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Integrating Collaboratories in e-Learning: Opportunities and Challenges

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Abstract: Collaboratories and e-learning are two forms of on-line academics that have many features in common. Nevertheless, in the last decades, they have experienced two completely different paths. Nowadays, e-learning is an established, well-adopted paradigm, enabling thousands students achieve distance education from almost every country in the world. Conversely, only a few of collaboratories have been successful in accomplishing their scientific objectives. Most of the collaboratories initiated in the last twenty years have either been discontinued, or they still result in poor performance (e.g., productivity, quality, and innovation) due to major technological and participation challenges.

Despite their current issues, collaboratories can play a crucial role in the international e-research infrastructure: besides reducing costs and helping scientists access physical resources located in remote laboratories, they enable the creation of a truly multidisciplinary environment in which researchers can integrate their competences, learn from one another, and advance scientific research within a marketplace for open, mutual exchange of intellectual capital. Moreover, the inherent complementariness of e-learning and collaboratories suggests that distance learning courses can be integrated with virtual research laboratories. This would enrich the offer of on-line universities. Also, it would enable the creation of a complete, interconnected, virtual academic system.

The aim of this paper is assisting the design and uptake of online collaboratories as an enhancement of e-learning. Thus, we discuss the opportunities and the challenges of integrating collaboratories in e-learning. First, we review the taxonomy of collaboratories and we differentiate their features. We describe the issues that impact on user adoption. Finally, we identify potential patterns of integration.

Introduction

Collaboratories and e-learning are two forms of on-line academics that have been explored for nearly twenty years. In the last decades, there has been an increasingly number of opportunities for distance learning, whether in forms of individual webinars, on-line workshops, open courseware, or in a more comprehensive and structured fashion, such as in the case of formal e-learning programs. They have enriched traditional education and they provide students and teachers with extensive and innovative opportunities for interaction and collaboration.

Simultaneously, the development of technology for Computer-Supported Collaborative Work (CSCW) has enabled the creation of collaboratories, that is, virtual research environments in which remotely-located researchers can work together and share knowledge, equipment in facilities, best practices, and data [2]. This, in turn, is meant to foster novel forms of virtual collaboration between international research institutes and professionals. Moreover, collaboratories might be the ideal platform for discussing models and paradigms for scientific research, and they might serve as test-beds for identifying the most effective practices.

Although the concepts of collaboratory and e-learning have been conceived in the same period, in the last twenty years, they have experienced two completely different paths in terms of technological development, market interest and growth, performance, and user adoption. Specifically, e-learning has shown a continuously increasing trend, and it is collecting success stories worldwide. Conversely, collaboratories still face major issues that in many cases overcome their benefits and introduce significant overhead. As a consequence, collaboratories, which were announced a fast growing market, still are an emerging field. Also, the feasibility of increasing the performance of scientific research through virtual collaboration needs to be proven by actual data.

Both collaboratories and e-learning systems consist of an elaborate collection of information and communication technologies having similar purposes, and they share several common features and patterns. Nevertheless, they have differences that render their models unique, in terms of social processes (e.g., roles, guidance), tools for communication and collaboration (e.g., platforms), and principles and rules (e.g., access, objectives, and norms).

In this paper, we review the concept of collaboratory and its history over the years. Then, we detail its taxonomy, and we analyse the characteristics of the ecosystem of virtual research. By highlighting the different aspects of operation of collaboratories and their social dynamics, we indicate the main challenges to the implementation of collaboratories, and we identify their best practices. Finally, we describe how it is possible to improve educational outcome and the performance of scientific research by integrating the model of collaboratories into e-learning programs offered by universities.

Collaboratories: the rise and fall

The term collaboratory first appeared in 1989, when Wulf [1] envisioned it as a centre without walls, in which researchers can perform their work without regard to physical location, interacting with colleagues, accessing both actual instrumentation and information in digital libraries, sharing data and computational resources. One of the first successful implementations of the concept is the Collaboratory on Information Infrastructure, established in December 1993 by Bell Communications Research [5].

