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PT Anywhere: a mobile environment for practical learning of network engineering

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PT Anywhere: A Mobile Environment for Practical Learning of Network Engineering

Alexander Mikroyannidis, Aitor Gómez-Goiri, Andrew Smith, and John Domingue

Knowledge Media Institute, The Open University, Milton Keynes, UK

The main challenges commonly associated with acquiring practical network engineering skills, are the requirements for access to specialised and up-to-date network equipment, as well as the high costs associated with obtaining and maintaining this equipment. The PT Anywhere initiative addresses these challenges by offering a mobile environment for acquiring practical knowledge and skills of network engineering. PT Anywhere facilitates learner-centred anywhere/anytime learning and offers learners access to high-quality interactive learning resources. Additionally, PT Anywhere employs Learning Analytics in order to help learners and educators in understanding and improving learning. This paper presents the learning design and software design principles driving the development of PT Anywhere, as well as the outcomes of an evaluation session conducted with members of the Cisco Networking Academy. The results of this evaluation indicate that PT Anywhere holds the potential to engage learners in different ways inside and outside of the classroom, without the need for access to specialised equipment.

Keywords: online experimentation; network engineering; interactive learning resources; mobile learning; open educational resources; learning analytics

Introduction

ICT is becoming a pervasive platform for the global economy and society. There are now almost 4 billion Internet users worldwide[1] with the number of smartphones

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[1] http://www.internetlivestats.com/internet-users/

growing to 6 billion by 2020.[2] As a result, an ICT skilled workforce and a digitally literate society is key to fulfilling the full potential for digital technologies. There exists however a significant gap in ICT skills. For example, it is estimated that about 40% of EU workers have an insufficient level of ICT skills and that there will be 800,000 unfilled vacancies for ICT professionals in Europe by 2020 (European Commission, 2016). Despite the fact that most future jobs will require ICT skills, a large portion of students do not have access to digital equipment. Additionally, the high cost of the specialised equipment required for teaching network engineering, compels many educators to reduce the hands-on time and enforce resource sharing, thus diminishing the experiential opportunity offered to their students (Frezzo, 2009).

The PT Anywhere[3] mobile environment aims at overcoming these barriers for acquiring hands-on networking engineering skills. Having the capacity to offer the same technological experience as the hands-on equipment, PT Anywhere offers educators and individuals access to rich computational resources that are embedded within interactive learning resources. This work is supported by the Cisco Networking Academy, a global initiative fostering the training of the next generation of Cisco network engineers. PT Anywhere extends Cisco's Packet Tracer network simulator, by offering a remote and mobile environment on top of the desktop-based Packet Tracer. This environment can be easily accessed from any web browser, thus eliminating the need for access to high-end simulation hardware. Additionally, PT Anywhere can be embedded as a widget inside interactive learning resources.

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[2] http://www.gsma.com/newsroom/press-release/smartphones-account-two-thirds-worlds-mobile-market-2020/

[3] http://pt-anywhere.kmi.open.ac.uk

The remainder of this paper is organised as follows. First, related work is presented in the fields of online experimentation, Learning Analytics, as well as mobile learning. We then proceed to introduce the learning design and software design principles of this work, followed by the software architecture, the Learning Analytics approach, as well as the evaluation of PT Anywhere. Finally, the paper is concluded and the future plans of this work are outlined.

Related work

Online experimentation and remote or virtual labs offer rich learning opportunities by allowing learners to control real or virtual equipment at distance in order to conduct scientific experiments. Remote and virtual labs build on top of numerous emerging technologies for supporting online experimentation and promoting the immersion of the learner in virtual environments recreating the real experience. There are different available methodologies in the literature for deploying remote and virtual labs. For example, the Virtual Labs project and the Excellent Teaching and Learning in Engineering Sciences (ELLI) project have investigated the lifecycle of simulation-based virtual labs (Bose, 2013; Frerich, Kruse, Petermann, & Kilzer, 2014; Hoffmann et al., 2016). On the other hand, the FORGE project has been focused on the deployment of remote experimentation labs (Marquez-Barja, Kaminski, Paisana, Tranoris, & DaSilva, 2015; Mikroyannidis et al., 2016).

Network simulation tools offer a virtual lab environment, where learners can experiment with a variety of virtual network devices and topologies. Currently, the network simulation tools most widely used in education are the Packet Tracer[4]

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[4] https://www.netacad.com/about-networking-academy/packet-tracer

simulator and the Graphical Network Simulator 3 (GNS3).[5] There exist several

comparison studies of these tools in the literature (Chou, Baker, & Vega-Herrera, 2016;

Makasiranondh, Maj, & Veal, 2010; Sari, Hatta, Wihidayat, & Xiao, 2018; Sun, Wu,

Zhang, & Yin, 2013). These studies indicate that both tools offer rich learning

experiences and have a positive impact on the learning achievements of students.

However, Packet Tracer offers a cleaner out-of-the box experience, thus limiting the

frustration factor for beginning learners.

