Artificial Intelligence tools and applications to promote the students' learning in Network Engineering courses

Herramientas y aplicaciones de Inteligencia Artificial para mejorar el aprendizaje de los estudiantes en asignaturas de Ingeniería de Redes

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Abstract- Network engineering is an essential knowledge field. But this thematic is very conceptual and abstract, and it is extremely complicated to illustrate through educative experiments. Thus, learning activities tend to be complex and theoretical. Consequently, academic results in Network Engineering courses are typically poorer than the average, and students suffer a lack of motivation and interest. Therefore, a pilot experience was conducted in Universidad Politécnica de Madrid, in order to address this challenge. Students in Network Engineering courses collaborated in heterogenous groups with Artificial Intelligence students, to design and implement a next generation traffic engineering application based on Artificial Intelligence tools. Thanks to artificial intelligence and "Learning by Doing" paradigm, network engineering students can create applications with a tangible result and consolidate their knowledge. Using surveys and official academic results, the improvement in the students' learning was measured during this pilot experience. A moderately significant advance was reported.

Keywords: Network Engineering; Artificial Intelligence; Collaborative Learning; Learning by Doing; Heterogenous groups; Universidad Politécnica de Madrid

Resumen- La Ingeniería de Redes es un área de conocimiento esencial. Pero se trata de una temática compleja y abstracta, sobre la que es difícil plantear experimentos educativos tangibles. Por ello, las actividades de aprendizaje suelen plantearse de manera teórica. En consecuencia, los resultados en las asignaturas del área de Ingeniería de Redes tienden a ser más pobres que la media, y los estudiantes a sufrir falta de interés y motivación. Por ello, se llevó a cabo una experiencia piloto en la Universidad Politécnica de Madrid, para tratar de abordar este problema. Los estudiantes de las asignaturas de Ingeniería de Redes colaboraron en grupo heterogéneos con estudiantes de Inteligencia Artificial para diseñar e implementar una herramienta de ingeniería de tráfico de próxima generación. Mediante las técnicas de inteligencia artificial y el paradigma de "Aprender Haciendo" los estudiantes de Ingeniería de Redes pudieron crear aplicaciones con un resultado tangible y consolidar su aprendizaje. Mediante encuestas y los resultados académicos oficiales, la mejora en el aprendizaje de los estudiantes fue medido durante la experiencia piloto. Un avance moderadamente significativo se comprobó.

Palabras clave: Ingeniería de Redes; Inteligencia Artifical; Trabajo Colaborativo; Aprender Haciendo; Grupos heterogéneos; Universidad Politécnica de Madrid

1. Introduction

Network engineering is one of the key technologies in the current digital revolution (Tomcos et al., 2020). Every modern communication system is designed according to the traffic theory and the computer network principia. Because of this fact, several job opportunities are directly or indirectly related to services, businesses, or innovations in network engineering. So, it is a discipline with a huge interest and added values for higher education students. Specially for Information Technologies (IT) students. But it also presents an important challenge. Network engineering and traffic theory is supported by abstract mathematical models (such as Poisson distributions, Markov models, etc.), and refers to large infrastructures and populations which are very difficult to visualize or imagine. Besides, some assumptions are not fully realistic and are not related to the daily experience of students (for example, the network congestion scenarios). On the other hand, educative experiments in the field of network engineering are extremely difficult to design and deploy. First, a controlled replica of an extensive network is required to emulate and manipulate traffic flows. This is only possible in a specific lab, with professional network equipment, which is not usually available (because of its high price). Nowadays other approaches to replace that equipment are being studied (such as virtual containers) but their performance is still poor (Hassan, 2022). Secondly, results from these experiments are not tangible or deterministic. Congestion scenarios, traffic balance… and other similar scenarios may show different outputs, as network engineering is basically a probabilistic field. Besides, the idea of "uncongested device" is not tangible and difficult to check using indicators such as the connection delay, for example. As a result, learning activities in network engineering courses tend to be complex and theoretical. With an extensive use of equations and probabilistic models, and a very limited number of lab practices and other experimental actions.

Consequently, academic results in those Network Engineering courses are significantly poorer (in average) than the medium results obtained by students in the entire degree. Not only that, but students also report low motivation levels in the annual surveys carried out by the University, in the context of the Internal Quality Assurance System (IQAS). Besides,

DOI: 10.26754/CINAIC.2023.0039

absenteeism rates are very high, because of the limited interest the students feel towards these contents.

