Grid Technologies for Virtual Laboratories in Engineering Education

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Abstract—**In this paper, Grid technologies are introduced to build e-Learning environments for engineering education. Service-oriented Grids open new fields of applications, the Learning Grids. The learning services concept based on a learning model and their deployment through Grid technologies are excellent means to integrate virtual laboratories into e-Learning environments for engineering education. The paper goes into the most important technical details, introduces into the used learning model, and shows the authoring of Grid resources for virtual laboratories. Examples from a virtual laboratory demonstrate the advantages of a Grid.**

Index Terms—**Engineering education, Learning systems, Simulation, Virtual reality.**

I. INTRODUCTION

The current generation of electronic learning (e-Learning) solutions has adopted the rather narrow pedagogic paradigm of information transfer, which features the teacher as someone who selects particular pieces of information and makes them available to students on the Web. However, there is no evidence that this approach to technology enhanced learning is in anyway effective. It has been adopted simply because it is an easy way to use the Web's facilities.

Remote or virtual laboratories with real or simulated experiments are becoming accepted in the engineering community for providing distance education and for augmenting traditional laboratories. Students have to modify instruments for a better understanding of the principle on which the plant operates. They even have to set their own conditions. From a pedagogical point of view, in this kind of environments the student has an active and central role in the learning process. Learning activities are inherently aimed at aiding the construction of knowledge and skills in the student, rather than the memorisation of information.

In keeping the student at the centre of the learning process, personalisation and individualisation become relevant aspects to be supported by technologies through the creation of the right context. The students can learn through direct experiences. So, the question remains – how do we provide better means for e-Learning environments combined with virtual laboratories while maintaining or improving the quality of learning by new information and communication technologies. A Learning Grid can contribute to the achievement of these objectives through the definition of the learning services concept and their deployment through Grid technologies.

Section II of this article introduces into the term Grid by presenting a general concept of Grid computing associated with its problems and the current state of technology and main standards. It describes the transition from the computational Grid towards the service-oriented Grid and the changes both in architecture and in philosophy. Then in Section III advantages of using Grid technologies in educational applications are discussed in detail. In Section IV an existing virtual control laboratory as an example of a Grid-based virtual laboratory environment and the learning model behind it are described and discussed in detail. Section V shows the Grid resources necessary to implement a virtual laboratory and Section VI deals with the authoring necessary to build learning units with embedded experiments. Finally, collaborative experimenting in a virtual laboratory is discussed. The article closes with Section VII summarising technologies and their potential influence on education.

II. WHAT IS THE GRID?

Historically the term Grid has been used describing a worldwide communication infrastructure for clustered computers that allows seamless transparent access to data and computing power on demand in order to solve large-scale computational problems. Such computing Grids cost a fraction of what a supercomputer costs. They are commonly known from engineering, science and commerce. Grid is also a new paradigm for the information technology. The well known World Wide Web will be succeeded by the upcoming World Wide Grid. The futurologists are promising that it will be possible to get large IT-resources "from a plug in the wall" without the necessity to know who provides the resources and where the resources are coming from. Nowadays such service-oriented Grids find applications in quite new areas not previously considered as the environments for a Grid. An example of such a new area is education. This is the topic mainly addressed in this article.

A. Grid basics

From a general point of view, a Grid is considered as a collection of clustered computational machines, the nodes. In order to have a powerful supercomputer by a Grid the computational problem has to be split into slices and assigned to these nodes. Each node processes its slice individually and after the completion of its slice the results are put back together. Grid nodes do not need to be placed in one geographic location; moreover, machines collaborating in the Grid may have different architectures and operating systems. It is obvious that these nodes need to communicate with each other based on some standards. Therefore a vital topic of security is involved for the interchange of data between nodes. Depending on the application the data should be kept confidential and protected from undesired external changes. Also other issues must be addressed, e.g. redundancy of nodes, quality of service and scalability.

A Grid shows some limitations and has to fulfil some requirements. The Grid is applicable only for tasks that can be easily split into smaller slices and that do not require the characteristics of a real-time challenge. In order to reduce the complexity of a Grid, a special layer is introduced that is for gluing the nodes on a logical level. This layer of software sandwiched between the operating system and the applications is commonly called middleware. Its spectrum ranges from execution environments responsible for the management of processes on nodes, to full development environments. What traditional Grids lack, are the standards on that they are built. In most cases when considering computational Grids, the methods of communication, the level of integrity between nodes and the architectures are each specially designed for a particular project.

B. *Service oriented Grid*

During recent years a new approach for building Grids has emerged. Instead of perceiving the Grid nodes only as computational elements of an infrastructure they became providers of services [1]. This shift, from strict computational capabilities to service suppliers, opens new fields of applications for Grids. The nodes, instead of only delivering their computational and storage capacity, are now regarded as providers of particular services. They may be parts of some code existing in multiple instances allowing the parallelization of the execution of an application. The nodes may offer individual services best suited to their own capabilities. Moreover, services developed for the usage in one application or Grid may be reused in new applications. The service-oriented approach has additional advantages. It introduces well-defined standards, allows the creation of searchable catalogues of services. Further details are described in Section II-C.

This new Grid philosophy allows perceiving it in analogy to the commonly known concept of power grids, where the consumer is not aware where and how the power is exactly produced. The consumer only receives the final product with a defined quality. In case of a pure computational Grid, the client receives the computational power not knowing where it comes from and what the resources are. But this power is limited to particular clients. When it comes to a service-oriented grid, the user receives the functionality he needs with the desired quality of service.

