Facilitating student understanding of Internetworking via e-learning

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Abstract

Learning Management Systems (LMSs) are widely used in higher education to improve the learning, teaching, and administrative tasks for both students and instructors. Such systems enrich the educational experience by integrating a wide range of services, such as on-demand course material and training, thus empowering students to achieve their learning outcomes at their own pace.

Courses in various sub-fields of Computer Science that seek to provide rich electronic learning (e-learning) experience depend on exercise material being offered in the forms of quizzes, programming exercises, laboratories, simulations, etc. Providing hands on experience in courses such as Internetworking could be facilitated by providing laboratory exercises based on virtual machine environments where the student studies the performance of different internet protocols under different conditions (such as different throughput bounds, error rates, and patterns of changes in these conditions). Unfortunately, the integration of such exercises and their tailored virtual environments is not yet very popular in LMSs.

This thesis project investigates the generation of on-demand virtual exercise environments using cloud infrastructures and integration with an LMS to provide a rich e-learning in an Internetworking course.

Sammanfattning

Acknowledgements

I would like to acknowledge ...

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List of Acronyms and Abbreviations

e-learning electronic learning

LMS Learning Management System

LTI Learning Tools Interoperability

LIS Learning Information Services

EC2 Elastic Compute Cloud

IT Information Technology

AWS Amazon Web Services

KTH Kungliga Tekniska Högskolan

TC Tool Consumer

TP Tool Provider

GLUE! Group Learning Uniform Environment

SCROM Sharable Content Object Reference Model

MOOC Massive Open Online Course

LXC Linux Containers

Chapter 1

Introduction

The use of electronic learning (e-learning) technologies has been well established in modern education to assist both students and instructors in their learning, teaching, and administrative tasks. One of the e-learning technologies most widely adopted by the academic community is Learning Management Systems (LMSs). A LMS is a software application that handles all aspects of the learning process [1], enabling instructors to design rich e-learning courses and students to experience self-paced learning using a variety of features, such as on-demand course material, video lectures, automatic delivery and evaluation of assignments, collaboration tools, etc.

Many courses, especially in various sub-fields of Computer Science depend on training events in the form of programming assignments, laboratory exercises, simulations, etc. These activities are crucial for students to gain hands-on experience with complex concepts and systems [2]. Although LMSs support on-line training events, such as interactive quizzes with automatic evaluation and analysis of results, providing training events that depend on using complex virtual environments and software are not yet very popular (and hence not widely supported or used).

One of the main advantages of using an LMS is that it supports the integration of external applications to provide personalized, domain specific e-learning, such as messaging and video streaming services, on-line office suites, collaboration tools, or even training environments with exercises tailored to the needs of a specific course.

1.1 Background

Hands-on experience is very important to achieve understanding of complex systems and concepts. For example, when studying computer networks, laboratory exercises are a common student activity. An Internetworking course often involves students studying the performance of different Internet protocols under different conditions (such as varying throughput bounds, error rates, and patterns of changes in network conditions).

These experiments depend on specific software, network topologies, and local or virtual hardware. Traditional approaches for realizing such environments depend upon the student's own hardware or on-site computer labs with pre-configured software[3]. More modern approaches involve remote access to virtual machines running on central servers or cloud infrastructures [4].

Currently LMSs do not have built-in support for such laboratory environments. However, one of the main advantages of designing an on-line course on top of an LMS that supports the integration of extenal applications is to provide tailored functionality for the course's and student's specific needs. Today, many LMSs, such as Instructure Inc.'s Canvas [5] LMS, implement the IMS Global Learning Consortium Tools Interoperability® (LTI®) specification. Learning Tools Interoperability (LTI) allows the exchange of information between the LMS and third party components, thus exposing internal functionality of the LMS to external applications in a controlled manner.

Supporting virtual laboratory environments in a LMS in order to meet the needs of an Internetworking course, requires the design of a software framework that implements the LTI interoperability specification in order to exchange relevant information between the laboratory environment and the LMS.