Collaboratories are more than online extensions to the conventional way of doing research, as e-learning is more than on-line training. Collaboratories are complex sociotechnical solutions that enable collaboration among scholars who generally are remotely-located. Their objective varies from sharing resources in the form of data and tools, to gathering people (e.g., researchers), competences and skills. The infrastructure of collaboratories (see Figure 1) connects three domains: people, information and facilities. This is a far more complex model than e-learning. Specifically, each domain contains mixed components of virtual communication and in-person collaboration, tangible instrumentation and distributed software, actual samples and data analysis based on grid computing. Thus, Information and Communication Technology plays a crucial role in supporting hybrid, rich and recurring interaction between individuals, data, and equipment. One example of the presence of loops between virtual and real processes occurring within collaboratories is the recruitment of the so-called ―virtual experimental subjects‖, who can be contacted using web-based tools, treated in the actual facilities of a research institute, and analysed in collaboration with remotely located scientists using distributed computing tools. However, loops increase the complexity of the system and they introduce many obstacles to achieving their goal. This is among the many reasons why collaboratories have failed their objective, in the last thirty years.

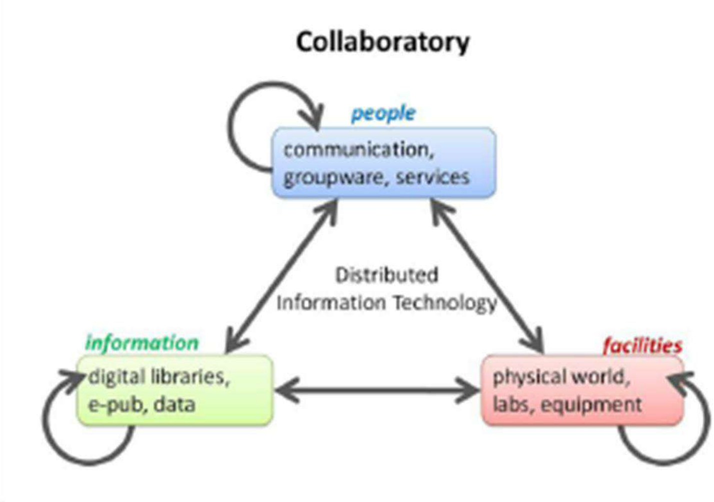

Figure 1: Model of a collaboratory

Figure 2 represents the evolution of collaboratories over the last 40 years, as from data collected by the Science of Collaboratories (SOC) initiative [4], sponsored by the National Research Foundation (NSF). The trend shows an increasing interest in the years from 1990-2001. This is consistent with data about e-learning. However, from 2001 on, many collaboratories have been discontinued, and the interest has progressively dropped. Conversely, the e-learning market is continuously growing, though it was by the Internet bubble, as well. However, there still is a large demand for collaboratories.

