FORGE: Enhancing eLearning and research in ICT through remote experimentation

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Abstract—**This paper presents the Forging Online Education through FIRE (FORGE) initiative, which aims to transform the Future Internet Research and Experimentation (FIRE) testbed facilities, already vital for European research, into a learning resource for higher education. From an educational perspective this project aims at promoting the notion of Self-Regulated Learning (SRL) through the use of a federation of high-performance testbeds and at building unique learning paths based on the integration of a rich linked-data ontology. Through FORGE, traditional online courses will be complemented with interactive laboratory courses. It will also allow educators to efficiently create, use and re-use FIRE-based learning experiences through our tools and techniques. And, most importantly, FORGE will enable equity of access to the latest ICT systems and tools independent of location and at low cost, strengthening the culture of online experimentation tools and remote facilities.**

Index Terms—**remote experimentation, FIRE, testbeds, eLearning, SRL, linked-data.**

I. INTRODUCTION

The Future Internet Research and Experimentation (FIRE) [1] initiative is a European endeavour that promotes the creation of wide-scale federations of high-performance testbed and experimentation facilities for internet and network-related research. These facilities include wireless and sensor networks, Software Defined Networks (SDNs), high performance computing, optical networks, mobile networks, and smart cities. With an ongoing budget of around 20 million Euros, a number of projects are funded to sustain the FIRE facilities and conduct large-scale internet research through them. Figure 1 presents the current projects that run under the FIRE program, illustrating the areas where the facilities and testbeds are being developed and/or used for experimentation.

Forging Online Education through FIRE (FORGE)[1] is a new project, funded under Framework Programme 7, which aims to transform the FIRE facilities, already vital for European research, into a learning resource for higher
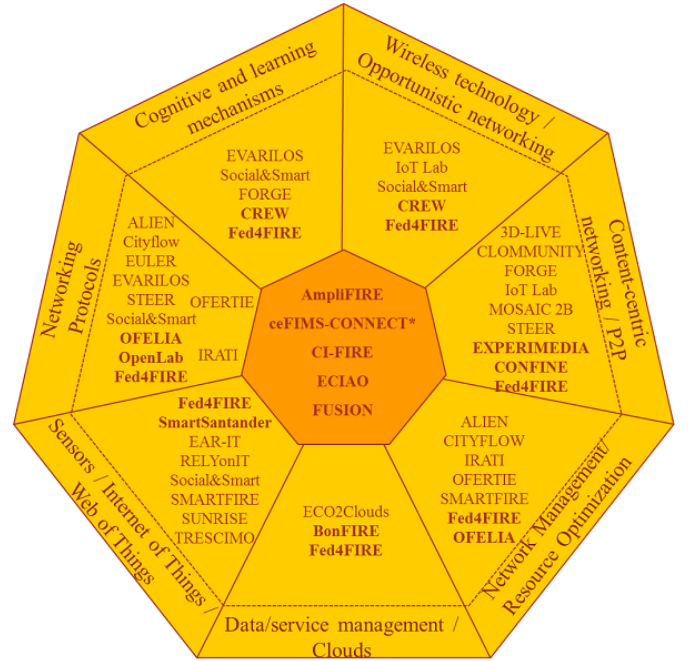
Figure 1: Projects under FIRE (source: [1]).

education. In short, FORGE will provide an educational layer over the FIRE facilities, enabling educators to easily create experiment-based learning resources.

The experimentation process is widely recognized as vital for both undergraduate and graduate engineering education and research. The main drawback is that developing and maintaining experimental facilities is costly. FORGE creates eLearning materials that take advantage of worldwide access to an existing enhanced set of such facilities.

Previous studies have shown the benefit of hands-on sessions or learning-by-doing approaches [2]. Recognizing that, in the last few years numerous initiatives have attempted to leverage the wide deployment of experimental

platforms such as Planetlab[2], Emulab[3], and Orbit[4] for remote experimentation with communication networks. For example, in the Mininet project students configured an emulated network reproducing well-known topologies [3]. With a more realistic angle, the Seattle project [4] offers educational access to PlanetLab through a browser-embedded plug-in for student assignments. The IREEL platform [5] allows students to easily set up real network experiments in order to answer lab questions. So far more than 15000 experiments have been run, and a survey of more than 150 students found that this kind of laboratories is significantly more efficient, in terms of illustrating key networking concepts, than a pure network analysis-based lab [6].