1.2 Problem definition

TODO: This is already stated above.Remove?

Hands on experience is very important aspect of the learning process in several fields of Computer Science, including computer networks.Understanding the domain specific concepts and problems of an Internetworking course, depends greatly on exercise material and laboratory practice. Today, such exercises, are not usually designed to extract suitable analytics for the instructor (as an instructor ideally wishes to evaluate each student's level of understanding of each of the different concepts covered in an exercise). Assessing the student's understanding is currently achieved ~~via~~ using additional training material, such as quizzes or assignments in forms of reports which are manually evaluated by instructors or by other students in the form of peer reviewing. These alternative methods both introduce a delay in feedback to the student (hence reducing the student's rate of learning) and are not scalable (for example, preventing their use in Massive Open Online Courses (MOOCs)).

Supporting an on-line version of an Internetworking course through a LMS that enables students to achieve the learning outcomes at their own pace, depends greatly on designing interactive practice environments. Such environments should be easily modified by the instructor to fit the needs of different exercises. Moreover, the environment must provide feedback for both students and teachers. Although today LMSs support a variety of training events, such as quizzes and assignments through integration of external services, on-line virtual laboratory environments that fulfill the requirements of an Internetworking course are not yet well supported and hence not widely used.

However, similar practice environments are common in on-line courses that teach programming languages. Such environments are part of systems that provide tools for designing coding assignments, and support several assessment methods, including automatic evaluation and grading of code and programming quizzes. These systems often provide standalone web applications or LTI integrations in LMSs that expose functionality for developing code, submitting assignments, and presenting feedback to users[6, 7].

This project aims to design a software framework that supports interactive training material for an Internetworking course that extracts suitable analytics of the learning process for both students and instructors, and integrates with a LMS to provide a rich e-learning experience.

1.3 Goals

The design of such a laboratory environment for an Internetworking course has to meet several user requirements from the perspective of both students and instructors, and integrate with a LMS to offer a rich e-learning experience. The expected outcome of this project is a software framework that supports instantiation of on-demand laboratory environments using cloud based technologies to enrich the learning experience of students, allowing them to proceed at their own pace. Additionally, the framework should enable a teacher to customize the environment according to different exercises' requirements, and provide the instructor with constructive feedback about each student's progress and understanding.

The process of designing this framework can be realized by achieving the following goals:

- ~~E~~asily build virtual laboratory environments,
- On demand availability of these environments should enable students to practice whenever they want, i.e, be self-paced,
- The framework should support evaluation and analysis methods to be applied to the exercise in a way that is useful for both instructors and students.
- ~~Integration of the~~ framework with the LMS ~~should~~ enable students to access the training environments via the LMS, and
- The method of integration of such exercise environments should be usable by others - thus an important part of this thesis project is documenting the selected method to facilitate the integration of a diverse set of external environments (for example, an ns-3 simulator configured for a particular simulation).

TODO: Rephrase this section later on. Fist paragraph contains very long sentences, and the list does not glue together with the paragraph

1.4 Research Methodology

Design science research addresses important unsolved problems in unique or innovative ways or solved problems in more effective or efficient ways. It focuses on the design and construction of ~~I~~nformation ~~T~~echnology (IT) artifacts that have utility in real-world, application environments. The ~~designed~~ artifacts, as the outcome of the research process, aim to improve domain-specific systems and processes [8, 9]. The utility, quality, and adequacy of a design artifact, is thoroughly evaluated under varying experimental setups to verify that it successfully fulfills the requirements.