On the contrary, Artificial Intelligence (AI) courses show an extraordinary performance (Ouyang et al., 2022): students report a very high motivation level, the students' interest towards this discipline is very significant too (probably because some of the most disruptive innovations in the last five years are related to AI), and many software frameworks, data repositories and other open resources are available to design and implement educative lab practices. But Network Engineering and AI are not as different as it could be imagined. First, both fields are based on probabilistic models. Secondly, both technologies need large data flows and/or populations to really be functional, fulfill the assumptions of the mathematical models and operate with the expected performance. Finally, AI applications can handle complex hidden patterns and non-tangible properties. It is enough to prepare a labeled dataset where the interesting situations are clearly identified and classified. Actually, some innovative network engineering applications (such as next generation firewalls or antimalware suites) are integrating AI mechanisms in order to improve their performance, although they are still prototypes or beta version in most cases. But they could be mature enough for an educative scenario.

This was exactly the situation in the Computer Engineering and IT degrees in the Universidad Politécnica de Madrid (Spain). In this context, it seems obvious to design an educative scenario where AI students and Network Engineering students could cooperate and work together. So, AI students can help Network Engineering (NE) students to build next generation (tangible) applications, lab practices and other similar learning activities which could make them achieve better academic results and feel more motivated and interested towards Network Engineering topics. Therefore, during the course 2022/23 in Universidad Politécnica de Madrid a pilot experience was carried out, in order to implement and test the real impact of this AI-NE cooperation in the students' learning. Students in Network Engineering courses created heterogeneous work groups together with students from Artificial Intelligence courses. Groups included from four to six people. And they should include at least two members from each specialty. Students collaborated to design and implement a next generation Network Engineering tool (a traffic filter, specifically) based on Artificial Intelligence technologies. Learning activities in Network Engineering courses were reorganized according to the "Learning by Doing" paradigm (Iftikhar et al., 2022), so every session included a short theorical introduction and a collaborative work time to continue with the next generation tool implementation. Besides, Artificial Intelligence courses were reorganized too, so their schedule allow students to participate in, at least, 30% of the sessions of Network Engineering courses. Learning evaluation was based on the daily work, the implemented NE tool, a written report, and the oral presentation.

The rest of the paper is organized as follows. Section 2 describes the context and methodology. Section 3 presents the results. And finally, Section 4 concludes the paper.

2. Context & description

In this section, the educative context is provided (Subsection 2.A), together with the pilot experience description with details (Subsection 2.B) and, finally, the research methodology we implemented (Subsection 2.C) in order to evaluate the impact and improvement achieved through this pilot experience.

A. Educative context

The Universidad Politécnica de Madrid offers two different degrees where Network Engineering have a very significant weight: Computer Engineering (CE) and Information Technologies (IT). In those two degrees, up to three different courses work Network Engineering principles and theory: Computer Networks (CN), Advanced Networks (AN) and Network Security (NS). Additionally, some optional courses such as Network Management (NM) could be also enrolled by students. Each one of these courses had an academic weight of 6ECTS (European Credit Transfer and Accumulation System) and thirty in-person sessions (sixty hours in total) homogenously distributed along fifty weeks. Specifically, for this pilot experience, we chose the course "Advanced Networks" as educative framework. Other subjects could join the experience in the future.

AN is course whose main objective is to work the competencies and abilities required to design, deploy and manage networked telematic services. That includes data formats such as JSON (JavaScript Object Notation), remote interfaces such as REST (Representational State Transfer), networking paradigms such as Publication/Subscription and cloud security mechanisms, among other topics. To achieve that objective, the AN course includes six thematic units. Namely:

- Fundamentals (U1): Quality-of-Service, Service Level Agreement, etc.
- Tele-traffic theory (U2): Erlang-B, Erlang-C, Engset
- Data formats (U3): XML, JSON
- Service description and deployment (U4): WDSL, HTTP
- Traffic engineering (U5): conformation, filtering
- Network structures (U6): sockets, endpoints, and tokens

Table I shows how all these units are distributed in time. Besides, it is shown the relative weight of every unit in the final marks. AN is a course in the third year of both degrees (CE and IT) and, typically, around seventy enrolled students are attending this course. Most of these students (96.3%) are men, as can be seen in Table II. Besides, the mean age is 21.7 years.

TABLE I. AN THEMATIC DISTRIBUTION AND EVALUACTION

Units	Schedule (weeks)	Evaluation weight
U1	1	10%
U2	2-4	20%
U3	5	10%
U4	6-7	10%
U5	8-12	30%
U6	12-15	20%

TABLE II. POPULATION STATISTICS (AN COURSE)

Participants	Women (percentage)	Mean age (years)	Deviation age (years)
66	3.7%	21.7	2.2

Evaluation in the AN course is based on short questionnaires, theoretical analyses and rubrics, which are publicly distributed during the first week (see Figure 1). These rubrics, as well as all educative materials are available in digital formats through the institutional Learning Management Systems (Moodle).

