VIDAR Lab: A Virtual Network Environment for Project-Based Learning of Undergraduate Students

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Abstract—The field of information technology is rapidly evolving, setting high standards for the academic education of future specialists. In order to meet this new demand, the authors would like to present a virtual network laboratory that provides university teaching staff with the flexibility to adapt both the content and methods to keep the lab up-to-date. This virtual lab was developed based on Graphical Network Simulator 3 (GNS3) and includes an integrated learning concept and assignments. It is called the "Virtual Internet Device Abstractions of Reality lab" (VIDAR[1]-lab for short) and will be used for part of the course *Communication Networks* at the Technical University Berlin. VIDAR lab uses the approach of virtualising the network hardware in order to keep the level of abstraction as low as possible, while still ensuring realistic practice-oriented work. VIDAR lab employs the concepts of blended learning and Project-based Learning (PBL) to provide an interesting introduction to the topic of networks and the Internet for undergraduate students with the assistance of smart micro methods. The lab is designed to be used both in an online format for remote teaching of hands-on activities and to be held as a PBL-based lab with the traditional way of teaching in Science, technology, engineering, and mathematics (STEM) education. The developed VIDAR lab was tested and evaluated with ten volunteers to ensure the quality of the didactic design and the applicability of GNS3 as a learning solution. The volunteers provided positive feedback on the developed lab, describing the learning experience as effective and enjoyable.

I. INTRODUCTION

The motivation behind this work is to provide high quality training for prospective academics in information technology as part of a university course and covers the redesign of a tutorial block (lab) in the *Communication Networks Lab*. The Communication Networks Lab is associated with the lecture *Communication Networks* held at the Technical University Berlin (TU Berlin) by the Telecommunication Network Group (TKN) at the School of Electrical Engineering and Computer Science (Faculty IV) and is intended for the education of undergraduates students either studying Electrical Engineering, Computer Engineering or Computer Science.

The lab is organised in blocks and covers the physical fundamentals of signal transmission and physical layer concepts, protocols and their mechanisms, the structure and behaviour of the Internet and networks as well as how applications access the network.

[1]In reference to the son of Odin and Grid, from nordic mythology.

The lab block will be replaced by the Virtual Internet Device Abstractions of Reality (VIDAR) lab to give the students the possibility to train practical skills and gain deeper insight into networks in general and the Internet.

For this purpose, the learning content and the manner in which it is conveyed should be in line with current state-of-the-art technology. This work combines the technical development of a learning environment based on GNS3 with the well-founded and well-known didactic concept of project-based learning to create a network lab that is attractive for students. In this work, the authors would like to display that it is possible to set up a robust virtual network lab based on open-source software for the education of undergraduates students.

The VIDAR lab uses the open source software GNS3 in order to simulate common network topologies by using the applied concept of virtualisation to abstract the whole network infrastructure and hardware. The toolbox for building networks consists of client/server nodes, switches for level 2 routing, routers for level 3 routing and backbone routers for Border Gateway Protocol (BGP) routing, all realised as virtual machines as shown in [1], [2].

In the first part of this work the authors present the educational concept of the VIDAR lab. This is followed by an overview of the developed structure and the assigned tasks of the network lab. The VIDAR lab was evaluated by ten student volunteers to ensure its quality. The results of the evaluation are discussed in the conclusion section of this work.

II. EDUCATIONAL CONCEPT

In order to provide the best learning outcome for the students the VIDAR lab integrates some didactic approaches that are well-known in higher education. Increased digitisation in educational and work settings are creating a demand for more use of digital media to strengthen learning outcomes [3]. The VIDAR lab aims to incorporate the concepts of blended learning and project-based learning and facilitate the introduction of networks and Internet topics using smart micro methods. Furthermore, we will discuss the relevance of employing different media to cater for the diversity of student learning styles.