Design~~ing~~, in several research fields, including IT, is an iterative process of planning, generating alternatives, and selecting a satisfactory outcome. Design science research, although it is not performed using strictly defined processes, can be summarized by three closely related cycles of activities (these cycles are the relevance cycle, the rigor cycle, and the design cycle)[10], that act as guidelines for designing, constructing, and evaluating an artifact. The relevance cycle establishes the application context that not only provides the requirements for the research as inputs, but also defines acceptance criteria for the evaluation of the research results. The rigor cycle provides past knowledge to the research project to ensure its innovation. It is contingent on ~~the~~ researchers to thoroughly research and reference this knowledge base in order to guarantee that the designs produced are research contributions and not routine designs based upon the application of well-known processes. The central Design Cycle iterates between the core activities of building and evaluating the design artifacts and processes of the research [8], until the acceptance criteria, as defined in the Relevance Cycle, are met.

TODO: can be hosted... This is wrong

This project is carried out using the design science research approach. The resulting software and documentation attempt to solve the problem of designing and realizing a framework for rich on-line laboratory environments for an Internetworking, e-learning course that can be hosted by a specific learning management system (Canvas LMS). The two different domains that define the context of this problem are the ~~computer networks~~ course domain~~,~~ and the LMS along with the integration of external applications into Canvas.

1.5 Deliminations

This project addresses the problem of designing and integrating virtual laboratory environments to support e-learning in an LMS for an Internetworking course. The laboratory framework, the expected outcome of this project, has to fulfill several requirements: usability for different types of users (instructor, administrator, and student~~,~~), integration into the Canvas LMS via the LTI specification, and satisfy the laboratory and pedagogical challenges of this particular course. Although there are different specifications for integrating external applications and services into a LMS [11], this project addresses only the LTI specifications, as this method is supported by Canvas (along with many other LMSs, for example LTI can be used together with edX as either a consumer or producer[12]). The design of the laboratory framework, is designed to suit the needs of a typical classroom (in this case approximately 30 students), thus its scalability is limited.

Testing the scalability of the designed system regarding the number of users is outside of the scope of this thesis project. However, a system might be scaled up on Amazon Web Services (AWS) by using larger instances (vertical scaling) or by creating multiple instances (horizontal scaling). Additionally, scaling up and down of services in clouds has been invested by others [13].

TODO: Internetworking assignments, and extraction of relevant analytics have also limitations. Make sure that they are reflected in this section.

1.6 Structure of the thesis

Chapter 2

Background

2.1 LMS

LMSs are software applications that automate the training, teaching, and administrative tasks of the learning process [1]. They have been widely adopted by higher education institutions to automate their organizational functions and provide a rich e-learning experience for both instructors and students.

Such systems are designed to provide self-guided services; rapid delivery and composition of learning material; tracking and reporting of progress through training programs, classroom, or on-line events; personalized content; and centralization and automation of administration [14]. From a learner's perspective the most common use cases of a LMS are planning ones own learning experience and collaboration with colleagues; while from an instructor's perspective the most common use cases are the design and delivery of educational content along with tracking and analysis of students' learning evolution [15].

The main functionality of a LMS concerns content organization and delivery, communication and collaboration, and assessment[1] of student's learning process. Some of the most commonly used features of an LMS for e-learning are video streaming of lectures, on-line notes and presentations, quizzes and practice environments, automatic evaluation of assignments (usually exercises with predefined input and output), wikis, discussion forums, etc [17].These services are either offered directly by the LMS or by integrating external applications that are designed according to specific interoperability standards. Section 2.2 describes this interoperability and integration in detail.

There are several LMSs in the market that are used by multiple institutions. In

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[1] Formative assessment is performed by teachers during the learning process, to modify and improve the teaching and learning activities. It is based on observation of students' individual efforts and development; thus, having a qualitative and diagnostic nature.

Summative assessment, performed by both instructors and students, is based on public criteria that aim to measure student's achieving of the course learning outcomes. [16]

the scope of this project the chosen learning management platform is Canvas [5]. This LMS was chosen because the system is open source, supports a well defined interoperability specification, and was selected earlier this year by KTH as their ~~future~~ LMS.