Learning Analytics has recently emerged as a new field with applications on

online experimentation and beyond. Siemens (2012) defines Learning Analytics as "the

measurement, collection, analysis and reporting of data about learners and their

contexts, for purposes of understanding and optimizing learning and the environments

in which it occurs". The field of Learning Analytics is rapidly developing and it

gradually shifts away from technology towards an educational focus (Ferguson, 2012,

2017). It applies techniques from information science, sociology, psychology, statistics,

machine learning, and data mining to analyse data collected during education

administration and services, teaching, and learning. The Learning Analytics field creates

applications that directly influence educational practice. For example, the OU Analyse

project deploys machine-learning techniques for the early identification of students at

risk of failing a course (Nguyen, Huptych, & Rienties, 2018; Rienties, Cross, &

Zdrahal, 2017). The Go-Lab project employs Learning Analytics in order to foster

awareness, create individual scaffolds for students, as well as support teachers in

monitoring learning activities and better informed decision making (Rodríguez-Triana,

Vozniuk, & Gillet, 2016).

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[5] https://www.gns3.com

Finally, mobile learning offers opportunities for new learning experiences outside the classroom and encourages new forms of collaboration among learners (Crompton and Traxler, 2018; Heflin, Shewmaker, & Nguyen, 2017). Learners are involved in real problem-solving situations, which provide the motivation to collaborate with other learners. Learners can extend their classroom learning to homework and field trips, e.g. by reviewing learning materials on their mobile devices or by collecting and analysing data using dedicated mobile apps (Bano, Zowghi, Kearney, Schuck, & Aubusson, 2018). In the context of remote and virtual labs, mobile learning enables learners to perform scientific experiments, either individually or collaboratively, without the need for access to a traditional desktop or laptop device.

Learning design principles

Pedagogical background

PT Anywhere extends Packet Tracer, an established pedagogical network simulation tool used by the global Cisco Networking Academy educational community (DiCerbo et al., 2010). With around 50,000 uses per day and a reach of over 1 million users, Packet Tracer is typically used in situ to offer students experience of a diverse range of networking protocols, networking technologies and their interactions. Packet Tracer and PT Anywhere are leveraging the paradigm of providing a pedagogical simulated internet on the internet, in order to offer learners and educators a safe space for experiential learning.

Based on the Scandinavian activity theory (Engeström, Miettinen, & Punamäki, 1999), Packet Tracer and PT Anywhere extend the learning experience and Zone of Proximal Development (ZPD) of nascent network engineers (Vygotsky, 1978). This is accomplished by creating different simulated contexts and guiding the learner through

the practical experience of building and troubleshooting complex network systems. The teaching model employed extends the notion of situated learning (Moss and Smith, 2010). Lave and Wenger (1991) explore the space and place occupied by the student during the learning experience. By creating an instructional simulated network, the situation of learning moves from traditional in-class participation. In social constructivist terms (Palincsar, 1998), this is described as the 'cognitive apprenticeship', thus redefining the interaction between the 'master' and 'apprentice'.

Facilitating learner-centred anywhere/anytime learning

Being a desktop application inherently puts limitations to the ways Packet Tracer can be accessed and used by learners and educators. In PT Anywhere, the user only needs to access the front-end via a web browser, thus making the application ready-to-use. This contrasts with Packet Tracer's installation process, which is platform-specific and poses a prerequisite for anyone wishing to use Packet Tracer for the first time. Allowing learners and educators to access Packet Tracer regardless of the device they are using has been one of the main principles behind the design and development of PT Anywhere. PT Anywhere facilitates learning for anyone who wishes to experiment with network simulations at their own time and pace, both within informal and formal learning contexts.

Within the domain of distance and distributed learning, there is always a tension providing the impact of an extended ZPD. In PT Anywhere, the relationship between the educator (the master) and the learner (the apprentice) is mediated by the environment of the simulated remote lab technology. PT Anywhere moves the learning situation and ZPD of the learner from the classroom, as well as the cognitive apprenticeship of the immediate teacher/student relationship into the immediate and

situated personal domain of the learner. As a result, PT Anywhere is fostering a learner-centred experience, where the educator is a remote entity facilitating the educational experience. PT Anywhere thus becomes a mediator extending the experience beyond the tradition of a practical (physical) lab, offering a multitude of simulated scenarios, where the learner may engage synchronously or asynchronously in either local or global simulated networking activities.

Giving learners access to high-quality interactive learning resources

Historically, the tradition of skills development and knowledge acquisition in network engineering has been focused on a hands-on experience using real networking equipment. PT Anywhere has allowed us to emulate industrial experience by creating a cadre of curriculum embedded labs and practical exercises, the quality of which is ensured via a rigorous production process (Mikroyannidis, et al., 2016; Mikroyannidis, Domingue, Third, Smith, & Guarda, 2015).

In collaboration with the pedagogically and technologically world-renowned Cisco Networking Academy, we are leveraging the Open Educational Resources (OER) movement (Atkins, Brown, & Hammond, 2007) by developing interactive learning resources that are offered as self-study OER to learners and educators. Within these OER, learners use PT Anywhere in order to simulate different types of networks and understand how network technologies work and interact with each other. These simulations are presented to learners in the context of interactive exercises, thus offering reflection and self-assessment opportunities throughout the learning resources. Learners are also provided with a variety of instructional videos demonstrating the use of network equipment. A sample of these learning resources is available in the form of an interactive eBook available to download and study for free (Domingue et al., 2015).