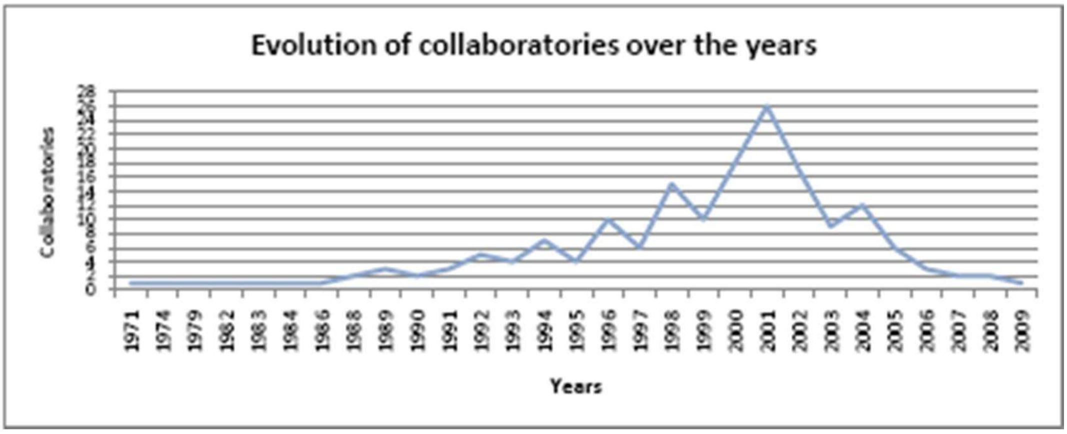

Figure 2: Evolution of collaboratories over the years

Bos et al. [3] explored why scientific collaborations are difficult to sustain on a virtual communication basis and they studied why efforts to establish a large scale communities have failed. After analysing 75 collaboratories, they suggested that collaboratories have not succeeded in crossing the chasm between the early adopters and the majority of people in the technology adoption lifecycle. In fact, scientific users inherently are innovators. Conversely, when it comes to applying the paradigm to a broader audience, infrastructures for distance collaboration show their weaknesses. To cope with this, it is necessary to analyse the heterogeneity of collaboratories, in order to address issues and benefits for e-learning, as well.

Taxonomy of collaboratories

The taxonomy of collaboratories is very different from that of Learning Management Systems (LMSs). Usually, collaboratories can be divided into two broad categories: resource-oriented (ROC) and activity-driven (ADC). Both are based on the concept of sharing. However, ROCs are based on objects. Conversely, ADCs involve sharing actual work. Within the former class, there are Community Data Systems (CDS), Shared Instrument Communities (SIC), and Community Infrastructure Development Programs (CIDP). Activity-driven collaboratories have a more networked organizational form, and they comprise Distributed Research Centers (DRC), Virtual Communities of Practice (VCP), and Open Community Contribution Systems (OCCS), which are accessed and contributed in a more participative fashion. Figure 3 shows a classification of collaboratories with respect to their classes and to their characteristics.

Resource-oriented	Activity-driven	Characteristics
CIDP	VCP	• low human involvement • high virtualization • asynchronous communication processes
CDS	OCCS	• medium human involvement • medium virtualization • focused on projects
SIC	DRC	• high human involvement • low virtualization • use of physical resources • synchronous communication processes

Figure 3: Classification of collaboratories

Collaboratories are almost equally divided among activity-driven (53%) and resource-oriented (43%). Figure 4 and Table 1 summarize the actual distribution of collaboratories among their main categories, as from data collected by the SOC initiative [4]. Low-involvement and medium-involvement collaboratories account for 30% and 28% of the total, respectively. In the largest class, there might be a bias effect caused by many institutions that consider their departments DRCs as soon as they have Internet connection. In general, low-involvement laboratories are easier to create and to maintain. On the contrary, the more physical resources are involved (e.g., instruments, facilities), the more complicated it is to implement successful collaboratories.

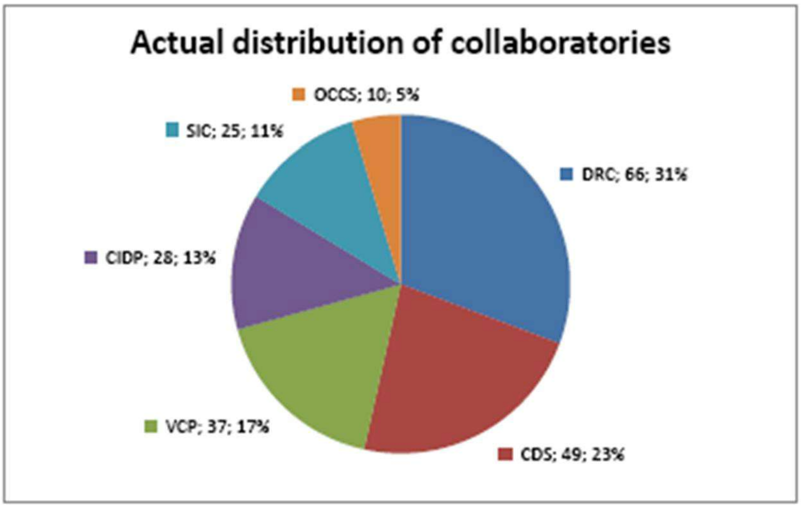

Figure 4: Actual distribution of collaboratories

Resource-oriented collaboratories

Resource-oriented collaboratories have the purpose of aggregating and exposing some type of resource, such as tools, collections of data, and documents. Basically, ROCs involve collaborative collection and use of existing value. Resources have a certain degree of persistency. Thus, after being organized and shared, it is always possible to add to the collaboratory, whether in the form of updated version, increased dataset or equipment upgrade. Usually, this is done in a mostly asynchronous fashion.