2.2 LTI

Interoperability is the ability to communicate, execute programs, or transfer data among functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units [18]. An e-learning platform usually consists of several services such as course and user administration modules, and learning applications that exchange information in a formal and standardized way.

The IMS Global Learning Consortium Tools Interoperability (LTI) specification establishes a way of integrating rich learning applications (often remotely hosted and provided through third-party services) with platforms, such as LMSs, portals, learning object repositories, or other educational environments [19]. The main goal of LTI is to standardize the process of building links for sharing information and exposing functionality between external learning tools and the LMS [20]. There are two major pieces of software involved in LTI. The first is called Tool Consumer (TC) and it refers to the software (such as an LMS) that consumes the output of external tools, and the second, is the Tool Provider (TP) which provides an external tool for use by the TC.

An example of a basic learning tool, is a service that accepts a request to perform a course assignment such as multiple choice question via a web form, evaluates the user input, and returns a pass/fail grade. In this scenario, the service is the TP and Canvas LMS is the TC. An administrator of Canvas, is required to configure the integration of the external tool, a course assignment for which the tool will be launched, and finally, choose whether the interface of the tool will be embedded in Canvas, or run in a new browser window. Figure 2.1 shows a basic flow for launching a TP from the TC. The user requests to ~~perform~~ an assignment~~, that is~~ configured to launch a~~n~~ LTI external tool. The TP authenticates and accepts the LTI Launch request by the TC and starts a session for that particular user that allows ~~him~~ to interact with the assignment.

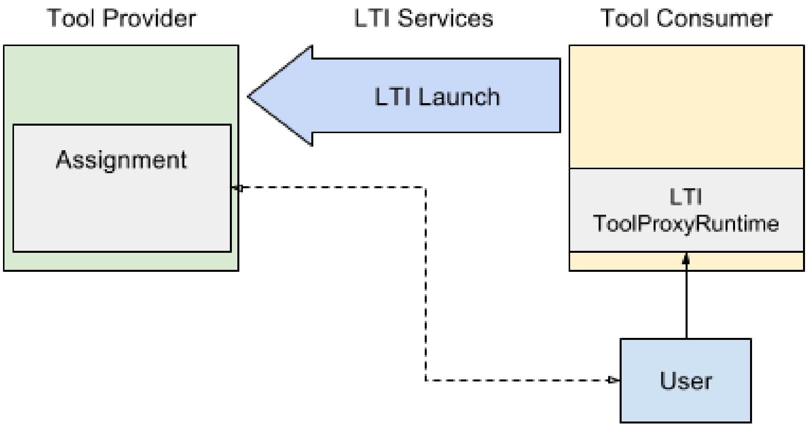

Figure 2.1: User launching an external tool

A TP often requires access to course related information, such as people, groups, memberships, courses, and outcomes. This information along with standardized ways of retrieving it are defined by the IMS Global Learning Consortium Learning Information Services (LIS) specification [21]. These services can be provided either by the TC or by a third party system. Canvas LMS implements the LTI version 1.1 which includes a subset of the LIS specification, called the LTI Basic Outcomes Service. In the example mentioned above, the information that Canvas provides to the TP when performing an LTI Launch are: how to access the LIS services, the resource identifier (assignment) for which a grade will be reported, and user information such as the unique identifier of the student. Figure 2.2 shows how a TP can communicate with LIS services to get user data and report the grade of the assignment back to the TC.