Understanding and improving learning via Learning Analytics

When learners study materials online, they leave data traces. In particular, learners make decisions: what materials to study and in what order, as well as how to interact with the available exercises. Learning Analytics allows educators to record and analyse the learner traces to understand the trajectory being taken supporting the identification and intervention of learners who are struggling and of course material which may be problematic and require revision.

We have prioritised the integration of Learning Analytics into PT Anywhere in order to acquire an insight into the learning experience offered by our software, as well as obtain the means to continuously evaluate and improve this learning experience. In the context of the Cisco Networking Academy with millions of students taking Cisco courses each year, the embedding of Learning Analytics offers opportunities to both students and educators to benefit from the paths taken both by course alumni and peers.

Software design principles

The learning design principles of PT Anywhere have informed its software design, thus resulting in a software architecture that prioritises the measurability of the learning experience, availability across multiple platforms, interoperability, simplicity of the interface and scalability.

Measurable learning experience

From its conception, PT Anywhere aimed to help learners to use it more efficiently so they could maximise their learning goals. The first step to improve any baseline situation is to measure it, so PT Anywhere anonymously records users' interactions through embedded Learning Analytics. These actions can be analysed afterwards by

custom or third-party tools to give recommendations to students or drive teacher interventions. The visualisation tools that we have developed for this purpose are described in a subsequent section of this paper.

Multi-platform

The front-end of PT Anywhere has been developed using HTML5 and JavaScript. Therefore, it can be executed in most of the modern web browsers and in a wide variety of platforms like Windows, Linux or MacOS. Thanks to its responsive web design, students can use it through their mobile phones (e.g., in Android or iOS) or embedded in an eBook. While Packet Tracer also has versions for Windows, Linux, Android and iOS, the last two are versions with limited functionality. Since the only thing it changes across platforms in PT Anywhere is the layout (i.e., no functionality is removed), we can ensure a consistent user experience across platforms.

Interoperable

The IEEE defines interoperability as "the ability of two or more systems or components to exchange information and to use the information that has been exchanged" (IEEE Inc., 1990). This exchange with PT Anywhere is ensured thanks to widely-accepted standards and can happen at different levels: (1) the functionalities can be used by any web application (e.g., to create new front-ends or mash-ups with other web apps) and (2) the data recorded can be exploited by any authorised tool.

The first goal is achieved through an HTTP API that shares most of the REST principles and a WebSocket API. The second one thanks to the Tin Can API, which is a specification for learning technology that allows to record experiences of a person in a flexible and simple way. Finally, it is worth mentioning that the use of HTML in the

front-end can make the latter easier to be interpreted by screen-readers, in comparison to interpreting desktop applications such as Packet Tracer. This feature therefore enhances the potential of PT Anywhere to act as an accessible network simulator.

Simple interface

One of the key features of PT Anywhere is the simplicity in the front-end design. Rather than replicating all the options that Packet Tracer offers, we have created a simple graphic user interface where the user can edit the topology (i.e., to create, remove and configure devices and links) and access the command line interfaces of the different devices in this topology. These are the two main features that we were expecting learners to use in conjunction with the offered OER. However, the front-end can be adapted and extended to address future teaching and learning needs.
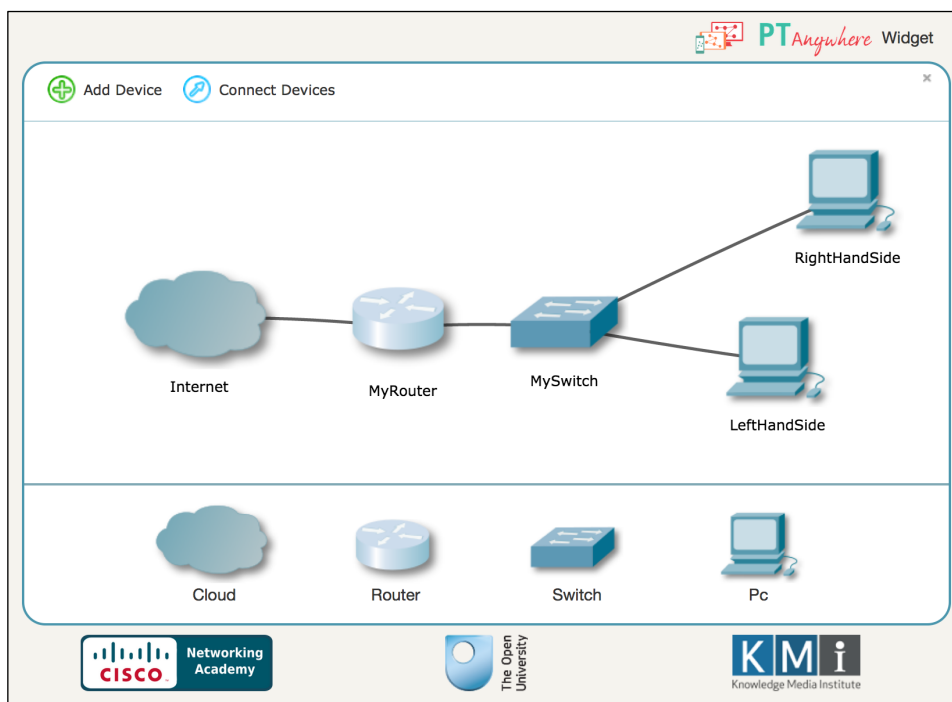

Figure 1. The default network topology of PT Anywhere.