Shared Instrument Communities (SICs) have the purpose of increasing remote access to expensive scientific instruments. This requires options for remotely controlling the instrument, *in loco* supervision, simple access to output information, and resource scheduling.

Community Data Systems (CDSs) are information resources that are created, maintained, or improved by a geographically-distributed community [3]. CDSs are mainly characterized by large audience and by specific policies that grant access to information and privileges to use it.

Community Infrastructure Development Programs (CIDPs) are interdisciplinary initiatives that involve professionals from multiple domains, research laboratories, universities, companies, and the government. They have the aim of developing the necessary infrastructure (e.g., software, instruments, methods, and protocols) for facilitating and improving scientific work in a particular domain.

Activity driven collaboratories

Activity driven collaboratories have a more networked organizational form, and they involve non-persistent activities for the creation of new value in a semi-synchronous fashion.

Distributed Research Centers (DRCs) are actual laboratories and research centres, working remotely. They can connect interdepartmental centres belonging to the same university, or they can aggregate different institutions and companies. Usually, they go beyond the interest of individual researchers, and they specifically focus on long-term joint collaboration.

Open Community Contribution Systems (OCCSs) are projects that aggregate many remotely-located individuals toward a common research problem with contribution coming in the form of work rather than data [3]. Usually, activities are open to the general public, who are free to participate to achieving the goal.

Virtual Communities of Practices (VCPs) mainly have communication purposes and they do not realize any actual research activity. The goal of VCPs is discussing specific topics of professional interest and sharing best practices, resources, techniques, and contacts. They involve the largest audience, and they often provide learning resources to increase the knowledge of participants. Thus, they are the extension of Virtual Learning Communities (VLCs).

Opportunities and challenges for e-learning

In addition to reducing costs and to implementing a comprehensive on-line academic system, the fusion of e-learning and collaboratories has the potential to dramatically enhance the performances of both learners and scientists. Indeed, e-learning lacks the opportunity of accessing real-life case studies, laboratory equipment, and experience in activities typical of higher instruction (e.g., writing research papers, analyzing actual samples, and working on chunks of complex projects). Currently, distance students work on simulated situations, and they interact with computer-based models and in virtual reality environments. Conversely, collaboratories can reinforce the typical experiential ―learning by doing‖ paradigm [7]. Situating learning in social interactions and collaborations was proven to be effective in engaging students and in helping them to achieve greater learning performance.

Simultaneously, collaboratories can benefit from standards and best practices that already are mature in the domain of e-learning. Also, they can leverage the user base of distance learning systems to validate assumptions, to fine-tune patterns, to enlarge their work force and even to find experimental subjects. In this regard, in [8], the authors describe how the Internet can be utilized as an alternative source of the so-called ―virtual subjects‖.

There is no particular domain in which the integration of collaboratories and e-learning would result in less effective systems: examples in the literature [4] [9] describe opportunities in almost all fields, ranging from nursing to engineering, from psychology to physics. Therefore, the convolution between collaboratories and e-learning has to happen regardless of the domain, in a structured, general framework beyond institutional, technological, cultural, and social boundaries. Three major steps toward realizing the potential of a comprehensive on-line academic system are the following:

1. understanding similarities and differences between collaboratories and LMSs;
2. identifying weaknesses, potential factors of failure, and beneficial technology;
3. defining a strategic roadmap to their integration.

LMSs and collaboratories: similarities and differences

E-learning captures several aspects of collaboratories. Specifically, there is a similarity between resource-oriented collaboratories and distance education programs based on centralized repositories of learning objects. Both enable advancing knowledge through the consumption of shared material. On the contrary, activity-driven collaboratories have the features of the exploratory process typical of group work and direct experience.

Nevertheless, there are many attributes of collaboratories that do not apply to e-learning. In general, the main difference between cooperative e-learning and resource-oriented collaboratories is in the way in which knowledge is exchanged. In the former, learning materials are mainly accessed by students, who do not actively contribute to the repository.

