A STEPWISE METHODOLOGY FOR USING VIRTUAL LABORATORIES TO TEACH NETWORK TECHNOLOGIES IN A DIGITAL ENVIRONMENT

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Abstract. This paper presents a stepwise methodology for using virtual laboratories to teach network technologies in a digital environment. It outlines the rationale for the objectives, learning tasks, software tools, and assessment criteria of the foundational, professional practice, and integration stages. The proposed methodology aims to establish a consistent connection between theoretical knowledge and practical activity.

Keywords: digital environment, network technologies, virtual laboratory, staged methodology, practical task, feedback, assessment, practical competence.

Introduction. A digital environment offers extensive opportunities to connect theoretical concepts with practical activity in teaching network technologies. Students studying this subject need to develop skills in designing network topologies, implementing IP addressing, configuring switches and routers, deploying network services, and troubleshooting. These outcomes require regular, systematically organised laboratory work in addition to an understanding of lecture content.

Laboratories equipped with physical devices provide practical experience. However, the costs of purchasing and upgrading equipment, the limited number of devices, and restricted opportunities to practise outside the classroom complicate the learning process. Virtual laboratories enable students to repeat the same task, compare multiple configurations, and observe the consequences of errors in a safe environment. Simulation-based activities help visualise complex network processes and develop practical skills [2, p. 15670]. Simply introducing a virtual laboratory into teaching is insufficient. Software selection must match the learning objectives, students' level of preparation, and task complexity. The choice of network simulators should take account of the instructional purpose as well as technical capabilities [5, p. 52]. Organising virtual laboratory activities progressively, from simple to complex, is therefore methodologically important.

The aim of this study is to develop a methodology for using virtual laboratories at the foundational, professional practice, and integration stages of teaching network technologies in a digital environment, and to define the objectives, content, tools, and assessment criteria for each stage. The study employed pedagogical observation, comparative analysis, modelling, systematisation, and generalisation.

The proposed methodology is based on the principles of progression, practical orientation, learner autonomy, problem-based learning, and feedback. Progression means that each new task builds on previously acquired knowledge and skills. Practical orientation brings laboratory tasks closer to real network administration activities. Learner autonomy supports the transition from reproducing a prescribed procedure to solving problems independently. Feedback encompasses identifying an error, explaining its cause, and correcting it.

The first, foundational stage focuses on understanding network structure and basic configurations. The visual interface of Cisco Packet Tracer is appropriate at this stage: students place devices, create connections, assign IPv4 addresses, configure basic switching and static routing, and observe packet movement. The platform's straightforward controls help connect theoretical concepts with practical tasks

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[1, p. 165]. The teacher demonstrates a sample topology and then assigns individual tasks with modified conditions.

At the second, professional practice stage, students move from following prepared instructions to independent design and troubleshooting. Virtual machines, servers, and network operating systems are combined within a single topology in GNS3 or EVE-NG. Students complete scenarios involving VLANs, dynamic routing, DHCP, DNS, NAT, and network services. GNS3-based virtual laboratories expand the scope of practical activities when physical equipment is insufficient [7, p. 4291]. Tasks at this stage require students to explain their chosen solution as well as produce a final configuration.

At the third, integration stage, students combine several technologies and virtual devices within a single network project. Integrating MikroTik CHR into GNS3 or EVE-NG enables practical work with RouterOS-based routing, DHCP, NAT, firewall configuration, and user access control. Students receive a complex, problem-based assignment involving the design of an organisation's network, the development of an addressing plan, the configuration of services, compliance with security requirements, and the diagnosis of network faults.

Progression between stages is determined by demonstrated competence rather than merely by completion of a topic. By the end of the foundational stage, students should be able to construct a simple topology independently and verify connectivity. At the professional practice stage, they should be able to configure network services and identify the causes of faults. At the integration stage, they should be able to develop a comprehensive solution based on technical requirements.