A. Blended Learning

The VIDAR lab strictly follows the approach of blended learning, also known as hybrid learning. Blended learning is defined as an educational concept which combines online educational materials and opportunities for online interaction with traditional attendance-based classroom methods. The VIDAR lab is firstly based on the *flex* model, where most of the content is presented on a digital platform and the educators are available for face-to-face consultation and support in the lab. Secondly, it is also based on the *labs* model, where all of the content is presented on a digital platform but in a permanent physical location and the students usually take traditional classes as well.

B. Project-Based Learning

PBL is the second and main macro method that is applied in VIDAR lab. PBL is a didactic approach that gives students the opportunity to earn practical skills with a problem-oriented mindset. In other words in this approach, a problem is specified to provide the foundation for developing problem-solving skills and a solution-orientated way of thinking. In recent years PBL has become more prominent in engineering courses. Some examples displaying its applicability to engineering education can be found in [4], [5], [6], [7], [8].

Problem-solving skills are trained by analysing and finding solutions to real-world problems. Just like blended learning, PBL is also implemented in various forms [9]. The PBL is a method that provides training in the innovative-thinking side of problem-solving, developing an entrepreneurial mindset by transforming ideas into economic solutions and sustaining self-directed learning [9]. The PBL also aims to teach students how to acquire applicable knowledge, work and learn together responsibly, integrate their knowledge from various disciplines as well as to analyse problems and create solutions which they can apply in different situations. The PBL approach provides the foundation for the structure of the VIDAR lab, refer to ??. It is mainly applied in the practical and project phase, but also starts in the theoretical phase with step 1 (refer to fig. 1). The PBL is applied in two ways in the VIDAR lab. Firstly, the completely guided phase is designed to follow the idea of project-based working. This includes self-study in the preparation phase and guided practical work for the milestone 0 and milestone 1 project. Secondly, the PBL is implemented in the mini project itself. In this phase the students adapt the previously learned steps and apply them to the given problem. To clarify the process, the students write documentation about the project.

Another important aspect of the PBL are the roles of teachers and students [8]. The approach of PBL was to apply a transition from supervised-based teaching of students by the teacher to autonomous engagement-based learning and working on tasks of the project throughout the duration of the project. It should also be mentioned that the task of the teacher has moved away from traditional teaching towards constructive guidance based on PBL.
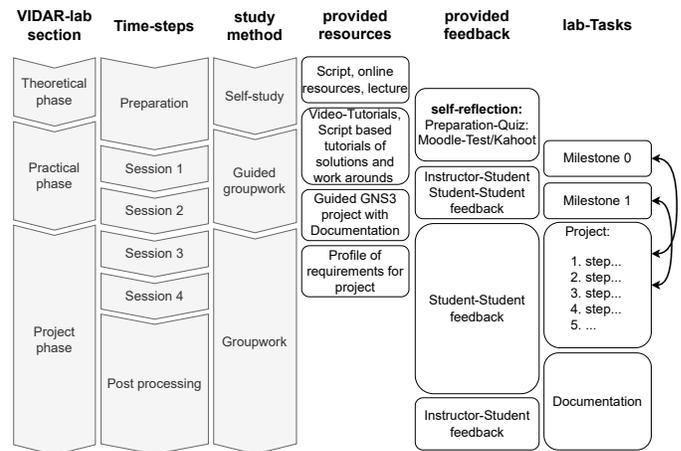

Fig. 1. Structure of the VIDAR lab and the application of learning methods in the context of the project phases.

C. Micro Methods

Besides the two macro methods, the VIDAR lab will extensively use the so-called sandwich method. The sandwich method is a typical micro method. Micro methods are integrated into the methods above them and are bound to certain tasks of the project. The sandwich method is based on alternating learning phases. The first phase is the transfer of knowledge, which is directly followed by active confrontation and practical use of the knowledge [10]. These two phases are repeated a few times depending on the size of the task to be completed. This micro method has proven to combine well with the PBL. The sandwich method is mainly applied in the first two sessions of the guided group work during the prepared GNS3 projects. As an example of how the sandwich method is applied, one of the first tasks is to follow a tutorial to configure the virtual network devices. This is followed by the task for the students to extend a given pre-configured network topology by two host PCs and three switches. For this extension, the students must directly apply the previously learned knowledge about the configuration of the network components to a real problem and get feedback by searching for a solution and troubleshooting.