Thus, in e-learning there is less of a resource-aggregation function, and interaction occurs in an opportunistic fashion. Furthermore, one of the main characteristics of activity-driven collaboratories is the consistency of the work over the long-term period. This is among the reasons why virtual conferences are not included in the category of collaboratories: their sporadic nature characterizes them in a different class, which is beyond the scope of this paper. Usually, collaboration between distance learners is guided by the instruction manager who assigns a set of small, independent tasks to each student. They, in turn, have an individual goal. Although this can be pursued with the help of the others, the nature of the activity is merely opportunistic. Conversely, in collaboratories, researchers contribute their knowledge to achieve common objectives. Moreover, although collaborative e-learning involves peer collaboration, there is an authority, the instruction manager, who guides the activity. Conversely, in collaboratories, researchers have equal importance in the decision making process. As a result, there is high chance of drifting from the objective (e.g., delay in submitting deliverables).

Potential factors of failure and benefits technological diversity

In general, e-learning platforms are more technologically robust than systems supporting collaboratories. In this regard, the latter are still in their early-stage phase: data repositories, instruments indexes, project management systems, and communication tools have to be integrated into a unique and sound framework. In the past decades, one of the main obstacles to the success of collaboratories has been the lack of usability of communication tools in terms of user engagement, ability to reproduce discussions. Although there have been tools for and for transmitting audio, video and complex data streams, technology has been missing the most basic need: simple albeit effective communication dynamics. On the contrary, technology is now ready to support novel interaction paradigms and new ways of communication between researchers as well as between learners and teachers. One of the main reason of the discrepancy in the evolution of platforms for collaboratories is the inherent fragmentation of universities at a cross-institutional level (e.g., lack of communication, different objectives, domains of prevalence), which prevents from giving a clear dimension to the market.

Among the potential factors of failure, there is the criticality of the domain of scientific knowledge, which requires validation by experts. Also, it is in continuous evolution and it changes rapidly. Current technologies for knowledge management are not ready for representing, managing and disseminating such entropy. Conversely, Learning Management Systems are suitable for structuring peer-to-peer group work and student-teacher interaction. Therefore, they can be utilized to start the discussion on methods for working towards common goals. However, contamination with the scientific domain brings issues, such as tacit knowledge, the diversity of skills and capacities, and individuals' approach to self-guided, hard work. These elements have a significant impact in differentiating formal and informal learning,

and they could be understood in a more deep fashion through the analysis of long-term work, such as that of scientific research.

Cloud computing is a great opportunity for resource-oriented collaboratories, as information can be uploaded and exchanged in an agile, reliable, scalable and cost-effective fashion. Also, this could alleviate the requirement for universities to locally allocate servers to store data. However, this requires multiple departments, laboratories and research centres to agree on a collaboration policy that quantifies the value of the data being contributed and exchanged.

E-learning systems are being integrated with social networking platforms, which in turn, can also increase the ability of researchers to connect to one another, to establish new contacts, and to explore collaboration opportunities. However, the majority of research labs, spin-offs, and university departments are off-line, they still rely on traditional forms of network presence or they show outdated information. Social networks can increase connectivity and they can ease communication. However, they have to be integrated with tools that enable research laboratories to expose and to access instruments and data.

As a consequence, VLs are implemented by researchers, research laboratories or departments, at an individual basis. Thus, as a whole, in many cases they are dispersed, redundant, expensive to maintain and almost impossible to interoperate. In this regard, when defining a roadmap to integration, the heterogeneity of collaboratories with respect to LMS requires considering each of the classes separately.

Strategic roadmap to integration

Integration between collaboratories and e-learning involves many different stakeholders, and it requires several complex steps to be realized in order to take place and to be effective. Also, it is a long, high-risk process that can be successful only if the Return on Investment is clearly defined for each of the participants. A tentative roadmap to integration is shown in Figure 5.