In the FORGE initiative, we will leverage these previous educational projects and integrate some of their functionality in a federation of testbeds. This will provide pre-designed and tested eLearning material, making use of state-of-the-art facilities, to a broad audience of educators.

From an educational perspective FORGE will promote the notion of Self-Regulated Learning (SRL) [7] through the use and propagation of FIRE learning solutions in online education. SRL is a term that describes an individual's ability to learn how to learn. In some university settings, the term SRL is more commonly described as independent learning or auto-didactic learning. From a cognitive perspective, SRL enables learners to become "metacognitively, motivationally, and behaviourally active participants in their own learning process" [7].

FORGE will use three different technologies to achieve its goal:

1) Social networking technologies to: increase access to learning content; enable learners and educators to easily create and publish learning content; and support collaboration amongst learners. The Open University's Social Learn environment [8] enables educators and learners to create learning paths from online resources to share.
2) Interactive eBooks, where rich multimedia content is intertwined with interactive pages to set up and run large-scale internet experiments.
3) Linked data to support: i) the delivery of learning materials through the provision of easy-to-use navigation schemes; and ii) the discovery and recommendation of learning materials through semantic links. For example, the DISCOU tool [9], from The Open University (OU), automatically displays OU courses that are related to the content of web pages as they are browsed.

The remainder of this paper is organised as follows. Section II presents related work for both technical and learning processes of this project. We detail the general

FORGE architecture in Section III. We then present in Section IV the experiment-driven Self-Regulated Learning process. Finally, conclusions and future work are presented in Section V.

II. Related Work

A. E-learning platform and networking testbeds

Experimentation is a key concept in engineering education. However, physical experimentation is often expensive and hard to maintain, and requires specific guidance through the experiment in order to avoid malfunctions or injuries to the operator. Although simulators can in some situations complement physical experimentation, physical experiments are mandatory in most engineering education areas, allowing learners to fully understand design procedures. Physical experimentation and simulation can both contribute to engineering education and can both be integrated within the same computer-based platform. Remote laboratories can provide remote access to experiments and allow students to access experiments without time and location restrictions, providing the necessary guidance and constraining operation in order to avoid setup integrity problems. Remote experiments can be ready all the time, and thus the remote laboratory concept provides a tool to sustain a learner-centric teaching approach.

Remote network laboratories support shared learner access to physical network equipment through an internet interface. Depending on the interface used to access the hardware, the experience of configuring, maintaining, and troubleshooting a network environment is close to the experience in a true campus network [10]. The interface that mediates access to the physical hardware significantly affects the quality of the learner experience, as reported in [11]. This study indicated the interface may improve the accessibility of the labs for learners who have had little prior network experience. Additional software is often used to augment the environment through reporting services that provide a detailed analysis of network behavior [11]. As aforementioned, these type of laboratories, employed to teach specific and general concepts, have been found more efficient than pure network analysis-based labs [6].

B. Self-Regulated Learning

FORGE will enable educators and learners to access and actively use FIRE facilities in order to conduct scientific experiments. We will thus follow a constructivist approach to education where learning takes place by students creating artefacts rather than assuming the passive role of a listener or reader. Our approach is based on a wide range of studies that have shown that with the right scaffolding competent learners benefit greatly from constructivist or learning-by-doing approaches [2], [12]–[14]. In another currently ongoing FP7 project, Working Environment with Social, Personal and Open Technologies for Inquiry Based Learning (weSPOT), the partners focus on Inquiry Based Learning (IBL), by propagating scientific inquiry as the

approach for science learning and teaching in combination with today's curricula and teaching practices.

The notion of SRL will also be promoted through the use and propagation of FIRE learning solutions in online education. SRL has become increasingly important in educational and psychological research. The goal is to give the learner greater responsibility and control over all aspects of technology-enhanced learning. Lately, as we have learned from our involvement in the FP7 projects Responsive Open Learning Environments (ROLE) and Sustaining Technology Enhanced Learning at a LARge scale (STELLAR), the advance of lifelong and informal learning has made SRL important in non-academic learning environments, where instead of instructor- and teacher-orientation, more learner-orientation is necessary [15].