Figure 1 shows the default network topology of PT Anywhere, which consists of

a single router, a single switch and two personal computers. The 'Internet' in this context is a connection to the underlying remote Packet Tracer server offering connectivity on the simulated internet. With a single router, the learner can see an entire network infrastructure as well as complete a range of complex networking skills. Additionally, learners may add more devices to the topology via the bottom panel of the interface.

Scalable

As PT Anywhere has been made publicly available, it needs to be scalable to allow as many learners as possible to simultaneously access it. To this end, we first optimised the most resource consuming part of PT Anywhere, i.e. the Packet Tracer instances running in the back-end. Figure 2 and Figure 3 show how vertical scalability can be achieved by improving the server where these instances are executed.
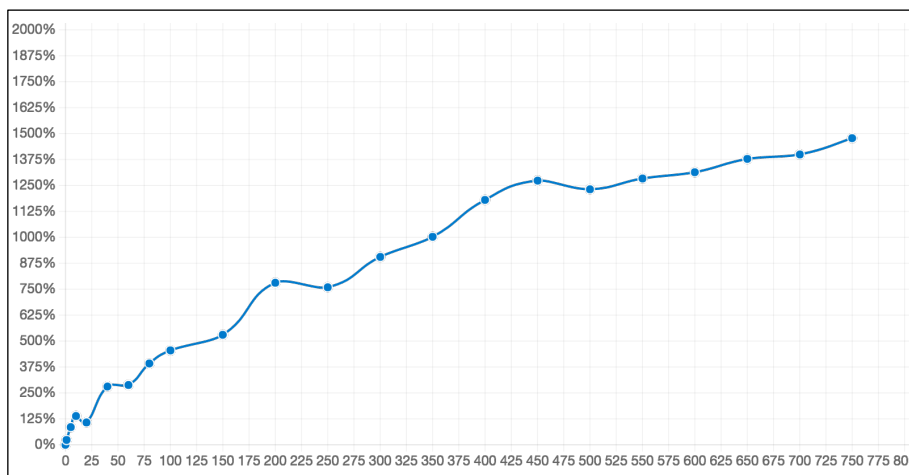

Figure 2. CPU usage per Packet Tracer instances running in a machine with 16 cores (maximum is 1600%).
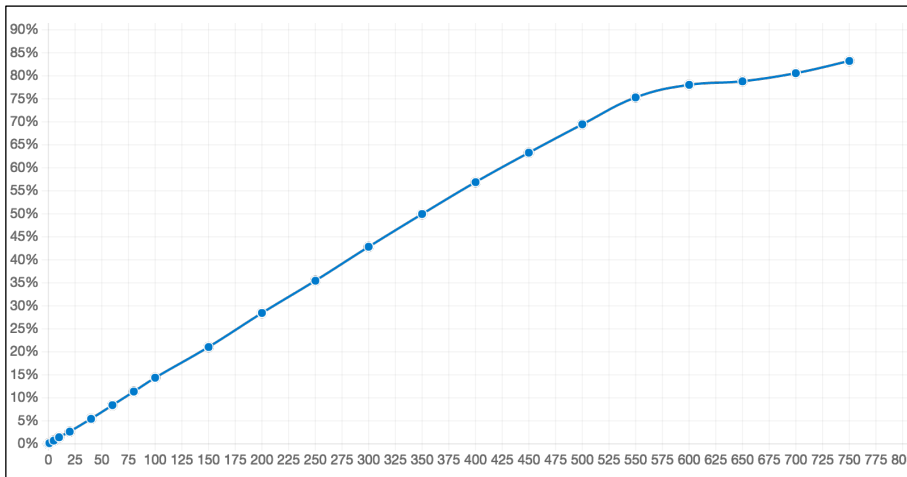
Figure 3. Memory usage per Packet Tracer instances running in a machine with 125GB of RAM memory.

However, PT Anywhere's design also allows horizontal scalability by adding new machines, which can create new Packet Tracer instances that the main web server can use transparently. In this way, the architecture avoids any bottleneck in the servers providing Packet Tracer instances.

Software architecture

The front-end of PT Anywhere is invoked by HTTP clients, which can be desktop or mobile browsers. The front-end is a JavaScript library which generates the HTML graphical components needed to interact with a Packet Tracer instance running in the back-end. This library makes requests to a public HTTP API, which abstracts the back-end. For each client, the API intermediates with an actual Packet Tracer instance managed by a machine called Packet Tracer Manager (PTM). The API relies in one or more PTMs to allow horizontal scalability.