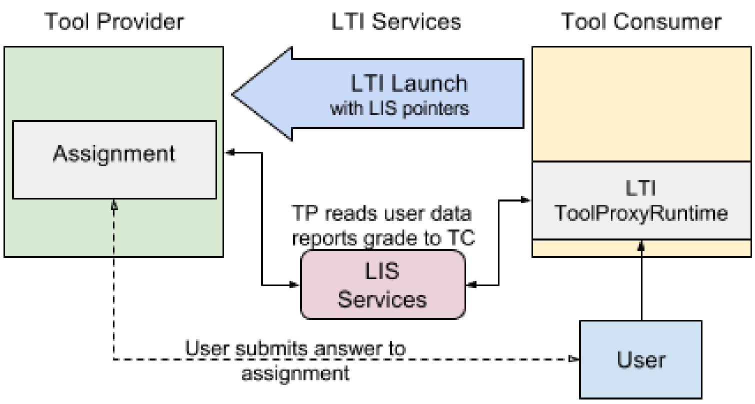

Figure 2.2: A TP using LIS services

2.3 Efforts to provide on-line exercise material

Traditional practice events in Computer Science involve laboratory environments and exercises based on virtual hardware and domain specific software. One of the problems is creating and managing these environments. Previously such material was packaged in virtual machines or run in an isolated environment (such as a sandbox or linux container ~~that is mentioned in~~ 2.4).

TODO: extend this paragraph

With the rapid growth of e-learning courses, the need for on-line exercise material has grown. Efforts in fields of cybersecurity include "A Comparison of Virtual Lab Solutions for Online Cyber Security Education"[22], "Top 10 Hands-on Cybersecurity Exercises"[23],

In addition to the environment, there is a need for domain specific source material. Some useful references and sources for exercise material regarding networking include "Hands-On Experience to a Massive Open Online Course on openHPI"[4], "Some Experiences in Using Virtual Machines for Teaching Computer Networks"[3], "V-Lab: A Mobile Virtual Lab for Network Security Studies"[24].

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More info

- What are the requirements for successfully completing an exercise?

  What information about a student's progress in or success with the exercise should (or could) be communicated back to the LMS?

- How are these requirements met by the chosen technologies?

2.4 Linux Containers

A container is a light weight operating system running inside the host system, executing instructions native to the core CPU, eliminating the need for instruction level emulation or just in time compilation [25]. Linux Containers (LXC)[26] is an operating-system-level virtualization method for running multiple isolated Linux systems (containers) on a ~~control~~ host using a single Linux kernel. It's purpose is to virtualize a single application rather than a whole operating system inside a virtual machine. LXC uses cgroups[2] to isolate resources such as CPU, memory, network, etc., and namespaces[3] to isolate the application from the operating system [28].

[2] Control groups (cgroups) is a Linux kernel feature that is responsible for managing resources such as CPU, memory, disk I/O, network, etc.

[3] A namespace wraps a global system resource (process IDs, mount points, network devices, stacks, ports, etc.) in an abstraction that makes it accessible to the processes within ~~the~~ namespace ~~that they have their~~ own isolated instance of the global resource. Changes to the global resource are visible to other processes that are members of the namespace, but are invisible to other processes [27].

Docker [29] is a Linux container engine, that provides the ability to manage Linux containers as self contained images. Docker utilizes LXC for the container implementation, has image management capabilities, and implements a Union File System (UnionFS). It features resource isolation via cgroups and namespaces, network and file system isolation through LXC functionality, and allows managing the lifecycle of a container. [25]

TODO: integrate the following
Docker is a project by dotCloud now Docker Inc released in March 2013, initially based on the LXC project to build single application containers. Docker has now developed their own implementation libcontainer that uses kernel namespaces and cgroups directly.

TODO: The following source provides better background on Docker - USE
"NCC Group Whitepaper Understanding and Hardening Linux Containers"

This should describe how the user can configure and deploy a container to realize a specific TP with a desired configuration.

2.5 Related work

The support for Interoperability specifications by several LMSs has allowed ~~the~~ rapid experimentation and implementation of external application frameworks that offer a variety of on-line training events for various Computer Science courses. This section presents these frameworks and ~~shows~~ how ~~their outcomes~~ are ~~related~~ to this project.

2.5.1 EDURange

Designing on-line training environments for the field of cyber security requires ~~to~~ overcome technical constraints, such as high availability and scalability, and pedagogical limitations, such as teaching analysis skills to understand complex systems and concepts via practicing [2]. EDURange addresses these issues by designing an open source framework that provides interactive security exercises in an elastic cloud environment [30].