Fig. 1 presents basic interactions between elements of a

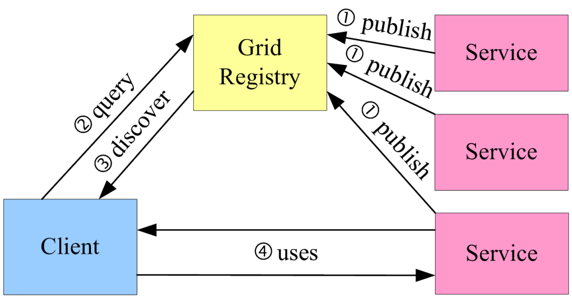

Figure 1. Structure of a service-oriented Grid environment

service-oriented Grid. Services published into a Grid Registry are queried and when discovered then instantiated depending on the user request. Mainly for sake of efficiency the client's communication with the service is direct but may also be virtualized.

C. *Technology and standards*

The realization of service-oriented Grids needs clear standards to have that interoperability of Grid elements and their reuse in other applications. The two main organizations involved in standardization of Grid technologies are the Global Grid Forum (GGF) [2] favouring the family of the Open Grid Services Architecture (OGSA) [3] standards and to some degree the competing Organization for the Advancement of Structured Information Standards (OASIS) [4] promoting the Web Services – Resource Framework (WSRF) [5] standards. Both organizations adopt the currently widely recognized Web Services and their extensions as their building blocks. These families of standards differ in the depth of the middleware integration, in the choice of the platform and in the programmatic languages of the implementation. But their general approach towards the Grid is the same.

The main functionalities delivered by the middleware of a service-oriented Grid are:

Location – allows the determination, whether the required service exists and at which locations it is accessible

Instantiation – allows the instantiation of the service on that host, which matches the capabilities required for the service running with a given quality of service.

Orchestration – allows the dynamical composition of more complex services.

In the example shown later, the middleware called GrASP [6] is used, which was developed in an EU funded project. It follows the OASIS recommendations based on the implementation of the WSRF called WSRF.NET, which uses Microsoft's .NET Framework as the implementation environment [7].

III. LEARNING GRIDS

Grids yield significant benefits to applications. The question to be answered here is what advantages may yield a Grid particularly to educational systems.

A. *Learning Objects (LOs) in a Grid environment*

In the concept of using LOs the learning content is split into reusable elements. These elements are used to build complex learning resources. In the world of service-oriented Grids the LOs are becoming fully functional services with their own user interface. They are independently interoperable blocks, which may be used as they are, or, moreover, are reused to build new more complex blocks using other Grid services, e.g. orchestration. LOs themselves can be nested. For illustration consider the complex LO example from Fig. 2. Delivering a nested LO for an experiment several components are necessary and each of them is implemented as a separate LO. The required components would be: the LO rendering the experiment environment, the LO displaying an Excel worksheet for evaluating results and a scope LO displaying the experiment signal histories. These components would be embedded into another LO, therefore constituting a new composed unit called e.g.: Experimenting 1, which itself could be nested in a more general LO. Due to the well-

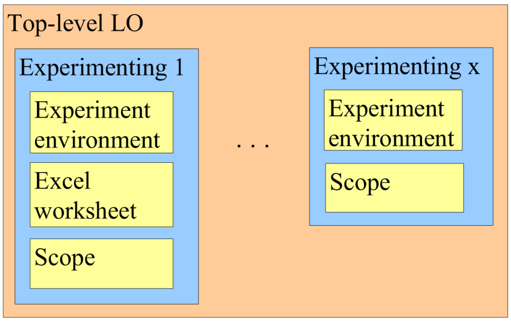

Figure 2. Example showing an arbitrary nesting of LOs

defined Grid standards, the learning courses can be built from LOs delivered by different Grid services. The Grid techniques offer the capabilities of cataloguing and easy managing LOs by using metadata. Metadata for describing LOs and ontologies for the semantic modelling of the learning domain can be used to build and execute distributed learning applications on a Learning Grid.

B. *Collaboration and communities*

The use of a common platform allows a better collaboration, both in sense of interpersonal communication for collaborative learning, as well as collaboration between applications existing within the Grid. A Learning Grid is a natural environment for its participants to create virtual learning communities. All participants belong to the same community of Grid users sharing the same tools, creating and sustaining professional relationships through time.

C. *Scalability*

An outstanding advantage of a Learning Grid environment is the approximately linear scalability inherited from its predecessor, the computing Grid. When the number of students enrolled to a particular course gets larger, more instances of a particular service will be created on the hosts within the Grid. When additional hosts are needed they do not have to belong to the same university or run the same operating system as long the services are implementing the same interface. Fig. 3 illustrates the characteristics of the average response time observed when only one node or n nodes are available on the Grid related to a particular service. Grids may grow from few resources to millions. In principle, there is no restriction in size, but the availability and latency of resources must be observed.