The second trend that we see is based on Linked Data [16], [17] the simplest form of the Semantic Web [18] where data representing any entity (*e.g.* person, place or organization) is identified by a Uniform Resource Identifier (URI) and can be linked to any other data item, forming a gigantic Web of Data graph. In general Linked Data is now being used by companies such as Google, Microsoft and Yahoo to enhance web search,[5] by Facebook to support the linking of social media resources[6] and by the BBC to support the delivery of online news content.[7]

III. FORGE INTEGRATED ARCHITECTURE

A. Integration in the Semantic Web Ecosystem

Building on the Linked Universities initiative [19] and EU projects such as Linking Web Data for Education (LinkedUp)[8], Linked Data will be integrated in FORGE as follows:

1) Delivery and navigation of learning materials – the rich structure provided by Linked Data-based descriptions supports the creation of easy-to-use navigation schemes. Additionally, semantic links and a uniform data format enable heterogeneous resources to be easily combined into a single space or page. Linked Data will enable us to combine data and services from multiple FIRE facilities into a single easy-to-navigate place.
2) Discovery and recommendation of learning materials – using semantic links we can highlight related resources. Linked Data will provide support for discovering FIRE facilities related to course materials, and vice-versa.

The experiment-driven approach of FORGE will contribute to fostering constructivist learning by turning learners into active scientific investigators, equipped with world-class experiment facilities.

From a learning technology perspective, FORGE will be building upon new trends in online education. More specifically, in online educational platforms such as iTunes U,[9] as well as in Massive Open Online Courses (MOOCs), such as Udacity,[10] Coursera,[11] edX[12] and FutureLearn,[13] we see the large-scale take-up and use of rich media content. These include video in a variety of formats, including webcasts and podcasts and eBooks, which can contain multimedia and interactive segments. In particular, eBooks provide a new level of interactivity since specific learning text, images and video can be closely integrated into interactive exercises. In the context of the European project Euclid[14] (EdUcational Curriculum for the usage of LInked Data), we have been producing such interactive learning resources about Linked Data and delivering them in a variety of formats, in order to be accessed from a variety of devices, both mobile (tablets and smartphones) as well as desktop computers. Building on this work, FORGE will produce interactive learning resources targeting a wide range of media and devices in order to maximise its impact on the eLearning community.

FORGE will enable students to set up and run FIRE experiments from within rich related learning content embedded as widgets inside interactive eBooks and Learning Management Systems (LMSs). The portability of widgets as bespoke apps that can be embedded into a variety of online environments will ensure that the FORGE learning solutions implemented as widgets will have a high reusability factor across multiple learning domains and online learning technologies. Figure 2 shows an example of such a widget used for finding open educational resources. The widget in question has been embedded into online courses offered by the Open University via two different environments: the Moodle LMS and an Apple iBook.

Additionally, an Educational Widget Store using Linked Data will be developed to host the FORGE learning widgets. Learners and educators who are looking for interactive tools for scientific experimentation will be able to find suitable FORGE learning widgets in this store, as well as contribute their own tools and share them with the eLearning community. A FORGE vocabulary will be developed for describing FIRE learning resources and FIRE testbed facilities from a learning perspective. This vocabulary will build upon existing ontologies such as Metadata for Learning Opportunities (MLO), eXchange of Course-Related Information (XCRI-CAP), or the Teaching Core Vocabulary (TEACH) [20]–[22].