EDURange is a software framework, designed to work on Amazon Elastic Compute Cloud (EC2) [31]. It allows teachers to easily build and scale dynamic virtual environments to host cybersecurity training [32]. This framework provides ease of use for instructors, by offering the flexibility to specify exercises at a high level and allowing the instructor to configure different aspects of the training scenarios in order to provide a tailored learning experience that focuses on analysis skills.

2.5.2 GLUE!

Group Learning Uniform Environment (GLUE!) is a middle-ware integration architecture that aims to standardize the integration of existing external learning tools into several LMSs [33]. It facilitates the instantiation and enactment of collaborative learning situations within LMSs, by using the distinctive administrative features of these systems to manage ~~of~~ users and groups. LTI or Sharable Content Object Reference Model (SCROM) are specifications for the integration of external learning tools into an LMS. Each LMS usually supports a single interoperability specification; thus, developing a universal external tool requires a ~~considerable~~ development effort to ~~cover~~ the different standards. In contrast, GLUE! proposes a software architecture that takes advantage of the common integration features of LMSs to integrate multiple existing learning tools into multiple LMSs.

2.5.3 edX

2.5.4 INGInious

Programming exercises are the most common form of practice for students learning computer science. Traditionally, the evaluation of these exercises, requires grading reports, reading, and testing source code, thus making it time consuming, especially for large class~~rooms~~. INGInious [6, 34, 35, 36] is a software framework that empowers instructors to easily construct coding tasks~~,~~ and supports automatic evaluation and grading of the code, thus providing both students and teachers with constructive feedback.

The framework consists of two main components: the frontend~~,~~ and the backend. The frontend provides a web interface where students perform programming tasks~~,~~ and an administration module that allows instructors to design these tasks. The backend is responsible for running and grading the code inside remote isolated Linux containers. Each container is specifically built for a particular programming language, according to configuration provided by the instructor or the administrator of the system, thus supporting the evaluation of tasks written in any programming language that runs in a Linux environment.

One of the main features of INGInious is that the frontend component can be used either as a stand-alone web application or as an external learning tool that is integrated into an LMS using the LTI specification. Additionally, the backend component scales horizontally very easily, since it utilizes a docker container for every task request, therefore it is suitable for MOOC platforms.

* Should extend this when I manage to integrate it to Canvas.
* Can reference the Vagrantfile that provisions the INGInious environment, as part of replicating the methodology.

A programming task in INGInious is designed using a configuration file that defines the task, a template file that presents the task to the student, and defines the input field for the code, and finally, a run file that executes the student code, and validates the output. The following example shows the minimum configuration required by the instructor, to design a simple "Hello World" task in Python.

Not sure if I should explain the following code, since it exists in the teacher documentation of inginious, or remove it completely.

```yaml
name: "Hello World!"
context: "In this task, you will have to write a python
  script that displays 'Hello World!'."
problems:
  question1:
    name: "Let's print it"
    header: "def func():"
    type: "code"
    language: "python"
limits:
  time: 10
  memory: 50
  output: 1000
environment: "default"
```

Listing 2.1: Definition of a task in task.yaml

```python
def func():
  @ @question1@@

  func()
```

Listing 2.2: Definition of a task in template.py

```bash
#! /bin/bash

# Parse the template and put the result in studentcode.py
parsetemplate --output studentcode.py template.py

# Verify the output of the code...
output=$(run_student python studentcode.py)
if [ "$output" = "Hello World!" ]; then
  # The student succeeded
  feedback --result success --feedback "Success!"
else
  # The student failed
  feedback --result failed --feedback "Your output is
   $output"
fi
```

Listing 2.3: Evaluation of student code by the run file

2.6 Summary

It is nice to bring this chapter to a close with a summary. For example, you might include a table that summarizes the ideas of others and the advantages and disadvantages of each ? so that later you can compare your solution to each of these. This will also help guide you in defining the metrics that you will use for your evaluation.