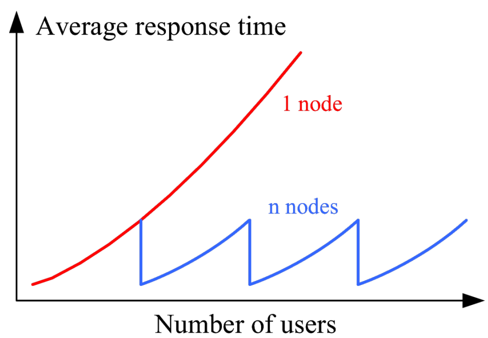

Figure 3. Average response time characteristic depending on the number of users of a particular service available from one or more than 3 nodes on a Grid

D. *Personalisation*

A very important feature of a Learning Grid is the fact that it can deliver learning contents from heterogeneous resources in a unified fashion and personalised according to the profile of the learner. The following procedure is in analogy to the power grid. A learner with a well-defined profile introduces himself to the Learning Grid and requests some contents relevant to his learning needs. The Learning Grid starts here to find the best suitable service for the learner's needs. This would match closely as possible the user's profile taking in account the user's location, language skills, level of advancement in selected topic, preferred form of delivering content, etc.

E. *Virtual Organizations (VOs)*

One of the main advantages of the new Grid technologies is their capability to integrate heterogeneous environments to an abstract entity. This property can be used to group resources of different universities to build a VO, e.g. a virtual university. Such an approach would allow specialization of universities in concrete areas and sharing the best offer with other universities.

IV. ELEGI VIRTUAL LABORATORIES

A. *European Learning GRID Infrastructure (ELeGI)*

In order to make the Learning Grid available for engineering education it is necessary to have both, a repository of LOs related to experiments in engineering education and a Grid framework including a course management system. The EU funded ELeGI project is one of the projects involved in bringing the power of a Grid to the educational domain. The main project goal is the development and demonstration of new learning scenarios, which opens the Grid approach for distance learning. The following two components of ELeGI are used to illustrate the concept of a Learning Grid.

B. *Virtual Control Laboratory (VCLab)*

The VCLab [8] has been originally developed as a generic tool to support students in engineering using professional design and simulations of automation processes. It uses a 3D virtual user environment to recreate and to visualize experimenting plants. One can interact with a displayed scene in a similar fashion like with real devices. The dynamical behaviour of the plant is generated by a simulator driven by simulation models. VCLab has in its repository the generic components and services necessary for building LOs for virtual scientific experiments on a Learning Grid of the engineering domain.

C. *Intelligent Web Teacher (IWT)*

VCLab is deployed on the ELeGI Grid by the IWT [9], which is a content and user management system. For learners registered through its portal, it provides a personalized profile, which must be compatible with the IMS Learning Design (IMS-LD) [10] specification. These data describe the learner himself/herself as well his/her preferences regarding the social context and learning styles. From the technical point of view, the profile is a standardized data structure. It is being used in two ways. First, it allows making a better choice regarding the content that should be provided to the learner; second, it also allows

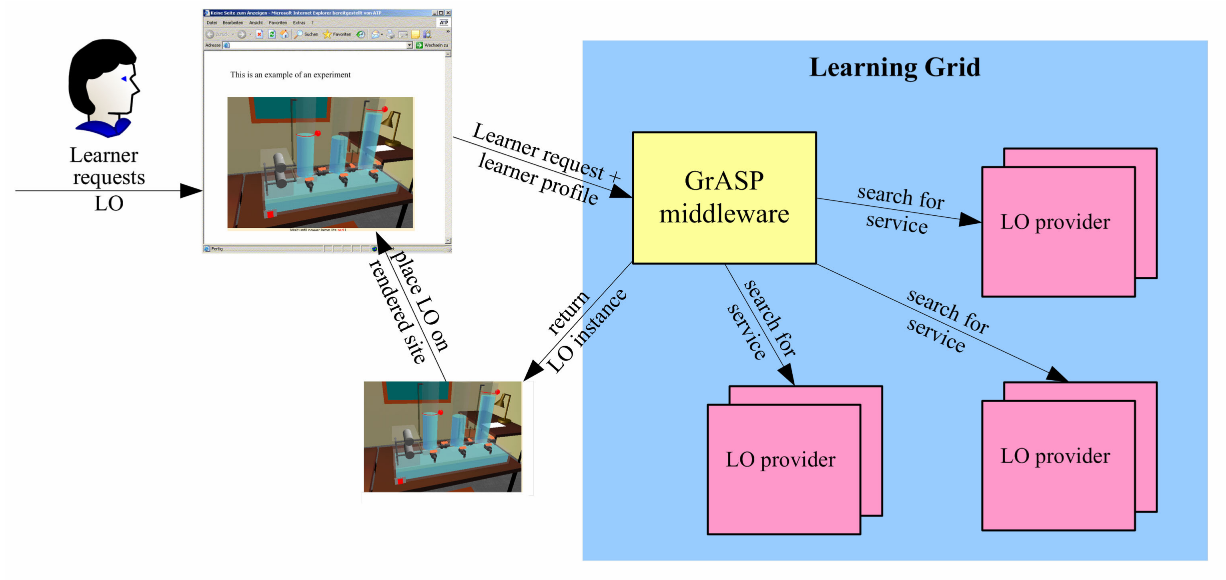

Figure 4. Process of instantiation of a Learning Object from VCLab in a Learning Grid

adjusting the selected content depending on the learner preferences.

IWT is an extensible platform, which runs self-composed LOs and embeds them into developed courses. In IWT LOs from external suppliers can be integrated using a driver concept. Such external LOs are self-contained objects with a well-defined logical function and with a full user interface. Analogical to device drivers, these drivers can be executed on behalf of particular resources handled by them. In this concept the learning contents have to be defined for which every type of resource has a driver associated with it. These drivers are Grid services with a well-known interface. Therefore they can be managed by the IWT portal, both with associated portlets, which are the essential parts of the LOs.