Nivel Aprendizaje / Criterios	Bajo (0%)	Poco (25%)	Medio (50%)	Bueno (75%)	Excelente (100%)	Nota
Claridad de la exposición (35%)	La presentación no es coherente y resulta imposible de seguir	La presentación no es poco coherente y resulta difícil de seguir	Algunas secciones de la presentación han sido claras, pero otras han resultado confusas y complejas	La presentación ha sido clara y coherente en general, aunque han existido pequeñas imprecisiones	La presentación resulta coherente y suficiente	
Solvencia y dominio del contenido (35%)	Los alumnos no han demostrado dominio de las tecnologías y procesos necesarios	Los alumnos han demostrado escaso dominio de las tecnologías y procesos necesarios	Han existido claras lagunas en la forma de expresarse y presentar el diseño	En general los alumnos han demostrado dominio del proyecto y la tecnología, pero con ciertas inconsistencias	La presentación ha sido solvente y los alumnos han demostrado	
Materiales (30%)	Los materiales de apoyo no han existido	Los materiales de apoyo han sido de muy escasa calidad	Los materiales de apoyo utilizados resultan de calidad escasa, con estilo poco cuidado y falta de información	Los materiales son en general válidos y coherentes, aunque hay algunos aspectos que pueden mejorar	Los materiales ayudan a comprender la presentación	
Total						

Figure 1. Evaluation rubrics (example)

On the other hand, Artificial Intelligence students enrolled different subjects such as Temporal Series (TS) or Big Data (BD). All of them with an academic weight of 6 ECTS. For this pilot experience, we chose as academic framework the course "Temporal series". The objective of the TS course is to work the abilities and competencies related to the data flows manipulation, hidden patterns detection and supervised learning and classification, among other similar topics. Specifically, students learn about Artificial Intelligence technologies such as the multilayer perceptron. This course is structured in five different thematic units. Namely:

- Data segmentation and decomposition techniques
- Filters: smoothing
- Data prediction and correction
- Intelligent classification: neural networks
- Multilayered systems

The TS course was organized in thirty in-person sessions too, during a period of fifteen weeks. The evaluation methodology and details are not relevant for this pilot experience, as there were not modified. As in the AN course, most of these students (65%) are men, as can be seen in Table III. Besides, the average age is 26.5 years old.

TABLE III. POPULATION STATISTICS (TS COURSE)

Participants	Women (percentage)	Mean age (years)	Deviation age (years)
53	35%	26.5	3.2

Both subjects (AN and TS) are scheduled in the same quarter (February 2023 – June 2023), and not student is enrolled in both subjects are the same time: populations are disjoint.

B. Experience description

The main action in the proposed pilot experience is the creation of heterogenous work groups between Network Engineering and Artificial Intelligence students. Through this groups, we plan to promote the motivation and interest of Network Engineering students, as well as improve their academic results. The design and implementation of tangible, functional and practical tools, and applications we hope will contribute to this objective. To allow this kind of activities, the AN course was reorganized.

First, the evaluation system changed. Students followed a Learning-by-Doing paradigm where they had to design and implement a next-generation traffic tool. This tool was an intelligent traffic filter, to avoid congestion situations and slow Denial-of-Service (DoS) attacks. The tool employed well-known datasets to train a multilayered perceptron (Heidari et al., 2020), whose output should be an alert when the network is close to congestion of under a DoS attack. To deploy this solution, network engineering tools such as eBPF (extended Berkeley Packet Filter) must be employed. Students were provided with documentation, including a description with details about the tool to be implemented, its requirements, expected performance, materials to be employed, etc. Students were requested to submit their code, together with a final report with all the design details and results, to the institutional LMS (Learning Management Systems). Additionally, all students had to preset their proposals in a public oral presentation. Four basic items were evaluated regarding this intelligent tool:

- Daily work (20%)
- Technical performance (30%)
- Written report (25%)
- Oral presentation (25%)

Second, the schedule and course organization were updated too. Students were asked to create heterogenous working groups. Each group include between four and six people with different backgrounds. At least, two students from each course (AN and TS) should be part of each group. Groups could be organized by students, but professors help them when needed. In-person sessions of both courses (AN and TS) were synchronized, so students could attend any of them indistinctly with no perturbation of other courses or activities. Artificial Intelligence students were asked to participate in, at least, ten in-person sessions of AN course. Table IV shows the final course discussion and organization during the pilot experience.

