (e-learning) by using AA-learning. An extension to Multi Agents System (MAS) mainly based on AA can include HA within what is called MAHAS (Multi Artificial and Human Agents Systems). The AA and HA can interact and exchange information and knowledge easily, with no constraining limitation related to the nature of an agent. The model is based on STROBE and proposes to enrich the languages of agents (Environment + Interpreter) by allowing agents to dynamically modify themselves – at run time – not only at the Data or Control level, but also at the Interpreter level (meta-level) (Jonquet and Cerri, 2004). From this point of view, a suggestion has been made to incorporate an evolutionary computation and machine learning technique into a conversation environment for the induction of communication protocols (Abdullah, Liquière and Cerri, 2004).

The third viewpoint is that of a set of agents that handle computer-grid communication through devices such as « Grid-e-Card » (Yatchou, Gouardères and Nkambou, 2004). Researchers assume that users may be brought together according to the knowledge they acquired or the objectives that they wish to attain. The method is based on management of user's electronic portfolio (e-Portfolio) as knowledge prosthesis and makes the most of e-learning qualification (e-Qualification) processes as aggregation methods to dynamically gather people in the loop, in virtual organizations by a focus on their interests. The main aspect of this contribution is the close contact with the Grid communications' protocols for peer-to-peer networking.

To conclude this discussion of issues around agents and networking, we recognize that the remaining challenges are numerous: i) The omnipresence of agents as a ubiquitous layer for dynamic services generation and deployment deals with multiple goals and assignments; ii) Cognitive environments as a structure to represent the partners in conversations embodying an agent's knowledge evolution through time require new linguistic abstractions compliant with the separation between programs and their evaluation context; and iii) The fusion of Grids and P2P networks as platforms for “novel” and “different” forms of socio-constructivist learning suggests the need for mixed communication and computation architectures.

3.3 Content-Rich Environments

The third approach to developing technological infrastructures for the Learning Grid is to focus on a real-world content-rich environments. Even though learners need to have an active and central role in the learning process, learning will not be accomplished without targeted knowledge to acquire. Therefore, services should be shaped according to teachers and learners' needs and, in some cases provide content-rich environments. Since the purpose of e-learning is to create conditions that facilitate the improvement of human knowledge and since “*no-one really knows just how we learn,*” researchers need to formalize appropriate characteristics and approaches in these structured educational environments (Allison et al., 2004). Many case studies point to the challenges of current ITS research in scaling up to real

world learning scenarios, such as supporting student construction of theories or performance of experiments. Several Learning Grid projects provide real-world content-rich environments:

- Building and using an Encyclopedia of Organic Chemistry by virtual communities communicating on the Web (project: EnCORÉ);
- Collaborative mediated spaces for distributed e-Science through the novel application of advanced knowledge technologies (CoAKTinG project);
- Enhancement of structure property correlation and prediction by increasing the amount of knowledge about materials via synthesis and analysis of large compound libraries (CombeChem project) (Bachler et al., 2004);
- Live communication with remote scientists, use of mobile sensing equipment to gather and submit local pollution data for visualization and analysis and the investigation of a remote sensing device in the Antarctic (Antarctic remote sensing project and the urban CO monitoring project) (Underwood et al., 2004);
- The e-Qualification process that contributes to the self-organization of nodes by a dynamic classification of people who enter the grid according to their need in their activity domain (Yatchou, Gouardères and Nkambou, 2004).

4 Functional Requirements for Grid Learning Resources Services

The previous section recorded research described at the ITS 04 Workshop to develop a Learning Grid infrastructures. In most cases, prototype architectures described a partial solution to the problem, focused on a single approach or single viewpoint of an infrastructure. This is appropriate as the field is at a very early stage in its research. This section provides an overview of the high level considerations and requirements of a Learning Grid and identifies functionality that should be supported. This functionality is divided into sections: pedagogical considerations and services to be provided, e.g., searching, qualification and support services.

4.1 Pedagogical Considerations

The new generation of learning services will fit into a ubiquitous and serendipitous learning vision in which computers and networks augment traditional classroom practices and act as catalysts for change in teacher practices. For example, computer-mediated learning promotes constructivist, student-centered, collaborative and inquiry activities. Constructivist teaching methods have a great potential to advance human learning, in part because they describe learning as a unique process for each individual or team, where manipulating and interpreting one's surroundings is central to learning. Yet, changing the classroom structure and organization to support collaboration or constructivist methods is very difficult. Constructivist activities are almost entirely insupportable without technology. They require extensive teacher training, are expensive in terms of teacher time, resources and labor and require concrete changes in the classroom.