Because IWT is built on the GrASP middleware IWT is also a Grid framework that delivers both, basic Learning Grid functionalities and its own services, which can be reused by objects being integrated using the portal.

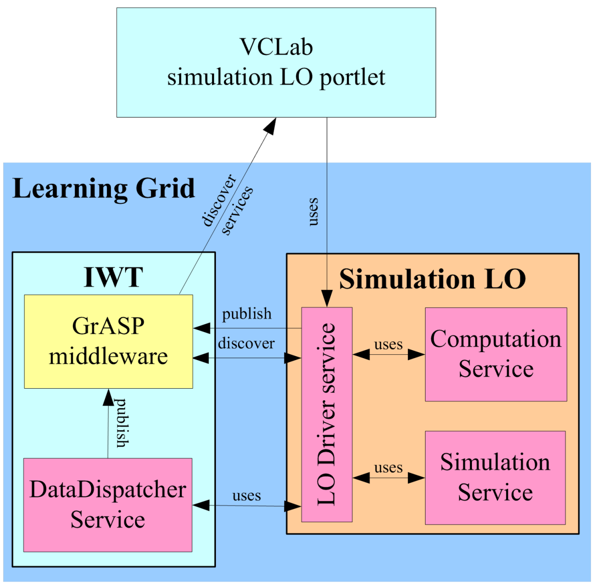

Figure 5. VCLab simulation LO architecture of ELeGI

D. VCLab in the ELeGI environment

The VCLab components are integrated as LOs into the IWT framework by using drivers as described in Section IV-C. The procedure of the instantiation of VCLab components as LOs is presented in Fig. 4. When the learner decides to take part in a course that uses VCLab resources, the portal receives a request to create the instance of the particular LO. The portal combines the original request with data withdrawn from the learner's profile and submits the created request document to the Grid, in this instance to the GrASP middleware. GrASP searches for the best service and best service provider matching the request and instantiates the driver service. The driver service returns the portlet which renders the LO for the learner depending on the personalization definitions in the learner's profile.

Fig. 5 demonstrates the architecture of this integration into ELeGI by an example using the VCLab Simulation LO. This LO uses the Computation and Simulation services through its driver service and additionally the DataDispatcher service, which is part of the IWT framework and provides the data storage and search capabilities for simulation models. The Computation and Simulation services from VCLab are not integral part of the IWT framework. As they comply with Grid services standards, they are registered in the ELeGI services catalogue and are published within ELeGI. Therefore, they can be reused by other LOs drivers and third parties, which require computation or simulation capabilities in other educational tasks.

E. The VSE Learning Model of ELeGI

Achieving a successful integration is not only performed on a technological level, but also in regard to pedagogical aspects. For this purpose a model for the delivery of Virtual Scientific Experiments (VSE) has been developed. This model splits a Unit of Learning (UoL) into four macro phases: *Presentation*, *Practical Situation*, *Abstract Situation* and *Institutionalization* phase, see Fig. 6.

The phase of *Presentation* provides the description of the didactic experience that the learner is about to start. To such aim, the description of the different phases of the VSE, the necessary information for the learner about the character and goals of the experiment and about the general reference regarding the operation of the software will be provided. The content of this type of LO is less interactive and the learner cannot influence the behaviour of the learning object.

The *Practical Situation* represents the phase in which the learner live the concrete experience. Simulation and the presence of a collaborative environment are available in which the personal learners' experience can be mediated from the interaction with the other learners. This phase has an iterative character and consists of five micro phases:

Active Situation – A fascinating and interactive scene in 3D is proposed, inside of which the learner will be able to move and manipulate objects. Simulations are run by a series of controls that the learner can opportunely vary, modifying in real time the behaviour of the simulation, observing its response and actively gaining personal knowledge.

Collaborative Learning – During this phase the learner has the possibility to mediate the personal knowledge with the others, to compare the results, and finally use the synergy between personal and collective construction of knowledge.

Assessment – This micro phase marks the transition from action to opinion by giving the learners a variety of questions to judge the current validity of the learning process. If the output is not adequate a possibility is offered to enter in a facilitated didactic situation, which leads to the phase of the *Addressed Situation*. The learner can enter again into the phase of *Active Situation* or *Collaborative Learning* in order fill own gaps. This ends in a further assessment with a loop back if not successful. Otherwise the phase of *Knowledge Institutionalization* is entered.

Addressed Situation – This optional phase, to which learners may be redirected in case an unsuccessful Assessment may provide an altered version of the *Active Situation* and give additional hints which should allow a facilitated understanding of the experiment.

Knowledge Institutionalization – It is the last micro phase of the *Practical Situation* when the knowledge validity is shown to the learner with a correct solution and a list of concepts which should be known after completing this activity.

The *Abstract Situation* macro phase is to extrapolate from the previously context an abstract model. It consists of the same micro phases as the *Practical Situation* and its execution is governed by the same rules. But instead of the simulation of a concrete case the activities will be set up on a greater interaction between theory and practice to induce the learner to test knowledge in order to achieve new goals. For example instead of a 3D scene in the *Active Situation*, e.g. the learner has to deal with a set of equations describing the experiment.

Finally the macro phase of *Institutionalization* provides the means for organizing and formalizing the acquired knowledge.