The content is provided in the form of various media such as a course script, Internet-based resources and video-tutorials. This is to ensure a broad range and different, parallel ways are presented for the students to acquire knowledge in the manner that best suits their own personal learning style. This ??

III. VIDAR LAB - NETWORK AND INTERNET LAB

VIDAR lab is divided into three parts. It starts with a theoretical phase which is guided by a script. This is followed by the practical phase and the project phase. fig. 1 shows the structure of the VIDAR lab. This paper focuses on the practical and project phase.

A. Theoretical Phase of VIDAR lab

The VIDAR lab starts with self study in preparation, corresponding to the theoretical phase shown in fig. 1 which aims

to get all students up to speed regardless of varying levels of knowledge. The main source of information will be found in the script with the content of the lab and organisational details, written in HTML and strictly oriented to the lecture, but with the focus on important VIDAR lab aspects. The mandatory topics to cover are highlighted as keywords at the end of the text. The blended learning approach of VIDAR lab is manifested in all three sections but intensively applied in the theoretical phase in the provided educational resources.

A small amount of the practical phase (refer to fig. 1) is also part of self study. Here, tools like Ping or Traceroute are used to support the theoretical description and tools like GNS3 and Wireshark are introduced and explained by tutorials. The tutorials are provided in both script-based and video-based form to support the different types of learners.

Before attending the sessions of VIDAR lab, a preparatory quiz by use of moodle is completed to give the students the opportunity to self reflect and get feedback on the first learning outcome.

B. Practical Phase of VIDAR lab

The practical phase begins with the first session in the VIDAR lab. The objective of the practical phase is to give the students the opportunity to transfer their theoretical knowledge into reality and to extend it in an application-oriented way. In addition, the practical phase is designed to prepare the students for the subsequent project. Since there is comparatively limited time available, the approach followed is to heavily supervise learning at the beginning of the phase while providing intuitive guidance as possible. This support decreases steadily as the practical phase progresses, thus enabling transition to independent project work (refer to fig. 1).

To give the work a project character of the project based learning approach, the tasks in the practical phase are divided into sub-projects called milestone 0 and milestone 1. The tasks of milestone 0 and milestone 1 are given to the students in the form of a preconfigured GNS3 project. The script guides the students through the tasks in a tutorial style and provides explanations and references to further information at appropriate points.

1) Milestone 0: The preconfigured GNS3 project milestone 0 is designed to give students a quick introduction to the operation of the software. It also focuses on showing the students the basic configuration of the virtual hardware devices. The project is divided into three sections, each of which contains a selection of tasks. fig. 2 shows the preconfigured milestone 0 project.

In the project itself, annotations and tasks are listed. When students open the project, they receive the most important information at first glance. In the lower left area, the first task block 0.0 of the milestone 0 project is marked. This deals with operation and configuration of the open source software solution used in the VIDAR lab for the individual Network Function Virtualization (NFV).

The second task block is labelled 0.1 and contains a sub-network that is completely preconfigured (10.10.10.0). A 3-tier architecture has been selected as the topology here, which is already extended to the branch office via the WAN (10.10.1.0). The aim of the assignment is for the students to extend the given network by a sub-strand (10.10.5.0). In doing so, the students learn how to build networks with GNS3. To do this, the components must be aligned using drag-and-drop and connected to each other using the cabling tool. Furthermore, the students have to apply the previously learned knowledge about the configuration of the components directly in a practice-oriented manner and configure the given components.

The third task block covers the use of Wireshark within GNS3 and, in addition, the two GNS3 internal functions of the NAT cloud and the interface node are introduced. Wireshark is to be used in a solution-oriented manner via analysis of the DHCP protocol.

2) Milestone 1: The milestone 1 project changes the focus from pure functionality achieved through correct configuration to aspects such as fault prevention, reliability aspects and performance aspects. The milestone 1 project also focuses more precisely on WAN topologies and the configuration of routers by setting up routing algorithms. In this project, the transition to independent solution-oriented work begins. The tasks are no longer processed in tutorial style; hints are merely given at appropriate points.