Resource-oriented collaboratories have to be targeted first. Then, activity-driven collaboratories can be incorporated in the process. The second stage is far more complex than the first one because, as discussed earlier in this paper, aggregating resources is less critical than co-creating value. Also, the majority of the

activities are inherently non-persistent. Thus, they need tools that enable to define their output and to make it valuable over the long term.
As a first step, universities, research centers and laboratories have to increase their presence on the Internet, and they have to establish networks at the national and international levels. They can start as small, interdisciplinary working groups for defining collaboration policies and patterns. Then, broader Community Infrastructure Development Programs have to be established to initiate the discussion about shared protocols, and to move forward the development of standards. One of the first purposes of Community Infrastructure Development programs is defining a unique operating model.

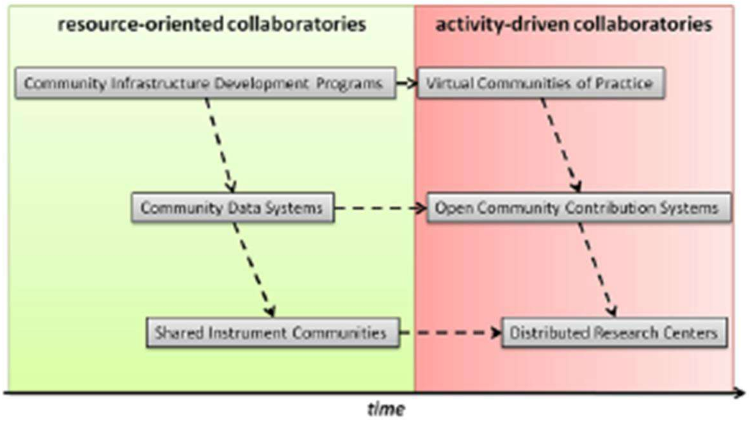

Figure 5: Roadmap to integration of collaboratories

The history of the Sharable Content Object Reference Model (SCORM) [7] is an example of successful large-scale implementation of effective methodologies. As the SCORM, a model for integrating collaboratories and e-learning would require some versioning system, so that users can access resources in a standard way. On top of this, it is necessary to develop an interaction language for defining and accessing resources, whether in the form of data, or tools, exactly as implemented in SCORM.
Subsequently, a shared set of tools has to be defined. As a part of this stage, a centralized resource management system has to be designed and developed, to alleviate individual stakeholders from the overhead of realizing their own tools, to avoid fragmentation, and to prevent every single research centre realize their own attempt of exchanging data and instrument in a way that is completely different from that of other collaboratories. As a consequence, Community Data Systems (CDSs) will be able to aggregate data in a universally reusable fashion. Among the critical items to be defined in the model there are the policies for accessing and sharing resources. In regard to the latter, it is necessary to guarantee that information is formatted using an appropriate data format, designed for interoperability, that is, ontologies and standards for tags and annotation have to be devised. As far as access is concerned, there basically are three main policies: free access, pay-per-use, or restricted access. Moreover, research centres can agree on a credit system so that the more the data they upload and share, the more they can download and use. Sharing datasets would enable the validation of scientific experiments and it would improve the overall quality of publications. Digital libraries play an important role in the creation of CDSs.
Simultaneously, an inventory of actual equipment has to be realized. Shared Instruments laboratories can be utilized by universities offering distance learning courses to provide students with hands-on experience. The commercial success of e-learning programs teaches that enabling access to resources in a Shared Instrument Community (SIC) can increase the revenues of research laboratories. This can be especially suitable for the current situation of economic downturn, when governments are cutting budget of Universities.

The main barrier to sharing instruments is the allocation of resources. Thus, in addition to the syntax for sharing and accessing resources, it is necessary to develop a language for describing, exposing, and controlling equipment. The syntax and the semantics for laboratory instruments have the purpose of enabling communication between tools and data, both in input and in output. Even if a technician is required to operate the instrument, a formal language can be utilized to model its behaviour. In addition to avoiding inconsistency and incongruence, it can wrap the actual equipment to render interaction completely transparent to the user, who simply accesses laboratory tools through standard operating procedures. As a result, after tools are allocated, they can be remotely controlled using a simplified, declarative language. Graphic languages and diagrams can be utilized to simplify interaction depending on users' familiarity with research (student or researcher). Thus, besides lowering the cost of scientific research, defining a formal language would enable using real tools on real data, even in laboratories of e-learning courses. Indeed, languages would be part of the model, and procedures themselves would be incorporated and shared as resources in repositories. Moreover, this would enable the creation of an archive of snippets where each procedure is an experiment, so that researchers can reproduce the same experimental conditions over multiple datasets, over the time. As result, scientific tests could be executed by simply loading a set of procedures and by applying it to a dataset. This, in turn, has two benefits. First, students can learn the fundamental steps for running an experiment and for using a piece of equipment.