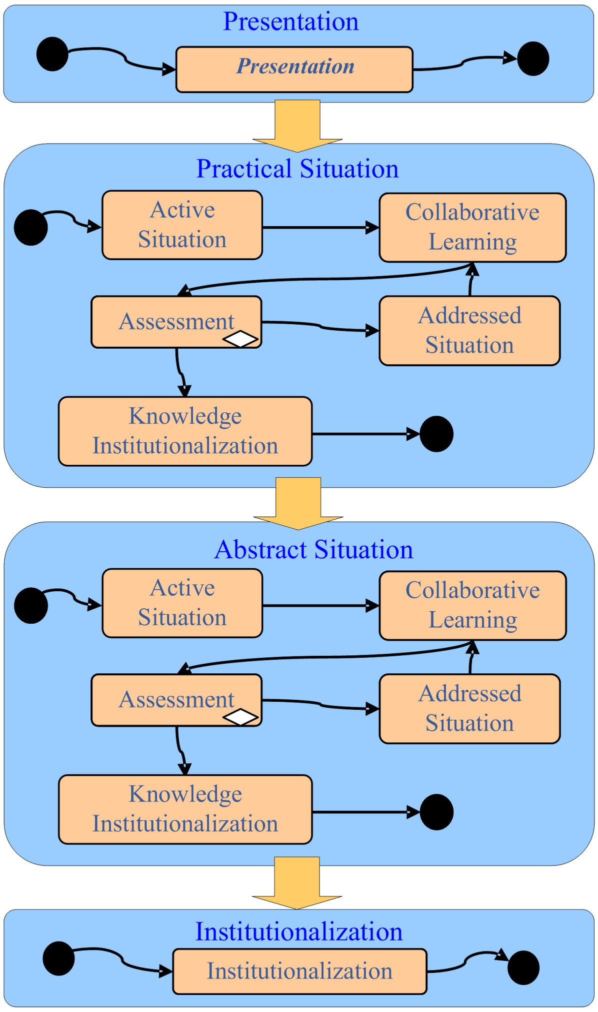

Figure 6. VSE learning model of ELeGI

F. *Unit of learning (UoL)*

The content managed by the IWT portal uses IMS-LD standardized forms of UoLs. This introduces an abstract layer over the technological aspects of resources in which authors can create their learning content in pedagogical instead of technical terms. This specification describes the recipients of a particular resource, the resource requirements in the sense of services required for executions, and the dependencies between resources. Commonly the XML language is chosen to describe IMS-LD objects, which need so-called IMS-LD players responsible for the LO delivery.

In ELeGI each UoL is described by an ontology, which defines the set of concepts to be taught. Each concept corresponds to a LO that constitutes the learning material. The macro phases from Section IV-E are delivered as a single LO or as a series of LOs. The ontology describes the order in which the LO will be delivered to achieve the teaching goal for a learner. Each UoL realizes the VSE learning model, which is modelled by the ontology. The LOs represented by UoLs and combined on the fly with the learner specific requirements are being delivered personalized by the IMS-LD player.

In the case of IWT, the CopperCore Engine [11] is used. The player loads the UoL prepared as an IMS content package, which contains the learning design description composed with the resources it describes.

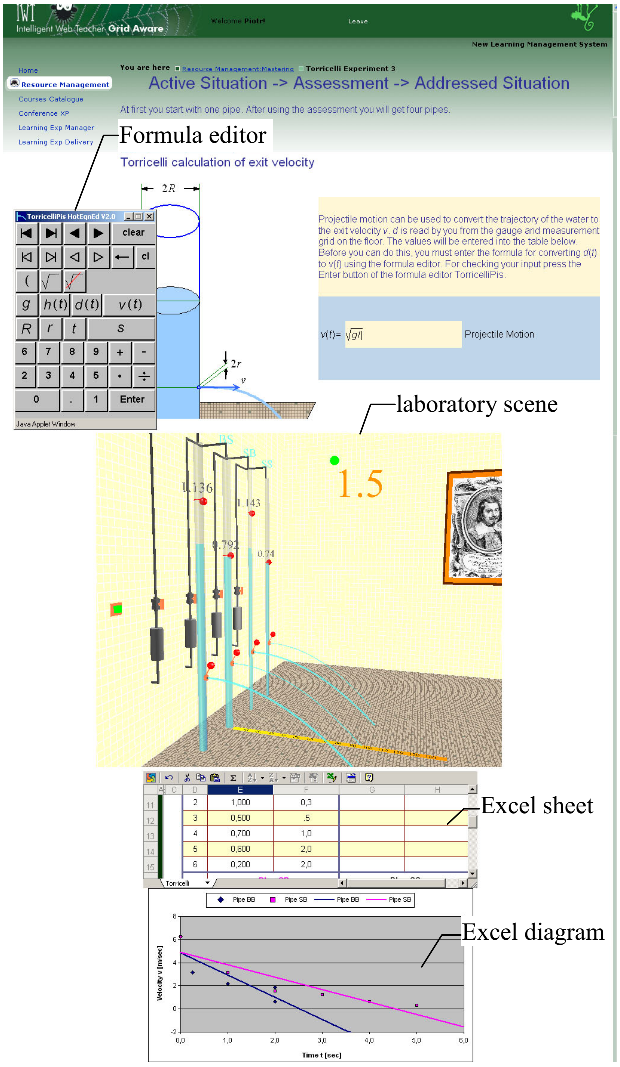

Figure 7. Screen shot section of an IWT session

G. *Example of an IWT session using VCLab LOs*

A section of an active learning session using IWT with LOs from VCLab is shown in Fig. 7. A web browser is used and the screenshot shows a section from the beginning of a nested Active Situation LO. Other sections, like assessment and addressed situation are not shown here. The example is taken from a simple UoL of learning Torricelli's law.