C. Project Phase

The project phase offers students the opportunity to apply the knowledge they have learned to a given problem. The students can choose a so-called mini-project. During the course of this work, two possible projects were defined. It is also conceivable that the students could suggest their own project proposals and implement them.

The scope of the mini projects should be about two sessions (240 min.). Documentation and description of the results should take place after the project work. The two sample projects presented in the following take topics from the milestone 0 and milestone 1 projects and deepen important aspects. The students can determine the focus themselves and work on topics that are in their area of interest. The first mini project presented is based on the topics from milestone 0. It is about the development and design of a small office and home network. The topics that were mentioned during the milestone 0 project will be deepened. The second mini project covers the topic of routing from the milestone 1 project. Various routing algorithms and their implementation will be examined and differences will be worked out. The concept of the autonomous system is to be adopted and the inter-AS routing algorithm BGP is to be examined. An example topology of this project is given in fig. 3.

Feedback in the project phase is mostly given by the group member and the other students attending the lab. The project phase is followed by the post-processing phase for documenting the outcomes (see fig. 1). This is an important last step for the students to reflect and organise the results and solutions of the given problem.

Milestone 0: Introduction to GNS3 and the Tools

Welcome to the virtual netLab of the TKN: Communication Networks practical course!
In the following 4 sessions, you can work on the basics of network technology and build up a small internet step by step.
Your control centre will be the software GNS3. GNS3 enables:
(1) - Build the topology
(2) - configure/control the individual network nodes
(3) - manage the virtual machines --> more information on this in the script.

Besides GNS3 you will need some important tools:
(1) - ping, traceroute etc.
(2) - wireshark
This project is for practising the basic skills.

0.2 NAT - Connect the real World, Analyse with Wireshark (DHCP/ARP)

The NAT interface or, alternatively, the cloud interface is a way of connecting the virtual topology with a real network.

The NAT node is used to create access to the to the Internet.

The cloud node can be used to create a connection to the local network via adapters. This then usually also includes access to the internet.

Wireshark:
Step 1: Make sure the nodes you need are enabled.
Step 2: Right-click on the link between two nodes to be examined. to be examined. --> start capture Wireshark opens.
Step 3: Observe the packets that are triggered by a DHCP command. triggered
Step 4: Analyse the functioning of the protocol.

0.0 Network-Nodes - The Virtual Hardware

VPC is a simple virtual PC simulator.
Applications: ping, DHCP

second client, e.g. Debian PC (TBC), for iperf

Simple hub with 8 ports

Switch with 16 ports, can be controlled via openFlow

FRRouter mit 8 Ports

openWRT Router with 4 ports

Simple NAT, e.g. for the connection to the internet

Interface to the local network

0.1 Tools & Topology - ping, traceroute

In this field, the aim is to expand an existing network so that communication between the individual VPCs is possible.
You can also practise using the tools ping, traceroute and Wireshark.

ping:
Step 1: Make sure that the required nodes are activated.
Step 2: Open the consoles of each VPC and execute: ping <ip address> of another VPC.
Step 3: Evaluate the output.

Traceroute:
Step 1: Make sure the required nodes are enabled.
Step 2: Open the consoles of each VPC and execute: trace <ip address> of another VPC.
Step 3: Evaluate the output.