Each PTM can handle one or more Packet Tracer instances and exposes an internal API to abstract this functionality. Each Packet Tracer instance will run in its

own isolated lightweight Docker container.[6] Containers are pre-started to reduce the session initialisation time. Furthermore, PTM reuses containers from expired sessions because this alternative is faster than discarding an old container and creating a new one. Clients will be unaware of this reuse, as the default network topology is always shown in the front-end at the beginning of every session.
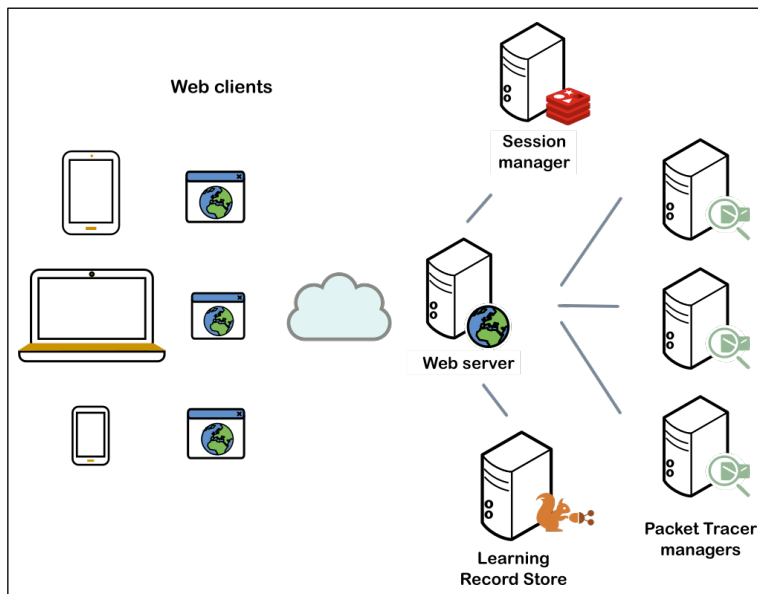

Figure 4. The PT Anywhere software architecture.

The API stores session specific data in what we call session manager (see Figure 4). This manager is a Redis instance with two databases. The first one stores the minimal amount of information needed to identify the Packet Tracer instance being used by the session and the second one can be optionally used as a cache to speed up

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[6] Docker Containers allow the creation of independent execution environments, which run on a single machine, share the same operating system kernel, are constructed from layered filesystems and share common files. This allows them to use less RAM and optimize disk usage.

Packet Tracer information retrieval. Optionally, the API can also record the student interactions in a Tin Can API compliant Learning Record Store (LRS), as described in the following section.

Learning Analytics

All interactions of learners with PT Anywhere are captured via the Tin Can API (also known as xAPI), a specification well established within the learning community, which aims at enhancing SCORM in simplicity and flexibility (Poltrack, Hruska, Johnson, & Haag, 2012). The Tin Can API records data in statements that conceptually capture a learning activity. These statements are composed by the following elements:

- *Subject*: The subject identifies who is learning. In PT Anywhere, students are anonymously identified.

- *Verb*: The verb defines the type of action that the student has carried out. In PT Anywhere, we have reused the following verbs from the Tin Can API registry:[7] "initialized", "terminated", "created", "deleted", "updated" and "used".

- *Activity*: The learning activities recorded by PT Anywhere are "Widget", "Device" (in the topology), "Link" (between devices) and "Command line" (the command line interface has been accessed for a simulated device). These activities have an associated result that identifies details for the instantiation of an activity, e.g., the name and type of the created device.

- *Context*: The context stores a session ID or categorises activities (e.g., a

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"Device" is a "Simulation activity" descendant). More detailed documentation is available in the PT Anywhere web page on GitHub.[8]

A dashboard has been developed in order to help teachers and students in carrying out exploratory analysis of the recorded data. The dashboard filters the recorded data by date or other features, such as the number of commands typed in the command line interface of PT Anywhere. The dashboard offers several diagrams which summarise data for a group of sessions:

- A histogram showing the number of sessions initiated per hour, which helps to understand the load of PT Anywhere.

- A histogram showing the distribution of sessions per number of user interactions.

- A scatterplot showing sessions per number of interactions and time.

- A state diagram visualising the steps followed in multiple sessions. This type of visualisation helps in identifying usage patterns.

The following visualisations are also available for each session, allowing an educator to inspect in more detail a student's session and a student to later review their own session or a session of another student:

- *The script of the session:* This script is an enumeration of the actions/interactions for the student.

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[8] https://github.com/PTAnywhere/ptAnywhere-api/wiki/Vocabulary-used-to-capture-user-interaction

- *A state diagram:* This is a graphical representation of the steps (i.e., learning activities) that the student followed. It is similar to the one used to visualise the steps for many sessions, but only showing the steps of one session.

- *A re-player:* This is a replica of the PT Anywhere user interface where the session can be replayed mimicking what the user viewed/experienced. The re-player allows to restart or pause the replay and to adjust its speed (e.g., to see it 16 times faster).

Evaluation

Methodology

In the context of this evaluation, qualitative and quantitative feedback was collected from educators and learners, in order to explore how they would complete a locally situated activity extending ZPD into their own space using a predefined experiment. Additionally, Learning Analytics data was collected in order to track the behaviour of each participant, as well as the collective and thus inform instructional design.