The middle part contains the animated 3D laboratory scene LO, where four pipes of different diameter can be filled by pumps with water to a given height. In the lower part of these pipes outlet valves of different diameter can be opened to let the water flow to the floor. The learner interacts with the experiment using this scene. Measurements are taken using a tape measure and a measurement grid on the floor and using a watch clock at the top of the scene. The scene is completely animated by the simulation service. The upper part deals with the relation between the trajectory of the water outflow and the exit velocity. The learner has to specify in this LO this relation in symbolic notation. The Formula editor is for entering the formula into the small window on the right-hand side. The symbolic user input is checked by the computation service and used below in the Excel sheet LO to covert the user measurement data into exit velocity data. The diagram is for illustration purposes.

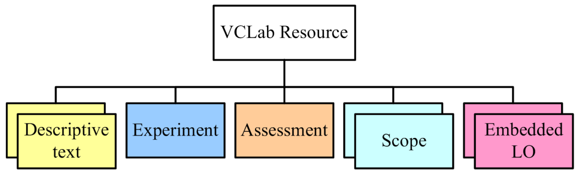

Figure 8. VCLab Resource structure

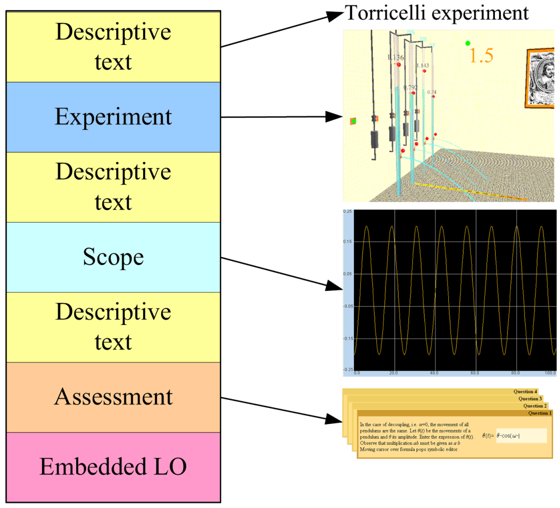

Figure 9. Appearance of elements in a VCLab Resource

V. THE VCLAB GRID RESOURCE

The LOs realizing the macro-phases of the VSE model in a UoL are generated using the VCLab Resource. Fig. 8 presents the general structure of this very generic resource. It consists of a set of optional abstract elements whereby some of elements may occur in multiple instances. Customizing this resource in a proper way will yield the different LOs of the VSE model. The appearance is also fully customizable by the sequence of elements in the resource as shown for the example in Fig. 9.

A. *VCLab Resource elements*

The *Descriptive text* element is used to deliver information describing the elements that are placed above or below of it or may be used to present additional information. From the technical point of view this element is implemented as a HTML formatted text section. It may contain also active elements, e.g. Java applets, which are not standard VCLab Resource elements.

The *Experiment* element realizes the 3D virtual user environment. It animates the behaviour of the experimental plant in the 3D scene and provides the means of altering the experiment parameters through a set of buttons or sliders rendered as 3D objects. For this purpose a 3D player is used combined with invisible controls that animates the scene and intercepts events generated by the learner. The current version of the VCLab Resource provides a LO with one experiment at one time.

The *Scope* element provides the possibility to display signal history plots in a similar manner like using an oscilloscope device. Several instances of *Scope* elements may be present showing in parallel different signals using different display modes and scaling parameters.

The *Assessment* element defines a set of multiple/single choice questions or questions that needs to be answered by entering the answer in symbolic notation, e.g. by mathematical expressions. Answers may be associated to events defining modifications of the experiment parameters.

Using the *Embedded LO* element the resource being created may also make use of already existing LOs to provide their functionality. Such an example may be LO for making notes of the measurements in an Excel sheet or a chat component for communication with other learners.

B. Learning model implementation

There is an obvious correspondence between the particular elements of the VCLab Resource and the macro/micro-phases of the VSE learning model. The design of the VCLab Resource was directed to allow the delivery of content and implementation mainly for the Practical and Abstract Situations, nonetheless the Presentation and Institutionalization macro-phase can be easily implemented using only descriptive text, e.g. enriched by recorded experiment scenarios in playback mode showing how to operate the experimental plant.

In case of the Practical Situation, the Active micro-phase is implemented by including the Experiment element within the resource definition. The Collaboration micro phase could be delivered by embedding an external LO, which provides a chat or video-conference capability. The Assessment micro-phase is implemented by the Assessment element. Answers given to questions may influence the content of the Experiment element resulting in the Addressed situation depending on a grade of correctness. Finally the Knowledge Institutionalization micro-phase is delivered mostly as a Descriptive text element.

The same approach can be taken for the Abstract Situation. In this case the Experiment may be replaced by using the Scope element. Signal plots observed in their raw form offer a more abstract observation and may lead to more general conclusions regarding the experiment results being observed.

The main reason for having a resource generic enough to be able to describe all phases of the VSE learning model, is the fact that the single micro-phases are often tightly coupled and that there is a demand for interaction between them.

VI. AUTHORING OF VIRTUAL LABORATORIES

Virtual laboratory models and its experiments require a large set of specifications for the related resources. Hitherto, in general the authoring of virtual laboratories is performed manually and by several tool chains. Avoiding this error-prone and tedious work an integrated authoring process of VCLab related Grid resources has been developed starting from a manuscript or storyboard and supporting the process until to the final UoL.