Task 0.1 - Branch office extension:
You now want to connect a remote office of a company to their intranet.
Use Add a Link to set up the topology, then configure the nodes and check with ping and traceroute if your extension was successful.
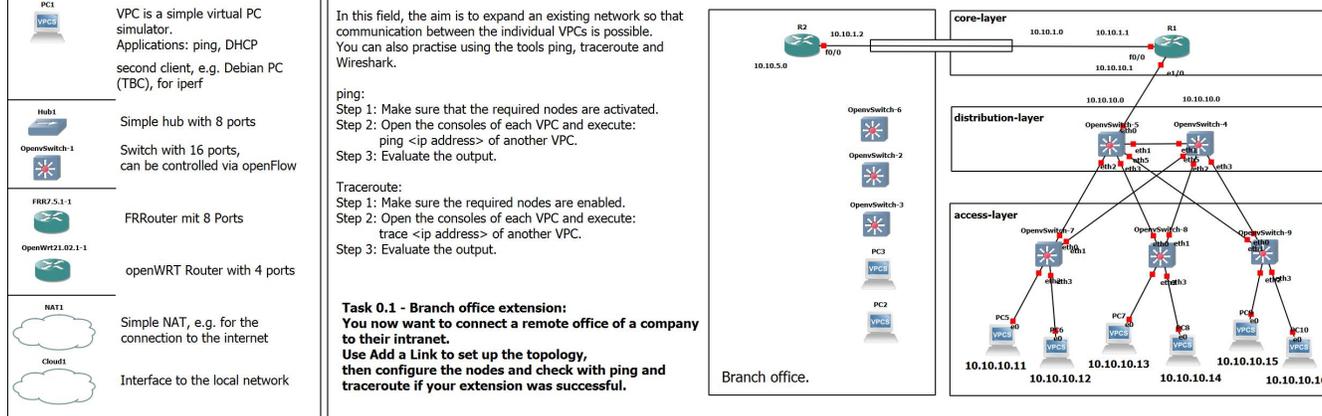
Branch office.

Fig. 2. Predefined GNS3 project called milestone 0 is a guided introduction to the work with GNS3 and the virtual hardware used in VIDAR lab. The GNS3 project is divided into three parts, each with a selection of tasks.
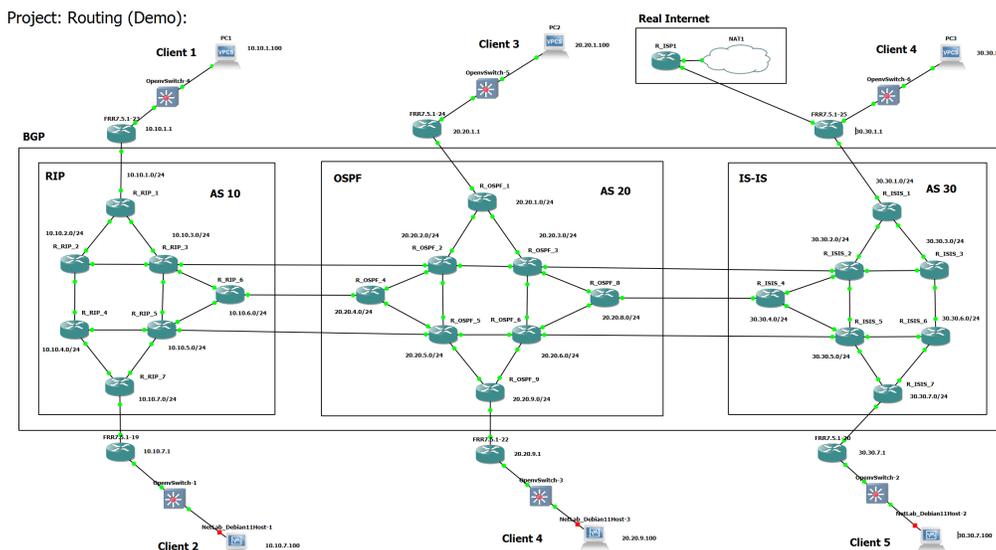
Fig. 3. Example topology for the proposed mini-project covering configuration tasks for various intra-AS routing algorithms and BGP as an inter-routing algorithm.

IV. EVALUATION

The evaluation concept is strongly based on two guidelines from TU Berlin and Humboldt University Berlin regarding the design of teaching evaluations. The reference for these guidelines can be found in the works of Schmidt [11] and Staufenbiel [12].

A. Test group and evaluation conditions

The evaluation took place on 16.03, 18.03. and 23.03.2022 in the computer lab of the TKN group of TU Berlin. The evaluation was attended by ten volunteer students. The test persons worked in groups of two or three students and two test persons worked on their own.