The evaluation was performed as an online asynchronous session that spanned over a 24-hour period. Participants were recruited from the Cisco Networking Academy on a voluntary basis. Every participant was asked to register in advance via an online form. In total, 390 participants were registered before the evaluation session. These were a diverse mix of Cisco Networking Academy tutors, students and alumni, both from the UK and abroad.

On the day of the evaluation, all registered participants were sent an email with instructions on how to join the evaluation session. In particular, they were provided with

a link to an online form containing step-by-step instructions. Participants were exposed to the PT Anywhere OER and were asked to use PT Anywhere in order to complete two networking simulation exercises. Subsequently, participants were asked to answer a bespoke questionnaire.

The questionnaire used in this evaluation was aimed at assessing the ease of use and learning effectiveness of PT Anywhere and its OER. It was mainly comprised of a set of statements to which the respondent is requested to record his/her level of agreement via a 5-Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire also included demographic questions and open-ended questions about the perceived pros and cons of PT Anywhere.

Questionnaire responses

A total of 111 responses were received to the evaluation questionnaire. All responses were recorded anonymously. Participants were predominantly males with a good distribution between all age groups (see Figure 5). Almost all participants (98%) declared that they have at least some knowledge of network simulations, which was expected as they are all members of the Cisco Networking Academy. Approximately one third of the participants declared that they are experts in the field of network simulations.
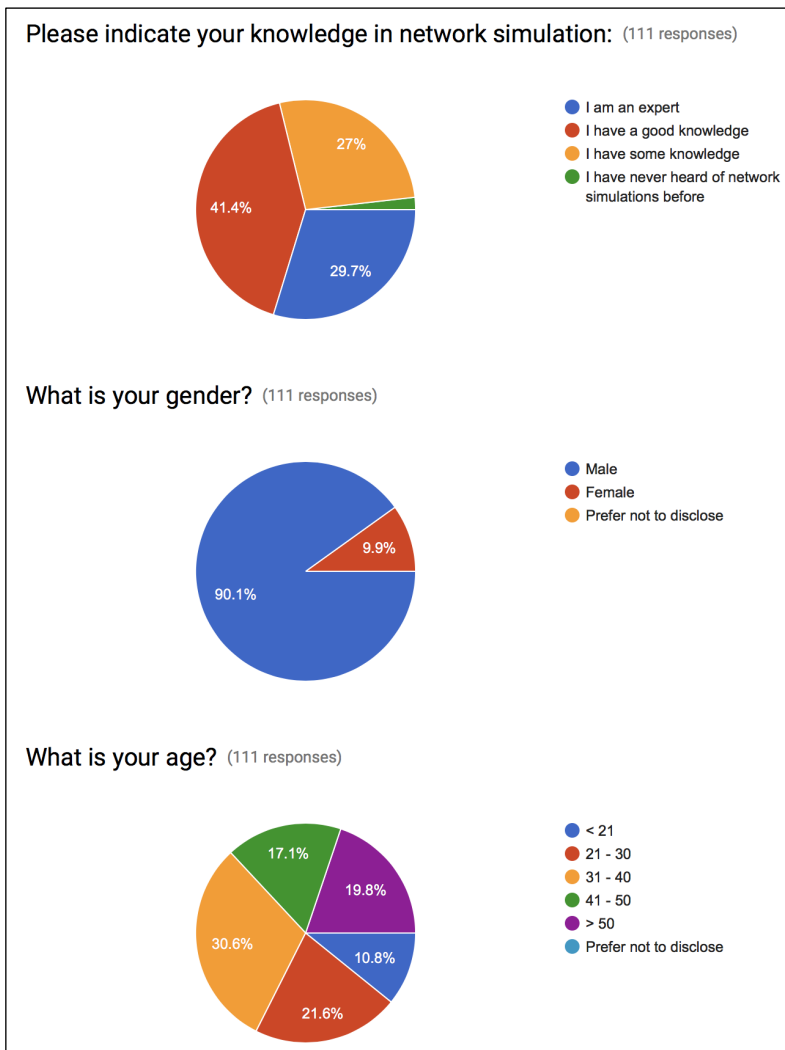
Figure 5. Demographic profiles of evaluation participants.