Chapter 3

Methodology

TODO: Rewrite and avoid repetition

What scientific or engineering methodology are you going to use and why have you chosen this method. What other methods did you consider and why did you reject them. What are your goals? (What should you be able to do as a result of your solution - which could not be done well before you started?) What you are going to do? How? Why? For example, if you have implemented an artifact what did you do and why? How will your evaluate it.

You might explain why Canvas is being used:

- it is likely that this will be the LMS at KTH
- it is open source so you were able to build your own instance and experiment with it.

In the design science paradigm, the rigor cycle provides past knowledge to the research project to ensure its innovation. Researchers ~~to~~ thoroughly research and reference the knowledge base in order to guarantee that the designs produced are research contributions and not routine designs based upon the application of well-known processes. The central Design Cycle iterates between the core activities of building and evaluating the design artifacts and processes of the research [8], until the acceptance criteria, as defined in the Relevance Cycle, are met.

3.1 Research Process

This thesis project is carried out using the Design Science research method. This type of research focuses on the design and construction of IT artifacts that have utility in the real world, in this case as an application environment, and aim to improve domain-specific systems and processes. In the context of this research, the real world problem is the lack of interactive virtual laboratory environments in the form of e-learning tools. More specifically, the major problem is to integrate such tools within an LMS, to assist the learning and teaching of an on-line Internetworking course.

Rewrite

Despite the fact that there is no strictly defined process for performing, design science research, there are three closely related cycles of activities that can be used as guidelines for designing, constructing and evaluating an artifact. The relevance cycle initiates the application context that not only provides the requirements for the research (e.g problem to be addressed) as inputs but also defines acceptance criteria for the evaluation of the research results, thus establishing a bridge between the contextual environment of the research project with the design science activities. It is often useful for defining the application context, to describe the people and the organizational and technical systems involved in the domain of the problem. In the context of this problem, the main inputs are the Internetworking course along with the functional and pedagogical requirements of its laboratory environments, the instructor and student user roles that are involved in designing a learning tool, and finally, Canvas LMS and its support for integrating external learning tools.

These inputs can be expanded to functional and user requirements of the artifact in a section later on.

The rigor cycle of Design Science research provides past knowledge to the project to ensure its innovation. Like traditional literature research, it guides the researcher to identify existing artifacts and processes in the application domain, solutions and design practices to relevant problems, and establishes a knowledge base that ensures the uniqueness and originality of the designed artifact. Here, the rigor cycle is represented by the background literature review, that validates the lack of existing solutions when it comes to domain specific laboratory environments that are offered by LMSs, and presents common practices and design methodologies for constructing and integrating such environments in similar information technology domains like cybersecurity.

Finally the design cycle, is the core of the research method, is tightly bound to the rigor and relevance cycle because of its iterative nature, that generates artifacts according to design specifications and evaluates them against requirements until the acceptance criteria of the research are met.

3.2 Research Paradigm

HTTP traffic widget from FORGE http://ict-forge.eu/wp-content/uploads/2016/01/FORGE-2015-P-D312-Final.pdf

Chapter 4

Implementation

So far basic setup of the following environments has been accomplished

- Canvas LMS in a vagrant virtual environment, with admin, instructor and student accounts.
- Integration of the LTI basic outcomes service. A student takes an assignment and the result is reported as a grade back to Canvas LMS.
- Bootstrapping of the INGInious backend and frontend modules. LTI integration to LMS was not successful during the first attempts.

Chapter 5

Analysis

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5.1 Major results

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5.2 Reliability Analysis

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5.3 Validity Analysis

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5.4 Discussion

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Chapter 6

Conclusions and Future Work

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6.1 Conclusions

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6.2 Limitations

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6.3 Future work

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6.4 Reflections

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Appendix A

Appendix Name X

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