TABLE IV. AN THEMATIC DISTRIBUTION AND EVALUACTION

Week	Activities	Week	Activities
1	U1 and presentation	9	U5. Fifth and sixth work sessions
2	U2	10	U5
3	U2. First and second work sessions	11	U5
4	U3	12	U5. Seventh and eight work sessions
5	U3	13	U6
6	U4. Third and fourth work sessions	14	U6
7	U4	15	U6, nineth and tenth work sessions and oral presentations
8	U5		

TS students, as they are not evaluated according to their participation in this pilot experience (but according to the usual criteria), could obtain up to two additional ECTS (optional) as a reward for their effort.

C. Research methodology

In order to validate the proposed action as a successful methodology to improve the students' results and motivation in Network Engineering courses, the following research methodology was implemented. Results from official surveys and academic results from the previous year (2021/22) were employed as control group. As can be seen in Table V, both populations were similar and comparable.

TABLE V. POPULATION STATISTICS (PILOT GROUP)

Participants	Women (percentage)	Mean age (years)	Deviation age (years)
68	5.5%	22.3	3.1

After finishing the educational period (June 2023), the official academic results were published (using the standard Spanish decimal scale, where 10 points refers the maximum learning and best performance). Besides, the institutional surveys analyzed the general motivation and interest of students towards each content, learning activities and subject. Surveys were fully anonymous and no information about the responders is available. Answers to the institutional surveys followed a Likers scale, where the maximum punctuation (5) means “Totally agree”, while de minimum (1) means “Totally disagree”. These surveys include up to eight different questions about every course, but only two of them were relevant for this study. Namely:

- Question#4: The lab practices and other activities are interesting and helpful to improve my learning.
- Question#8: In general, I feel satisfied and motivated with this course.

Using these inputs, statistical tests were employed to analyze if a significant improvement is achieved by students in the pilot experience compared to the control group. Specifically, the Mann-Withey U test was employed, considering different p-values.

3. RESULTS

Figure 2 shows the distribution of official academic results, for the pilot and control groups. As can be seen, the mean, minimum and maximum value has increased in the pilot group. For example, both the mean and maximum value increased around 21.5%.

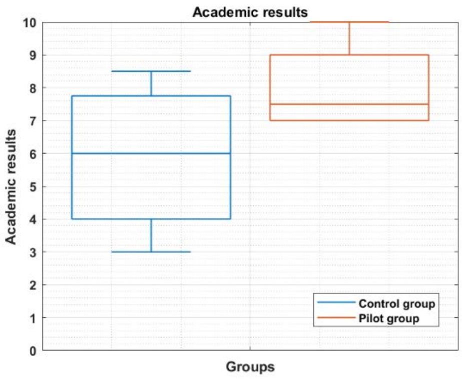

Figure 2. Academic results: distribution and comparison

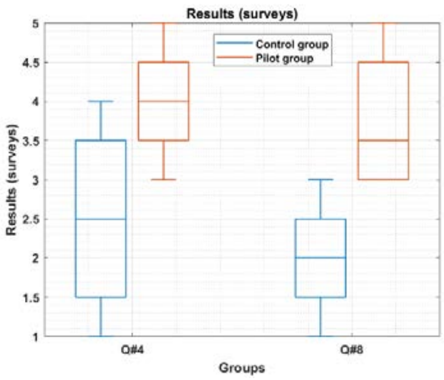

Figure 3. Surveys: distribution and comparison

Similarly, Figure 3 shows the distribution of students’ answers to the institutional surveys (only for the relevant questions). As can be seen, in this case, the mean, minimum and maximum value has increased in the pilot group too. But this is not enough to conclude a significant improvement happened, as both distributions are overlapped. Table VI shows the results from the Mann-Withey U test. As can be seen, a significant improvement is reported in all three indicators, although with different p-values. In general words, question Q#8 from the surveys reports the most significant improvement, while the academic results and Q#4 show a similar behavior.

TABLE VI. STATISTICAL TESTS: RESULTS

Academic results	Surveys Q#4	Surveys Q#8
Significant $p < 0.05$	Significant $p < 0.05$	Significant $p < 0.01$

4. CONCLUSIONS

In the 2022/23 year, a pilot experience was conducted in Universidad Politécnica de Madrid, in order to improve the students learning, motivation and intertest towards Network Engineering courses. The experience, in general words, was based on heterogenous working groups between AI students and Network Engineering students, in order to design and implement a next-generation traffic filter using intelligent technologies. Results show a significant improvement in the academic results and the motivation level. The proposed action could be applied to other educative context and institutions, where computer engineering or IT degrees are available. But it is essential to define a motivating framework for AI students, whose course must follow a similar schedule than the NE courses. Besides, the novelty of this experience may affect the results and long-term analyses are required.

ACKNOWLEDGEMENTS

The research leading to these results has received funding within the framework of the educational innovation project IE23.1204, funded by the Universidad Politécnica de Madrid in its 2022-2023 call.

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