Figure 6 shows the responses to the Likert-scale questions, regarding the perceptions of participants about the quality, ease of use and learning effectiveness of PT Anywhere and its OER. As it can be seen, very low percentages of disagreement with all statements were recorded. The respondents expressed strong agreement especially regarding the ease of use of the offered learning content, the appropriateness of this content to their background, the quality of the content, as well as the clarity of the learning outcomes and structure of the OER. Additionally, the majority of respondents (63%) agreed that they would continue using PT Anywhere beyond the scope of this evaluation session.
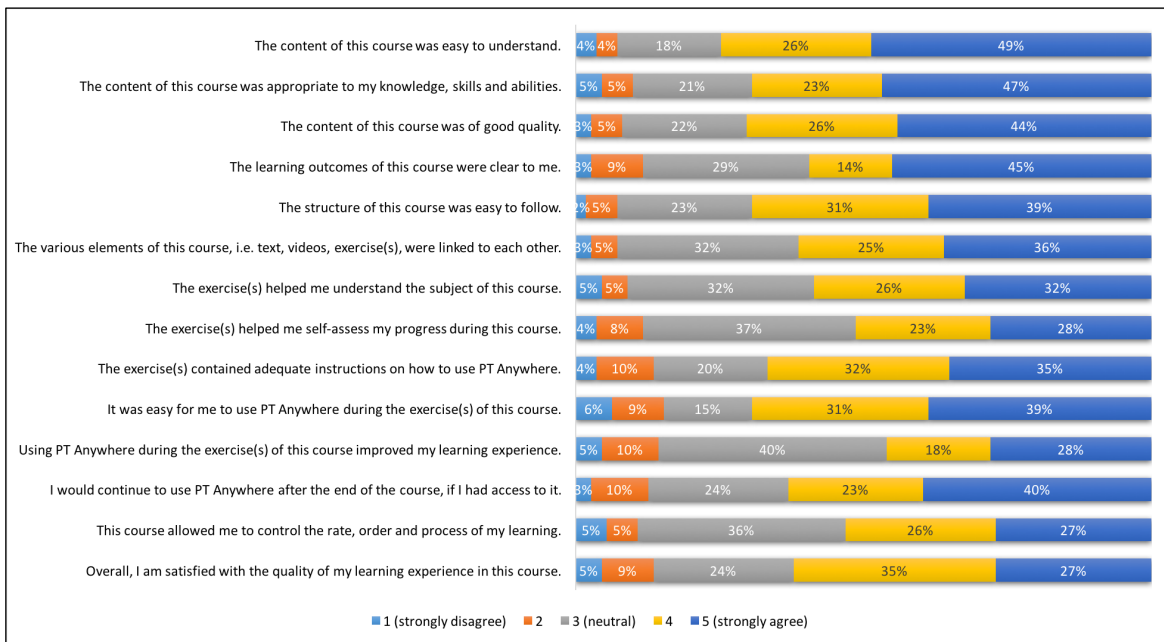
Figure 6. Responses to Likert-scale questions.

Nevertheless, a high percentage of neutral opinions was recorded regarding the use of the exercises for self-assessment (37%), as well as the ability to control the rate, order and process of learning (36%). 40% of the respondents also expressed a neutral opinion as to whether the use of PT Anywhere improved their learning experience. These results indicate that the structure and pedagogy of the OER can be further improved in order to better facilitate self-study and self-assessment, as well as offer better pedagogical integration with PT Anywhere.

The questionnaire also included some open-ended questions about the 3 things participants mostly liked about PT Anywhere, as well as 3 possible improvements participants would suggest. Overall, PT Anywhere was very positively received by participants. The fact that complex desktop-only simulation software (Packet Tracer) has been made available via a simplified interface on a mobile device received the most positive comments, as outlined in the following responses:

"This is really a great tool to have and I would love to use this on a permanent

basis. I take my iPad everywhere and any spare minutes I have, I study the Cisco course and it will be so useful having this to hand."

"Overall a very pleasing experience for an online tool. Personally, I would prefer a similar layout to that of the actual PT; though I understand why it needs to be kept simple!"

"The ability to use the Packet Tracer software within a web browser is very useful for a school like mine where PC's have old, incompatible versions of both Packet Tracer and Java."

Several bugs and possible improvements to PT Anywhere were also reported. Participants mostly pointed out time lags in the execution of commands. They also indicated the need for more types of networking simulation elements (e.g. devices, cables) to be available for use within PT Anywhere:

"At present, the interface for PT Anywhere is rather laggy which can detract from usability."

"Very sluggish response in the virtual terminal"

"Improve speed; add more device types"

"More Modularity, Types of cable connections, Models of the routers in GUI...etc."

Finally, most respondents agreed that PT Anywhere cannot replace the Packet Tracer software, but instead it complements the original software, as it offers opportunities to be used in different mobile learning contexts via different devices and platforms.

Learning Analytics data

The Learning Analytics data recorded during the evaluation session provide valuable information about how users interact with PT Anywhere, in addition to their own judgments provided via their responses to the questionnaire. Using this data, we can determine which users completed each task or the time they invested in each task, thus allowing us to quantify their engagement level.

Figure 7. State diagram of the steps followed in multiple PT Anywhere sessions.

The state diagram of Figure 7 shows the most frequent series of steps followed by participants when using PT Anywhere. As it can be seen, most participants started interacting with the command line interface from the very beginning, without making any changes to the simulated network topology. This is consistent with the main focus of the given exercises, which required participants to execute a series of commands.

Table 1. Extracted features per session.

Name	Description
Session duration	Time elapsed between a session start and its last registered activity.
Exercise completion	Whether or not the user completed each exercise successfully.
Number of learning activities	Learning activities classified as "create' (device or link), delete (device or link), "update" (device) or "cmd" (use of device's command line).
Most used commands	The ten most used commands (counting aliases as normal commands): ?, ipconfig, configure, do, exit, enable, interface, end, sh, no, hostname, show, ip, ping.