Yet, student-centered methods have been shown to be very effective in the classroom. This approach places the focus on the student, not the teacher. Inquiry and social discussion

are seen as central to the development of student thinking, problem solving and inquiry skills. Apprenticeship and collaboration have been adjuncts to learning for centuries. Additionally, human learning is a social process, consequently active collaboration with other students, teachers, tutors, experts or, in general, available human peers, by using different kinds of collaboration technologies, including enhanced presence (social learning) should be considered.

As technology begins to reshape educational methods, available education resources are being redefined, permitting consideration of a wider range of teaching methods, beyond teacher-centered didactic instruction. Computer-mediated teaching is well suited to support and strongly promote constructivist teaching. It can focus attention on each student's actions and learning, support each to interpret and be engaged in construction of her own questions and help each manipulate and interpret an environment. Clearly personalization and customization have emerged as ways to improve the efficiency of computer interaction with users and to make complex systems more usable by and more supportive of the learner. Customization or 'changing something to make it just right for you' is related to learner demand, while personalization or 'changing something so that it is suitable for what a particular person wants or needs' is related to the teacher or to the system demand. Intelligent tutors on the Learning Grid can be responsive to the student's learning and dynamically modify their own reasoning about a student's presumed knowledge.

Other pedagogical considerations include rich environments, since knowledge construction occurs through direct experiences where concepts are understood from their manifestation in realistic contexts (access to real world data) and the manipulation of sophisticated software interfaces and devices. The functional specifications of a Learning Grid should be built according to users' needs as expressed by current developments on the web, on core layers designed to provide answers to requests made by any user of the system and on dissociated components from actual intelligent tutoring systems. The aim is to have closed interactions between entities, humans and computers for knowledge construction during e-learning sessions. In these activities, knowledge production is the result of interactions where humans learn from machines and vice versa. It appears that current services of the Open Grid Services Architecture (OGSA-basic) may not fit or be compliant with those of Grid Learning Services (GLS-specific).

It appears that higher level services such as those emerging from semantically rich domains should be implemented. Meanwhile, according to the needs, some authors classify services as:

- **Stateless** represented as pure functions. The advantage of easy composition of purely functional services comes at the cost that they can only weakly represent a state;
- **Conversational**, which are generic and difficult to realize within a distributed and asynchronous context.

Another long-term pedagogical goal for the Learning Grid, in addition to encouraging more constructivist and student-centered learning, is to extend teaching and learning to the under-served and those not helped by traditional education. For centuries, traditional lectures

and books have succeeded only with the top quadrille, or top fourth of students. The Learning Grid has the potential to challenge and augment traditional activities by introducing new teaching methods (simulations, multimedia, virtual reality) to support methods that can not be easily implemented in the classroom. New technology can help not only the gifted and motivated, but also the disadvantaged, financially insecure and unmotivated. Technology is already helping life-long learners—all citizens—who are daily called upon to absorb and to integrate vast amounts of knowledge (e.g. web sites) and communicate with multitudes of people (e.g. email).

4.2 Identification of services

The variety of pedagogical considerations described above argues for the provision of a wealth of Grid services in the Learning Grid. Some of the required services are described in this section and illustrated in Fig. 1.

Collaboration services: collaboration is a complex conversational process that goes far beyond a simple information exchange. To support such a “ubiquitous conversational process,” one must consider the social context where the learning process occurs. Accordingly we do not consider the learner’s ability in an abstract way, but relate it to a specific situation or context. Collaboration implies community membership, working together, providing added value, sharing and executing tasks in order to reach a common goal. Learning is no longer an isolated activity – it implies mutual trust, shared interests, common goals, commitments, obligations, exchanging of services, a genuinely proactive, motivated behaviour (Allison et al., 2004). Some collaboration tools have been proposed, e.g., I-X Process Panels whose function is to aid in processes that create or modify one or more “products” (such as a document, or other physical entity).

Communication services: based on basic services offered by the OGSA, or on specific tools to be built: e.g., i) BuddySpace an Instant Messaging environment (based on the Jabber protocol), ii) Compendium as an approach to aid cross-functional business process redesign (BPR), creating shared understanding between the team members (searchable group memory) (Bachler et al., 2004).