Fig. 10 presents a typical composition of a single LO, which is used to realize a Practical Situation macro-phase from Section IV-E. It contains metadata describing its content, the usability feature for the learner and the definition for the Grid service to be used for its execution. It also contains the necessary data files for its execution and references to other LOs, which may be embedded within this LO.

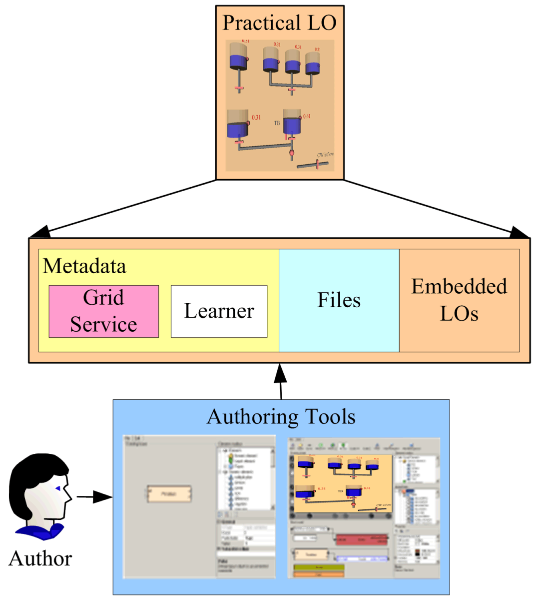

Figure 10. A typical composition of a LO and its authoring

As the experiments designed using the VCLab Resource show a complex structure, there is a need for the use of authoring tools for composing its elements. Here, a short overview is given.

All tasks to build a UoL are performed by using the VCLab authoring tools as shown in Fig. 11. These tools are of generic type to describe the simulation model, the 3D visual representation, the assessment and to compose all resources to a UoL to be published on the ELeGI grid. In addition, these tools are itself Grid resources published as Grid applications available for authors.

The Descriptive text resource (Section V-A) can be produced using third-party HTML editors. Complex mathematical expressions may be added by embedding the HotEqn Java applet [12], which interprets LaTeX expressions and renders them accordingly.

The creation of the Experiment resource is more laborious and happens in two stages. First, the experiment has to be described by a simulation model in using hierarchical block structures consisting of a set of differential and algebraic equations. The simulation parameters can be defined such that they can be manipulated by the learner. The simulation results are directed for animation or plotting in real time. This stage is performed by the *Simulation Model Authoring Tool* which contains a graphical user interface for constructing simulation diagrams.

Second, the *Visual Objects Authoring Tool* is used to generate the 3D model for the visual representation of the experimental plant. Then the elements of the 3D model are bounded to the inputs and outputs of the simulation model. The creation of the Assessment resource is supported also by the *Assessment Editor*. This gives direct access to visual elements, which are controlled depending on the answers to provide information for the Addressed Situation.

The implementation of the Active Situation in the Abstract macro-phase is performed by the Scope element, which is implemented by a Java applet integrated with the simulation model. Signal outputs generated by the simulation model are directed to the Scope element.

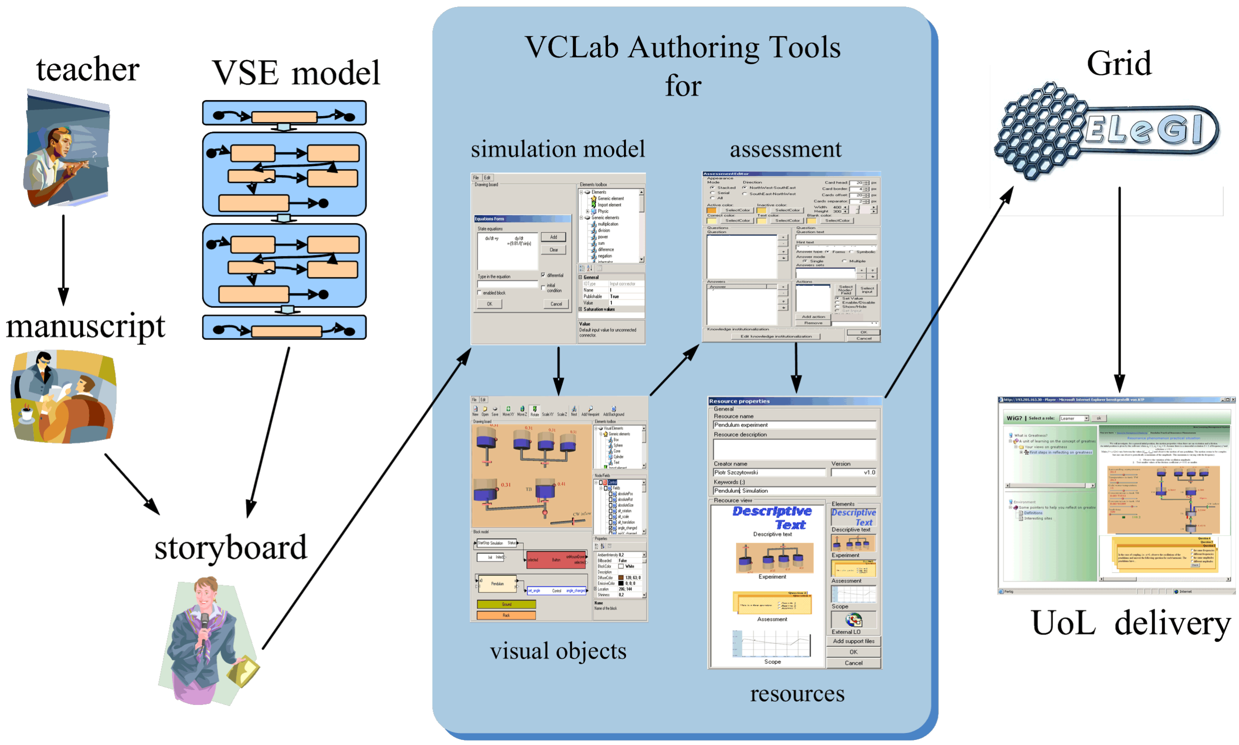

Figure 11. From a virtual laboratory idea to a UoL

At the final stage the *Resource Editor* is used to mount all the resources together into one LO and make it available for the direct deployment into the Grid environment.