After defining criteria and patterns for sharing resources (that is, Community Infrastructure Development Programs) in the form of processes, data, and instruments, it is possible to aggregate communities each specialized in methods, topics, practices, research interests, and learning paradigms. Virtual Communities of Practices can be established as an extension of scientific communities, working groups, thematic conferences, and workshops. Also, communities can grow following experts and domain specialists.

The next step is the implementation of Open Community Contribution Systems, which are more complicated than VCPs, because they involve actual work. This, in turn, is connected to a set of other issues. The property of data and tools can be easily identified and managed. On the contrary, the property of work, knowledge and intellectual capital is harder to define, to capture, and to quantify. In the last decades, OCCSs have been implemented as code sharing platforms (primarily for open source software) and repositories. Sporadically, project management systems have been utilized to organize volunteer work. Instead, they have to evolve into workflow management systems based on knowledge. The radical step in this is to move from a paradigm based on volunteering to a system in which participants are partners, and they act as co-workers. Consequently, they have to accept tasks and deadlines, and they have to show commitment. Simultaneously, OCCSs have to include genuine volunteers and individuals who are willing to dedicate their effort to research. However, their tasks have to be micromanaged, and they must not be critical for the project. Alternatively, there can be some form of compensation that enables them to be formally included in the process.

As the process is developed, and work becomes more structured, the last step is the transition from an open contribution model based on the interests of individual researchers, to an institutional approach to science and research. Distributed Research Centers are the eventual endpoint and the last step of this process. In DRC, group dynamics, the business of data and tools, best practices and workflow management are integrated in a framework for delivering high quality research and education.

Conclusion

As a large number of universities are activating e-learning courses and several of them are completely switching to an on-line system, there will be an increasing need of tools, platforms, and models for helping students collaborate beyond group projects. In addition, universities offering e-learning should include collaboratories in their program to provide students with comprehensive academic-wise training. Specifically, both traditional and virtual universities can benefit from the integration of collaboratories in their research models, in order to foster international collaboration between scholars, to improve the utilization of resources, and to increase the quality of scientific research in a cost-effective fashion.

Collaboratories have the potential of becoming fundamental components in the national/international e-research infrastructure, and they can be integrated in e-learning. One of the main difficulties has regarded the way information has to be shared among many distributed laboratories. This is a two-fold problem: on the one hand, there is the need of a centralized storage system in which data are categorized, classified, organized. In this regard, the cloud computing paradigm will support new solutions for collecting data. On the other hand, there is the need of defining the boundaries of the Community and the policies for sharing and for accessing data. This is a far more sophisticated item, because it involves political issues. Indeed, requires universities to have specific rules for cross-institutional collaboration, especially regarding intellectual property, publication rights and authorship. To this end, there is a need of implementing a constant dialogue in a top-down fashion, to overcome the sparse current patterns of collaboration between individual researchers. Social networks already support Learning Management Systems in facilitating the dialogue between peer students, and reporting to their instructor.

The history of SCORM can be utilized as a model for the transition from unstructured, volunteer-based research in resource-oriented collaboratories, such as Community Data Systems, Shared Instrument Communities, and Community Infrastructure Development Programs, and in activity-driven collaboratories, that is, Distributed Research Centers, Virtual Communities of Practice, and Open Community Contribution Systems. Also, SCORM can be the starting point for integrating collaboratories and their resources into Learning and Research Management Systems.

However, the integration process requires investments, political will, and time. Technology adoption must include a period for migrating data, for interfacing equipment, and for collaboration agreements, in addition to the time necessary to get acquainted with a new, virtually enhanced (instead of virtually refurbished), academic system.

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