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[5] http://schema.org
[6] http://ogp.em/
[7] http://www.bbc.co.uk/blogs/bbcinternet/2010/07/bbc_world_cup_2010_dynamic_sem.html
[8] http://likedup-project

[9] http://www.apple.com/education/ipad/itunes-u/
[10] http://www.udacity.com
[11] http://www.coursera.org
[12] https://www.edx.org
[13] http://www.futurelearn.com
[14] http://www.euclid-project.eu
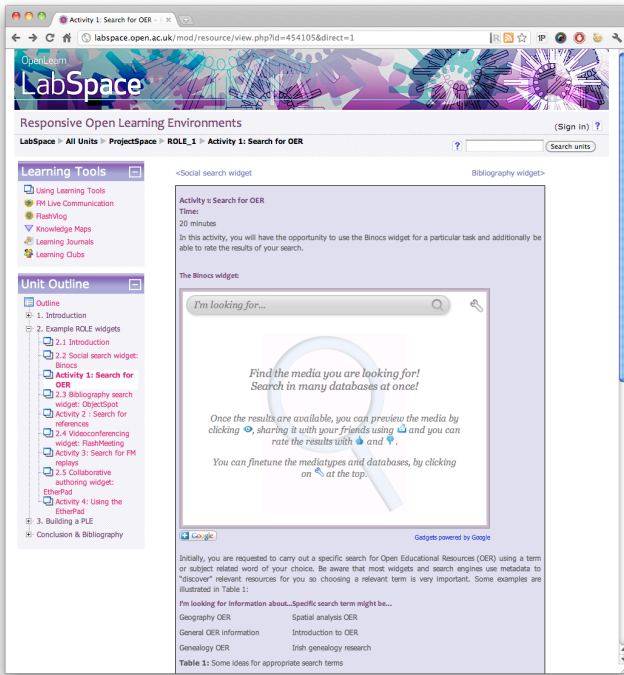
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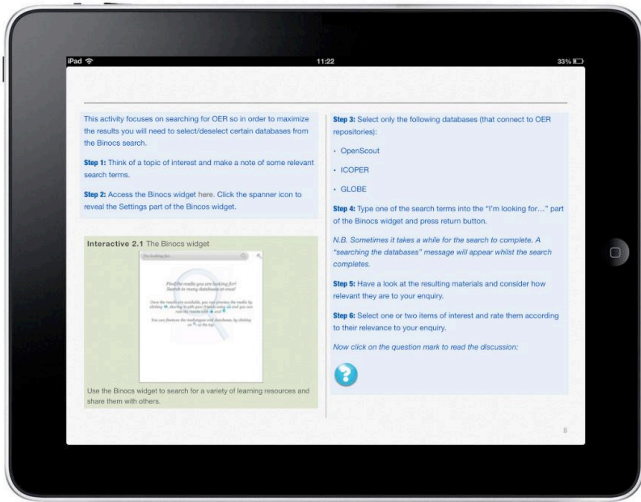
(b)

Figure 2: Integration of a learning widget inside (a) the Moodle LMS and (b) an Apple iBook

Figure 3: Interfacing learning content with FIRE facilities.

B. Interfacing with FIRE Infrastructure

Liaison with FIRE facilities and activities is of great importance to FORGE. Requirements regarding experimentation within a Lab course are analyzed and communicated to other FIRE initiatives like Fed4FIRE[15].

The FIRE federation has already developed Application Programming Interfaces (APIs) and tools to support ex-
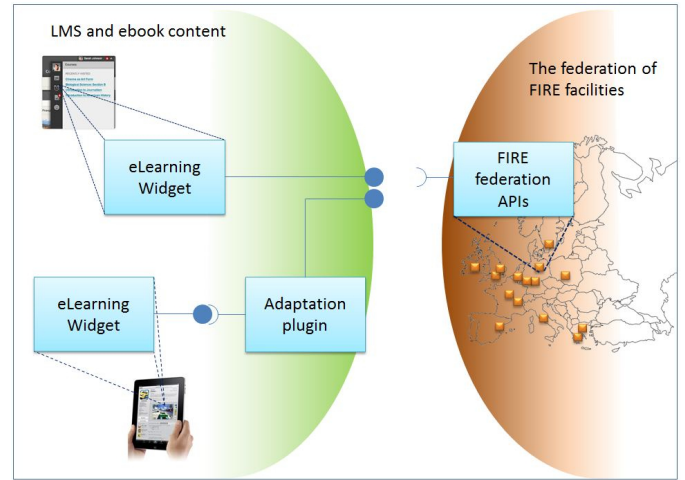
perimentation and to facilitate communication and user authorization between testbeds. FORGE has already identified some issues that are not expected to be entirely solved by Fed4FIRE or that are not high in its agenda. These issues will be addressed via some adaptation plugins that will provide interfaces to decouple communication between learning widgets and FIRE APIs (see Figure 3). This will help the reusability of the components across different sets of applications.

