A NEW MODEL FOR AN INTRODUCTION TO COMPUTER NETWORKING COURSE – A CASE STUDY

Joyce Vogel*	Jerusalem College of Technology, Jerusalem, Israel	joyce@g.jct.ac.il
Dan Bouhnik	Jerusalem College of Technology, Jerusalem, Israel	bouhnik@jct.ac.il

* Corresponding author

ABSTRACT

Aim/Purpose	The Introduction to Computer Networking (ICN) course, which was once a course that was only included in computer networking programs, is now a critical component in most Computer Science and Software Engineering degrees. Given the widespread adaptation of the course, it is crucial to address its flaws, since these shortcomings result in high failure rates and inadequate understanding of network concepts even among students who pass.
Background	To address this issue, at the Jerusalem College of Technology (JCT), we suspended our ICN course for one year in order to research better methods of teaching the course. We analyzed other successful networking courses and created our revised approach.
Methodology	We created a newly revised ICN course and tested it in two semesters. In the spring of 2023, 331 students were enrolled in the course, and in the spring of 2024, 285 students were enrolled. We used quantitative and qualitative methods to determine the course's success. Grade assessments were used to determine academic success, and student surveys were used to determine student satisfaction.
Contribution	This paper outlines the reforms made to our networking course, which can be applied to similar courses across all higher-education institutions. The problems our initial course design encountered are typical of networking courses in higher education; therefore, our study's outcomes can be useful to faculty seeking to enhance their networking courses.

Findings	When using the top-down approach, the students found it easier to understand the concepts taught in the ICN. Practical Labs gave the students real-world experience and helped reinforce the theoretical concepts taught in the lecture. Recitation-type activities integrated within the lecture created more interesting lessons and increased student engagement.
Recommendations for Practitioners	We strongly recommend that instructors of an ICN course include more interactive activities to boost student interest and participation in the course. Labs with real-world examples are vital for understanding and integrating the more theoretical course material.
Impact on Society	As the world becomes increasingly connected and digitally dependent, the need to train skilled computer network professionals is greater than ever. It is therefore imperative to create computer networking courses that can successfully educate computer scientists to fill the need.
Future Research	In the future, we would like to research other activities that can be used in the hands-on labs.
Keywords	top-down approach, wireshark, practical material, PBL

INTRODUCTION

The world is undergoing a profound digital transformation, with nearly every aspect of daily life and business operations now reliant on interconnected systems. Advanced networking infrastructure has become crucial to support the vast increase in connected devices that power our modern world. Industry has responded by creating more networking positions. In recent years, there has been a steady increase in networking jobs, and the trend for an increase in networking fields is predicted to continue. The U.S. Bureau of Labor Statistics (n.d.) predicted a 13% increase in network-related employment between 2023 and 2033.

With industry demanding the need for more networking skills (Fraire & Durán, 2021), colleges and universities worldwide have responded by providing more opportunities for students to study computer networks in their respective academic institutions. Computer networking courses are either required or elective for most of the computer science and software engineering degrees, and many now offer bachelor's degrees in the field.

Initially, it was assumed that teaching computer networking courses to the modern-day digital native student would be simple. Digital natives, a term that was coined in 2001 by Marc Prensky (2001) is used to label the generation that grew up surrounded by digital technology (Mertala et al., 2024). They were already adept at accessing the internet in elementary school, so it appeared clear that they would grasp and do well in computer networking classes at the college or university level. However, the exact opposite was found to be true. Students find the computer networking courses to be both difficult to understand (Prvan & Ozegovic, 2020) and boring (Balakrishna, 2023; Sarkar, 2006), which results in high dropout rates and even higher failure rates. Given the importance of computer networking courses and the extensiveness of where these courses are being offered, research must be conducted to identify the factors that make the course difficult for students, and solutions must be provided to solve these problems. The aim of our case study is to identify which pedagogical tools can be effectively integrated into a computer network course and evaluate their impact on student engagement and learning.

Similar issues to the ones mentioned above plagued the Jerusalem College of Technology's (JCT) Introduction to Computer Networks (ICN) course. It is a required course for computer science majors

with a prerequisite of at least one semester of programming. The purpose of the course is to provide students with a comprehensive background in digital communication as well as a robust understanding of how computer networks work. Given that they have some experience in high-level computer courses and their upbringing in a technologically advanced society, it was assumed that they would both enjoy and succeed in the course. We were surprised and disappointed to find that the opposite held true. Although the dropout rate remained low, since cancelling the course would adversely affect their ability to graduate with a degree in computer science, the failure rate and student dissatisfaction were significant. It was decided to temporarily suspend the course for the 2021/2022 academic year and instead focus on revising it. The year was spent researching comparable computer networking courses and finding solutions to improve our course. New tools, technology, and other resources were added, along with revised instructional approaches. We conducted research on our newly revised ICN course by using both quantitative and qualitative methods. We found that not only did students achieve greater success rates in the newly devised course, but also had a higher level of course satisfaction. We believe that our course's enhancements may be readily modified to benefit other computer networking courses throughout the globe, which is vital since a computer network course equips students with the foundational knowledge and practical skills needed to design, maintain, and secure the networks that power today's digital world. As the number of computer networks grows, there is a greater need to provide skilled employees, which in turn increases the importance of improving computer networking courses.