The procedure of the evaluation started by providing the

script and video tutorials to the test persons around one week before the test sessions took place.

The evaluation session had a duration of around 120 minutes. After the practical work on the milestone 0 and milestone 1 project the test students filled out the evaluation form. fig. 4 summarises the characteristics of the test group.
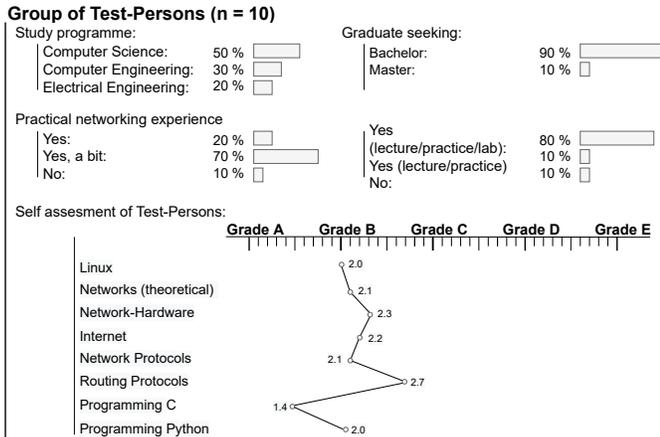

Fig. 4. Results of the evaluation of the properties of the group of test persons to estimate how representative this group is for the target group.

B. Evaluation of learning methods in VIDAR lab

The following section is dedicated to the evaluation of the applied learning methods to the practical phase of the VIDAR lab.

This section of the evaluation form includes two question parts regarding to the learning methodology and the group-work. Due two persons work on their own to test the possibility to do the VIDAR lab in self-study here, are only n=8 answers given. The results related to this are shown as a profile line in fig. 5.
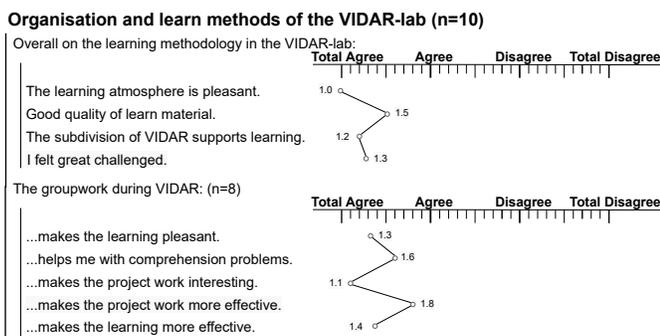

Fig. 5. Results of the evaluation on the organisation and learning methodology of the volunteers. The survey takes place after the students attending the test session of the VIDAR lab.

The learning methodology of the VIDAR lab is rated as good by the test persons. The learning atmosphere in particular was consistently rated as very pleasant. The structure of the VIDAR lab with its division into theoretical, practical and project phase was also rated as very good in terms of

learning success. The group work is rated by the students as having a very good effect on the learning climate and on the project work. The benefit of group work for understanding and efficiency is rated somewhat lower. However, it should be noted here that the differences are small and in the area of significance, so that overall the implementation of group work in the VIDAR lab was rated successful.

C. Evaluation of practical phase

The following section is dedicated to evaluation of the practical phase of the VIDAR lab. The results related to this are shown as a profile line and absolute frequencies bar diagrams in fig. 6.
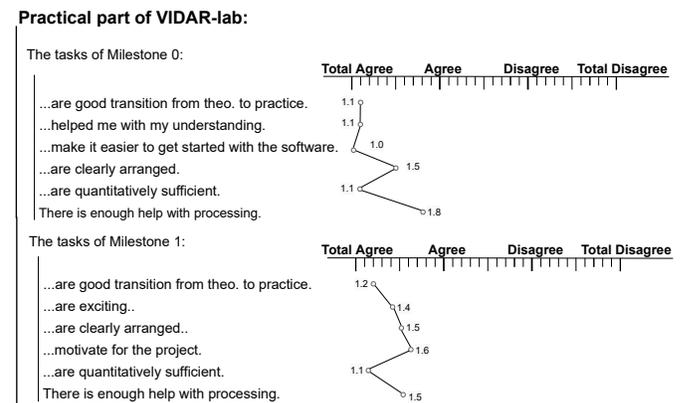

Fig. 6. Results of the evaluation of the practical part of the VIDAR lab. The survey took place after the students attend the test session of the VIDAR lab.