One such example is a generic wrapping of the well-known Slice Federation Architecture (SFA) API [23] exposed by many FIRE facilities to a format recognized by learning widgets, together with a way to facilitate the management of user accounts. As another example, one concern is the scheduling of the execution of a lab course on experimentation platforms when a high demand is expected. Although Fed4FIRE deals with common APIs and authorization mechanisms and even some facilities address the resource scheduling, up to now it seems that there is no solution for the issue of multiple reservation and scheduling. FORGE will implement additional API wrappers so that the learning widgets and LMSs can handle experimentation requirements.

IV. Experiments-driven Learning process

As aforementioned, FORGE will advocate the conceptualization of SRL by applying the FIRE learning solutions within the eLearning domain. SRL research within the ROLE project has produced the Psycho-Pedagogical Integration Model (PPIM) shown in Figure 4 [24]. The ROLE PPIM divides the learning process in four learner-centred phases:

1) The learner profile information is defined or revised.
2) The learner finds and selects learning resources.
3) The learner works on selected learning resources.
4) The learner reflects and reacts on strategies, achievements and usefulness.
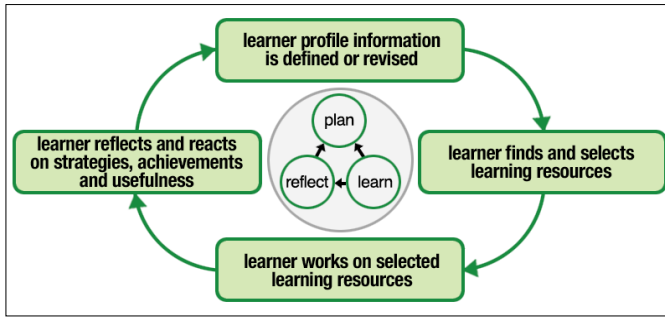
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[15]http://www.fed4fire.eu

Figure 4: The ROLE Psycho-Pedagogical Integration Model (adapted from [25]).

The learner will implicitly or explicitly perform these phases during learning, with support from widgets and interactive learning resources.

In order to illustrate the application of the PPIM in FORGE, let us consider a scenario involving an informal learner. Jane is 42 years old and has chosen to take a Computer Networks course from the OU. She is a mature student who has worked for many years and would like to broaden her horizons. She likes to learn but because she is working full time needs to be disciplined in her approach to her new studies.

Before the course commences, Jane decides to prepare herself for it, by updating her educational technology-related skills, keeping in mind that it has been some time since she has taken any academic courses or used technology directly to aid her learning. Thus she starts her study preparation by trying to find an online course that focuses on the new learning technologies, because her OU Computer Networks course is going to be delivered primarily in an online environment.

In essence, Jane is going to approach her Computer Networks course as follows:

1) Setting her goals;
2) Looking for appropriate and recommended learning tools;
3) Using those learning tools to enhance her skill set; and
4) Reflecting on the learning process.

In this process, Jane is aided by a number of widgets available for various learning purposes: She uses a 'goal-setting' widget to record a list of her goals; she then uses the Linked Data-enabled Educational Widget Store to discover suitable FIRE facilities available as widgets inside interactive learning resources; she uses the resources she finds in order to learn about the construction and operation of Computer Networks; finally, she reflects on her experiences by providing feedback as comments and ratings in the Educational Widget Store. By using the FORGE widgets, Jane gets acquainted with a variety of FIRE facilities, such as PlanetLab, or an OFELIA test-bed with SDN capabilities, which allow her to explore networking implications under real conditions.

At the end of this process, Jane realises that she has acquired a lot of new learning resources and learning techniques, and she has experienced a whole set of new learning tools in the form of widgets. She is now prepared to start the OU course in the upcoming semester and she also plans to keep on using these widgets throughout the course.