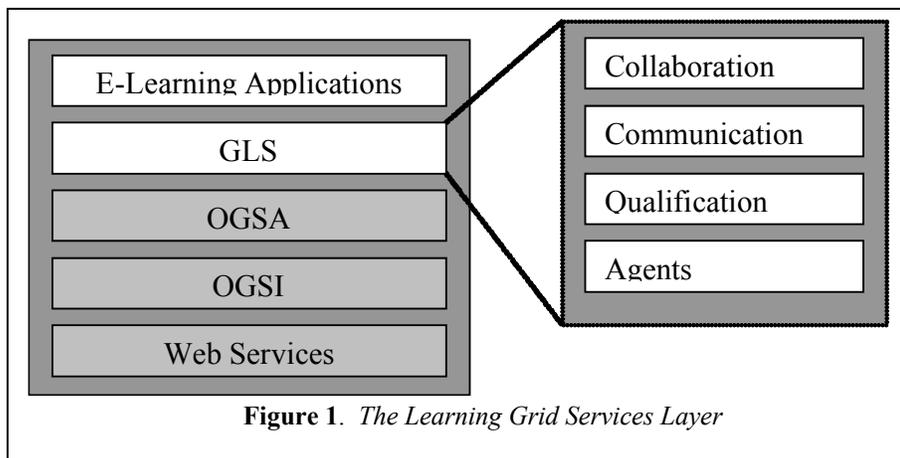


Figure 1. *The Learning Grid Services Layer*

Customization services: to develop creditable curriculum for each student. It will suggest alternative learning approaches, negotiate customized lessons, construct materials to be presented and will automatically streamline the search, customization and assembly of educational resources. The approach is to automatically generate metadata from encoded descriptions of instructional resources, structure and classify student needs and generate lessons. All is based on learner models and electronic vita for each student (respecting privacy requirements) and uses metadata and ontology for knowledge manipulation and intelligent course tailoring.

Personalization services: to adapt services to different types of users with different backgrounds and needs. These services will rely on the cooperation of different distributed, autonomous, goal-oriented entities based on ontological and user modeling techniques.

Support services: to help the student when he/she has a general problem related to the system. This should not be confused with assistance, which is related to a learning process.

Learning styles services: to take into account the way a student may like to acquire knowledge from the system.

Searching services: to help teachers and learners locate appropriate resources.

Security services: to identify and authenticate all the users and also to protect the system from any hacking attack that may cause problems such as denied services.

Qualification services: i) to compare the pedagogical value of educational resources; qualify a resource for a curriculum; ii) to assess the quality of resources according to parameters like user comment and rating (large review), iii) to diagnose student capabilities (Vassileva et al., 1999). To support this feature, we think that e-Qualification as a gatekeeper will assume management of the quality of services (QoS). To take this aspect into consideration, actual indexation should not only consider meta-data that focus on the demographics of the resource (e.g., author, student age, grade, media type) but also those important to teachers and learners such as social characteristics (gender, main language, ethnicity), cognitive characteristics (cognitive development, spatial ability, math fact retrieval speed), reading level or affective characteristics (self-efficacy, motivation, beliefs, attitudes towards the subject) to name a few.

Clearly the wide variety of required services argues for a form of ‘Service Abstraction.’ Thus, several low level services might be combined to a single higher level service. A large number of required services will not enable them all to be considered properly. Some may be grouped in a layer as tasks for a general process, e.g., e-Qualification may have many tasks for qualification.

5 Conclusion

This paper has presented several perspectives on the new field of Grid Learning Services (GLS), focusing first on the research of participants at the ITS 2004 workshop and then looking at the functional requirements of a Learning Grid with a view towards how future networked learning will be supported. The GLS workshop suggests several issues, including:

- Evolution and the maintenance of ontologies used in GLS for exchange, communication and personalization.
- Omnipresence of agents as a universal substrate for the generation and the deployment of dynamic services for the user.
- Cognitive environment as a structure to represent the peer-to-peer matchmaking in the conversations corresponding to the evolution of the agents' knowledge during their evolution in time.
- Combination of services that will allow the generation of "on-demand" services.

The GLS workshop brought answers to two important question types: i) techno-centered questions linked to the 'intelligence of the services,' by considering the 'Semantics' in the description, the discovery, the selection and the composition of services, and ii) the personalization-centered questions that asks] how to achieve greater personalized adaptation of these services to the users.

Another question that appeared from the discussion relates to the assessment that the "Peer-To-Peer" Grid has preserved a structured and unstructured duality for dialogues, which allows a system to take into account the emergent global phenomena resulting from local interactions between virtual and human actors. Consequently, we have the opportunity to learn about knowledge if we can dynamically build some "Peer-To-Peer" exchange protocols from the users' expectations and behaviors.

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