The tasks for the milestone 0 project in GNS3 were rated as good overall by the students. The aspects regarding entry into the practical phase and getting to know how the software worked received a particularly good rating. The milestone 0 project also helped with understanding. The visual structure for clarity and the help provided while carrying out tasks were rated somewhat more critically. Nevertheless, both points are still in the good range. The tasks for the milestone 1 project in GNS3 were rated as good overall by the students. The aspects describing the scope of the tasks and the transition from the theoretical to the practical phase were rated particularly well. The clarity was assessed similarly to milestone 0.

D. Evaluation of the applied software solution GNS3

This section is intended to evaluate the use of the GNS3 software in VIDAR lab. This point is of particular importance because the VIDAR lab was designed to be based on GNS3 and GNS3 was previously considered to be good software for this application (visualisation of network topology). This section includes a general assessment of the work with the GNS3 software, an opinion on the use of GNS3 in the VIDAR lab and a query as to whether problems have occurred and, if so, to what extent. The results related to this are shown as a profile line in fig. 7.

In general, the application of GNS3 was rated as very positive. The aspects of joy in working with the software,
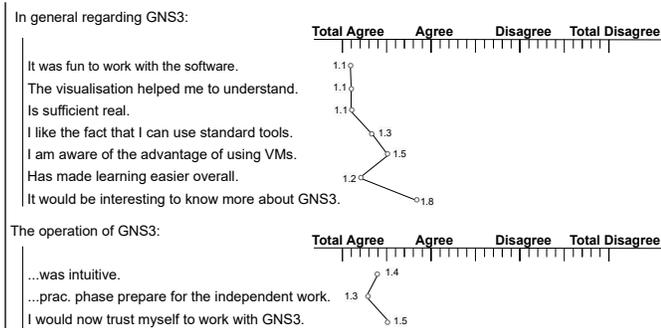
The work with GNS3 in VIDAR-lab:

Fig. 7. Results of the evaluation of the appliance of GNS3 in VIDAR lab. The survey takes place after the students attending the test session of the VIDAR lab.

the visualisation and the level of abstraction, which was rated as comparatively low, were particularly emphasised. Furthermore, the software was rated by the students as good support for learning and it was appreciated that the standard tools such as Wireshark, ping and Traceroute were used. The students agreed that the practical phase prepares them well for independent work with GNS3.

V. CONCLUSION

The adapted learning concept based on PBL and the resulting division of the VIDAR lab into the different phases received a positive evaluation. The GNS3 software was well-received by the students, who rated it as intuitive and commented that independent work was possible after a short training period. This aspect is of central importance for the project work. The degree of abstraction of the chosen solution was assessed as very real, which was also a goal in the implementation of the VIDAR lab. The use of GNS3 makes the VIDAR lab easy to maintain by the instructor. This gives the instructors the freedom to focus on supporting the students and periodically keeping the content up-to-date.

It should be mentioned that the group of ten volunteers is statistically not very reliable. The VIDAR lab will be introduced into the university degree course in late 2022 and will be evaluated further by the quality management of the Technical University Berlin.

A disadvantage is that the network lab is dependent on the continued development and maintenance of the GNS3 software. Due to the large open source community, it is very likely that the software will be improved and maintained in the future. Compared to the work of [2], this evolution is clearly observable.

In summary, combination of the use of GNS3 as a platform for the virtualisation and visualisation of the network with the concept of PBL as an educational concept provides a versatile learning environment for networks and Internet. The authors would like to promote and recommend the use of GNS3 along with associated open source virtual network components for the development of virtual network labs as part of university degree courses.

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