In FORGE we have identified five Prototype lab courses that will be designed, implemented and executed to support the SRL process previously described. They will drive the initial requirements of the approach and the architecture. These proposed courses are from the areas of wireless networking, network flow control and internet science. Overall, these labs offer a close match to the Networking and Communication "learning outcomes" from the ACM/IEEE CS2013 curricula [26]. FORGE will thus offer the following labs to the community:

- Hands-on Wireless LAN connectivity labs where students will be able to obtain practical skills in configuring these wireless networks and to gain better insights into the theory, such as the hidden terminal problem. These labs will allow students to acquire the leaning outcomes from the "NC/Mobility" core-tier2 component of the CS2013 curricula.
- Studying Networking implications labs will enable learners to build a simulated Internet, either individually or in collaboration with other learners. These labs will provide the leaning outcomes from the "NC/Local Area Networks" core-tier1 component.
- Network architecture labs will provide a simple interface to the OneLab environment, with all its experimentation tools available over the worldwide PlanetLab testbed. These labs will provide the leaning outcomes from the "NC/Introduction" core-tier1 component.
- A hands-on experience with flow control protocols and different traffic classes will enable students to understand how transport protocols such as TCP may impact the performance of the network, and how their control mechanisms react in the face of various network conditions. These labs will allow students to acquire the leaning outcomes from the "NC/Resource Allocation" core-tier1 component.
- Hands-on experiences with application layer protocols and with how to provide reliable data communication will illustrate two fundamental concepts from a typical introduction to networking lecture, namely the evolution of HTTP and the concept of Reliable Data Transfer. These labs will address the "NC/Networked Applications" core-tier1 and "NC/Reliable Data Delivery" core-tier2 components.

Thus, through the FORGE initiative, we will be able to offer labs for every core component of the CS 2013 curricula while offering a rich learning experiment through

an enhanced SRL process. We also plan to investigate how to incorporate the only elective from the Network and Communication component, the "NC/Social Network" elective course as well as other components from the CS2013 curricula, such as Information Management or Parallel and Distributed Computing.

V. Conclusion

Forging Online Education through FIRE (FORGE) will study and develop new processes and approaches to online learning based on the integration of Future Internet Research and Experimentation (FIRE) facilities and eLearning technologies. Moreover, FORGE will inject into the higher education learning sphere the FIRE portfolio of facilities and tools to embrace the concepts of Experimentally Driven Research.

Through FORGE, traditional online courses will be complemented with interactive laboratory courses, supplying an in-depth and hands-on educational experience. In addition, FORGE will redesign eLearning tools and enhance existing Learning Management Systems (LMSs) with new functionalities to enable a seamless interactive experience when accessing FIRE facilities, thus providing a hands-on experience using the latest networking equipment, with evidence of innovative and advanced practice for learners.

FORGE will also allow educators to efficiently create, use and re-use FIRE-based learning experiences through our tools and techniques. And, most importantly, it will enable equity of access to the latest ICT systems and tools independent of location and at low cost, strengthening the culture of online experimentation tools and remote facilities.

Currently the FORGE project it is at a early execution stage. However, the design of the courses and teaching materials and the enabling of the facilities are tasks that are already ongoing. In the near future we will have an evaluation of the experience from the learners' and educators' point of view. This feedback will provide us with valuable information to improve and reinforce the educational model that FORGE proposes.

Acronyms

API	Application Programming Interface
FIRE	Future Internet Research and Experimentation
FORGE	Forging Online Education through FIRE
IBL	Inquiry Based Learning
ICT	Information and Communication Technologies
LinkedUp	Linking Web Data for Education
LMS	Learning Management System
MLO	Metadata for Learning Opportunities
MOOC	Massive Open Online Course
OU	Open University
PPIM	Psycho-Pedagogical Integration Model

ROLE	Responsive Open Learning Environments
SDN	Software Defined Network
SFA	Slice Federation Architecture
SRL	Self-Regulated Learning
STELLAR	Sustaining Technology Enhanced Learning at a LARge scale
TEACH	Teaching Core Vocabulary
URI	Uniform Resource Identifier
weSPOT	Working Environment with Social, Personal and Open Technologies for Inquiry Based Learning
XCRI-CAP	eXchange of Course-Related Information

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