Table 1 summarises the extracted features per recorded user session. Analysing the correlation of these features (see Figure 8), we see a strong positive linear correlation between passing the first exercise and passing the second one. Furthermore, both of them are correlated to the number of times the "ping" command was typed. These correlations are explained by the fact that the second exercise was an extension of the first one and in both of them the ultimate goal was to make a successful ping.

The heatmap chart of Figure 8 also reveals which commands are usually executed together. For example, "enable" and "configure" are executed together because to configure a device a user usually needs to be in the privileged mode. When it comes to activity types, creating a link or a device often comes accompanied by a removal activity. Information like this can drive educators to emphasise the explanation for these commands, or to include contextual hints activated after a long inactivity period as an engagement strategy for students that face difficulties.
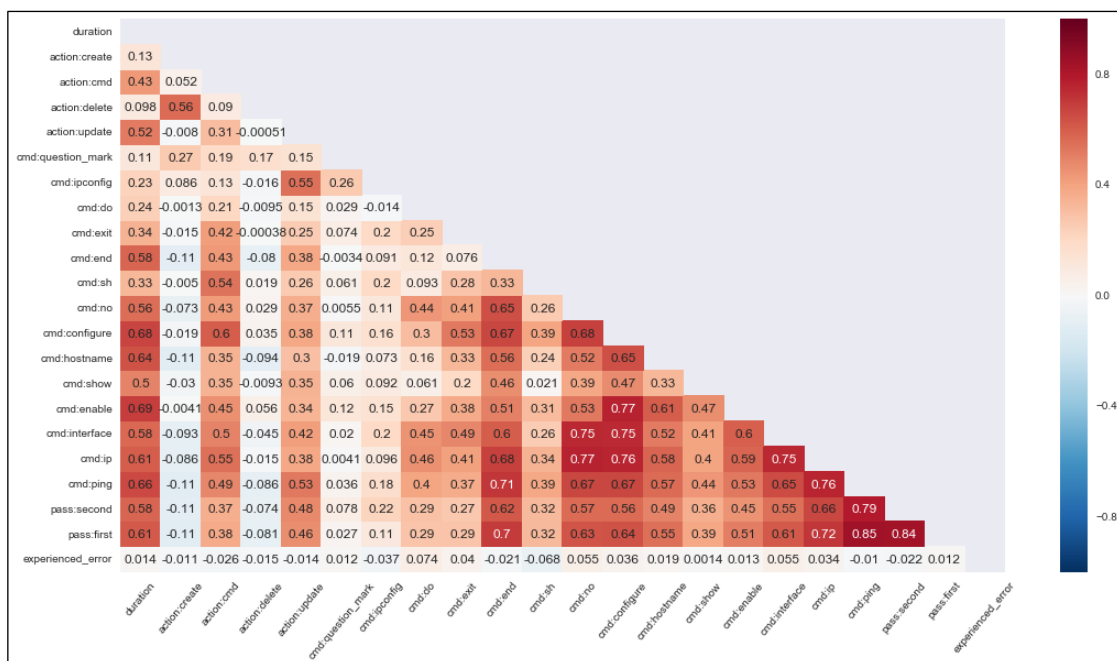

Figure 8. Heatmap chart of feature correlations.

Conclusions and future work

This paper has presented PT Anywhere, a mobile environment based on three main principles: facilitating learner-centred anywhere/anytime learning, giving students access to high-quality interactive learning resources and understanding and improving learning via Learning Analytics. Following these principles, PT Anywhere has been designed with the goals to: be multi-platform, interoperable, have a simple interface, be scalable and measure learning experience.

PT Anywhere inherits the pedagogical principles upon which Packet Tracer was built, i.e. experiential learning and situated learning. PT Anywhere also builds on top of the powerful software architecture and services of Packet Tracer that allow learners to accurately simulate Cisco networking devices. On the other hand, PT Anywhere is differentiated from Packet Tracer by offering mobile learning opportunities, thus facilitating ubiquitous learning. Furthermore, PT Anywhere extends the software architecture of Packet Tracer by offering a simple, mobile and responsive interface, instead of a desktop-based interface that requires a local installation of the software.

The resulting environment and its complementing OER enable learners and educators to engage with network engineering learning materials and experiment with network simulations from their mobile devices wherever they are and whenever they want. The evaluation that was carried out has provided us with valuable insights into how PT Anywhere and its OER have been received by the community of network engineers, as well as how they can be further improved.

The next steps of this work will be directed towards the further development of PT Anywhere and its OER, in order to address the shortcomings and limitations identified during the evaluation with members of the Cisco Networking Academy. The extensive expertise of this community of network engineers will be employed in order to improve the learning experience offered by PT Anywhere. One of the learning experience improvements we will be exploring is the automatic adaptation of learning to the learner's situation through personalised recommendations and monitoring, thus taking advantage of the potential of Learning Analytics. Additionally, we plan to apply the lessons learned from the development and deployment of PT Anywhere to other simulation areas besides network engineering. Finally, we will be further leveraging the open education movement by joining forces with well-established open education

initiratives, such as the OpenLearn project.[9] These synergies will allow us to engage a wider audience and reach additional educational communities towards addressing the global gap in ICT skills.

Acknowledgments

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