The final deployment of a UoL needs support from third-party authoring tools. In this case, the RELOAD IMS-LD editor [13] and the Knowledge Representation Tool (KRT) [14] is taken, which allows the construction of ontologies and packaging of the resource, adding existing LOs by referencing and adding the necessary metadata that describe the UoL as a whole. The UoL package is published as an executable resource using the IWT-GA portal functionality. The publication process includes specifying the group of learners, which will have access to the UoL and assigning the roles of these users for the interaction with the resource.

VII. COLLABORATIVE EXPERIMENTING

The VCLab resources can be configured to deliver a collaboration environment together with a 3D laboratory scene including several embedded experiments. Participants of this virtual environment can be students of different universities participating simultaneously in the Learning Grid. They are represented in the scene by avatars and they communicate with each other by means of a text chat and expressing gestures or of a video conferencing tool. An experimenting group may have a tutor and must have one student who is the master. The master is actively experimenting while the others are passive. The master's role can be passed to each of the participants to control the experiment. The avatars are designed such that all participants can see the manual actions of the master's avatar in the scene.

Such a virtual meeting place could be the seed of creating a virtual learning community within a VO. This functionality is delivered as a LO integrated within IWT. This LO for conducting experiments simultaneously in a group is more complex.

Because simulations can consume large computational resources, it would be hard to implement environments consisting of several experiments using the classical approach (all running on a single host). In case of a Grid every separate experiment or several instances of one simulation task can run on a different host within the Grid. This clearly demonstrates the advantage of a Grid over classical solutions. Moreover, this allows building more complex environments, which are richer in content. Due to the scalability of Grids they can also be easily extended with additional elements.

Fig. 12 illustrates the collaboration concept. The VCLab Collaboration LO embeds in this example two different experiments, which are running on two separate hosts within the Grid. It is worth to notice, that by every instantiation of the Collaboration LO its supporting simulation LOs may be delivered from different Grid nodes depending on the current state of the Grid and availability of the hosts. From the learners perspective there is no difference in learning experience what is assured by the quality of service constraints.

VIII. CONCLUSIONS

Learning Grids contribute to the achievement of the objectives given in the introductory chapter to this article through the definition of the learning services concept and their deployment through Grid technologies. Learning services will be consumed in dynamic virtual communities based on communications and collaborations where learners, through direct experiences, create and share their knowledge in a contextualised and personalised way. This way of learning using grid resources can become now more open to learners in the engineering domain. From

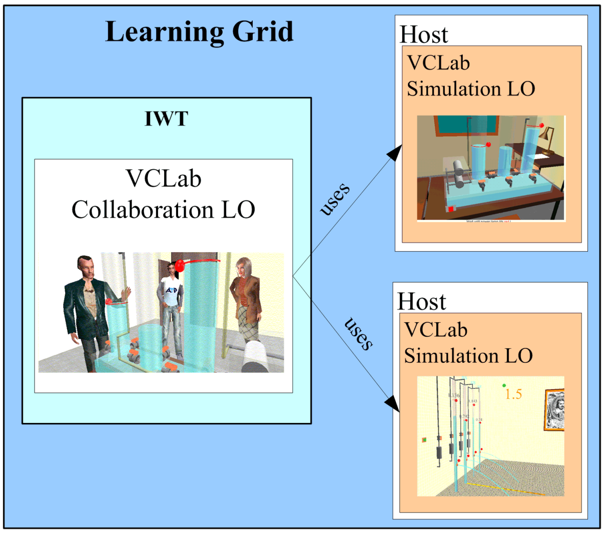

Figure 12. Composition of LOs for collaborative experimenting

the 3D visual representation the learner can get the information more effectively than only from 2D scopes or only from a textual representation.

As shown in this paper, the author of a course that contains an experiment does not need to learn or to worry about a programming language to formulate a simulation problem. He can start with his ideas working on the desktop by specifying the mathematical model and the visual appearance of the plant using authoring tools. The grid approach allows using professional simulators and large simulation models that are closer to reality than academic ones. Simulation allows time scaling of experiments which gives results faster or slower, respectively. The grid approach also allows integrating inhomogeneous resources.

From questionnaires and structured interviews of an evaluation of a VCLab example conducted by independent institutions one can conclude that the users found that the virtual laboratory learning activity and the implemented system is not very difficult to handle and the visualisation is very supportive for understanding the experiment. The direct simulation of the presented theoretical models has been highlighted to be very helpful for the understanding of a model presented in the first phase of the learning activity. The didactical concept was rated as supportive for the learning process.

The application of Grid technologies in education is of course a much wider topic than presented in this article and by the practical example of a virtual control laboratory. Nonetheless the most important aspects of utilizing service-oriented Grids in distance learning for control education are presented.

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