The components of the stepwise methodology for using virtual laboratories are summarised in Table 1.

Table 1

Instructional component	Foundational stage	Professional practice stage	Integration stage
Objective	Master basic concepts and procedures	Perform complex configurations and troubleshoot faults	Develop a comprehensive network project
Main tool	Cisco Packet Tracer	GNS3 or EVE-NG	GNS3/EVE-NG + MikroTik CHR
Task type	Model-based exercise and simple individual task	Problem-based laboratory scenario	Project and case-based assignment
Teacher's role	Demonstration, instructions, and immediate support	Problem setting, consultation, and analysis	Expert assessment and reflection
Assessment	Correct topology and connectivity	Configuration, diagnostics, and explanation	Functionality, security, and justification of the solution

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A Three Stage Instructional Model for Using Virtual Laboratories

Table 1 presents the overall structure of the three-stage instructional model. Each laboratory session comprises motivation, orientation, practice, assessment, and reflection. The motivation component explains the relevance of the task to real professional activity. The orientation component sets out the problem, available resources, and expected outcome. During practice, students create and test a configuration. During assessment, the outcome is checked against established criteria. During reflection, errors and the chosen solution are discussed.

The foundational stage provides a high level of support: the teacher demonstrates procedures, supplies concise instructions, and gives immediate feedback on errors. In subsequent tasks, some steps are omitted to increase learner autonomy. At the professional practice stage, a problem scenario and technical requirements replace a prescribed procedure. At the integration stage, students plan and implement a network project, document test results, and defend their solution.

Assessment should extend beyond whether the final network functions. Process assessment considers the suitability of the topology, the correctness of the addressing plan, the sequence of configuration steps, the diagnostic approach, and the error-correction strategy. Final assessment examines connectivity stability, service functionality, security settings, and the quality of the justification for the solution. The educational effectiveness of a virtual laboratory depends on how the learning activities are organised [4, p. 8].

Checklists, configuration files, screenshots, brief explanations, and reflective notes can be used for formative assessment. After each attempt, students record the error that occurred, how they identified it, and how they corrected it. This approach allows the problem-solving process to be assessed rather than rewarding the copying of a completed result. The teacher identifies common errors across the group and develops additional explanations or differentiated tasks for the next session.

Independent learning tasks are assigned at three levels. At the reproductive level, students configure a network by following a model. At the productive level, they independently configure a network under modified conditions. At the creative level, they select the most appropriate option from several solutions and justify its advantages. This differentiated task structure supports students with varying levels of preparation within a shared laboratory environment.

The proposed methodology transforms virtual laboratory use from proficiency with a particular software application into a pedagogically guided activity. The logical progression between stages enables students first to master simple visual operations, then to implement configurations resembling those used in real environments, and finally to solve complex network problems independently. Selecting platforms according to learning objectives prevents technical complexity from obstructing understanding of the subject matter.

The instructional model enables teachers to specify the session objectives, task difficulty, level of support, and assessment criteria in advance. For students, it clarifies the expected outcomes and the requirements for progression to the next stage. In this respect, the virtual laboratory serves as a digital teaching tool that combines practical exercises, assessment, feedback, and reflection.

Effective teaching of network technologies in a digital environment requires the progressive use of virtual laboratories according to pedagogical objectives. Their use should not be arbitrary or determined solely by software capabilities. At the foundational stage, Cisco Packet Tracer supports the acquisition of basic concepts and procedures. At the professional practice stage, GNS3 or EVE-NG supports complex configuration and diagnostics. At the integration stage, virtual devices such as MikroTik CHR are incorporated into comprehensive project tasks.

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The effectiveness of the methodology depends on arranging tasks from simple to complex, progressively increasing learner autonomy, combining process and final assessment, and providing regular feedback. Future work should develop a digital system based on this model to manage laboratory tasks, automatically check configurations, and provide individualised instructional recommendations.

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