LITERATURE REVIEW

Teaching reforms have been researched and advocated for many college and university-level courses, including those in the computer science field. Outdated instructional practices need to be replaced by more modern teaching techniques. Teachers need to transition from the role of expert to that of a guide. There should be less didactic lecturing and more interactive lessons. Learning attitudes must shift from passive to active, where students can utilize many other resources beyond teacher notes/slides and the course textbook. Classroom experiences should be more student-centered (Sukackė et al., 2022), where the concept of learning-by-doing is the norm (Wu & Na, 2013; Zhang et al., 2023).

Many of the issues that the teaching reform addresses can be solved by the Problem-Based Learning (PBL) methodology (Pupik Dean et al., 2023). PBL is an instructional approach that creates a student-centered learning environment (Vogel & Bouhnik, 2024). Students are presented with a problem they need to solve, and it is during this process of solving the problem that they learn (Li et al., 2022). Students have access not only to the traditional lecture notes/slides and written textbooks but also to the internet, which is rich in supplemental material to help them problem-solve and gain new knowledge. The teacher's role is no longer that of a knowledge provider but more of a learning facilitator who scaffolds the learning process (Hmelo-Silver & Barrows, 2006; K. Smith et al., 2022).

PBL is a teaching strategy that can be used at all levels of education, from elementary school to higher education (Ricaurte & Viloria, 2020), and it may be used to teach a wide variety of subjects. It has been implemented across the globe, which is evident from the abundance of research done in the United States and Europe on how to successfully implement PBL learning in the classroom (Pupik Dean et al., 2023).

 The University of Calgary created a Dual Language Project that implemented the concepts of PBL for an undergraduate course. The students enjoyed the real-world applications of their learning and appreciated the independence that was granted to them throughout their learning process. Furthermore, they obtained a deeper understanding of the subject matter (Roessingh & Chambers, 2011). Clark (2017) created a course, Digital Media, which was based on video and image creation and implemented via a PBL curriculum. By giving her students both a voice and control over their learning process, she found that participation increased dramatically from that of a traditional course.

Students were more eager to learn and contribute in the active-learning environment. The Department of Chemical Engineering at Yachay Tech University in Ecuador designed a PBL-based project that required its engineering students, who were at different stages of their academic career, to work on a joint project. PBL increased the students' professional development and, in particular, helped them develop an engineer's logical thinking process (Ricaurte & Viloria, 2020).

Moreover, PBL is an excellent teaching methodology that can easily be adapted for a computer network course at both an undergraduate and a graduate level. While some programs adopted PBL to teach the entire module, other programs used a blended approach consisting of lectures and problems. Linge and Parsons (2006) redesigned a master's degree course in networking that used the two-threaded approach. Theoretical information was still taught via traditional lectures, but practical skills were developed by the implementation of PBL. Linge and Parsons (2006) reported both quantitative and qualitative success. Not only did the students in their course achieve better scores on the final exam, but student satisfaction with the course was also high.

At the University of Michigan at Dearborn, they designed and tested a new course project that followed the PBL framework for their computer networking course. Students were given the freedom to make independent decisions about parts of the project, which enhanced their sense of ownership of their work. This, in turn, led to them investing more time and effort into their work. The project was both challenging and meaningful. Care was taken on the one hand not to make the project too difficult, such that the students would be frustrated and give up, but on the other hand, not to make it too easy so that they felt that all they were doing was following a bunch of rules that were set forth before them. Lastly, a real-world problem was presented to the students so that they could recognize the authenticity of the project. The end-of-semester report on the course concluded that PBL improved student engagement as well as learning outcomes. The students themselves also offered very positive feedback on the course (Song et al., 2022).

In a private Brazilian university, in the spring semester of 2016, four undergraduate networking courses underwent an experiment where PBL activities were applied to the course. Since the previous runs of the course were taught without the implementation of PBL, they were able to compare student performance of a networking course taught via traditional methods vs. one that was enhanced by PBL. Their findings included an improvement in attendance, which they attributed to a higher level of commitment to the course, which then led to an increase in final grades for the course (Martins et al., 2017).

While the ICN course faces the same challenges as a typical higher education course, it also has additional complications. The course is comprised of many theoretically complex concepts, which makes the course difficult to comprehend (Prvan & Ozegovic, 2020; Woolcott & Bui, 2023; Zou, 2011). Terminologies are hard to understand, and acronyms are confusing (Chang, 2004).

Students complain about it being dry and boring (Balakrishna, 2023; Zou, 2011). While PBL strategies could be applied to offset this problem, many programs are hesitant to implement them for a networking course due to time constraints. Other student-centered, active-learning activities have been advocated since students learn more effectively from practical activities (Sarkar, 2006).

In the ICN course, where the concepts are complex and dry, there is even a greater need for hands-on labs to help students achieve a deeper understanding of the theoretical material (Jeyamala et al., 2021; Prvan & Ozegovic, 2020). Case studies have been conducted that require students to build their own private networks and conduct experiments within them. Sometimes studies were conducted on students who were required to build their own networks outside the classroom using their own personal items, while other studies documented students who built private networks inside the campus labs.

Chang (2004), for example, divided his class into smaller groups and required each group to build and research a personal network independently. He reported that he conducted his experiment over a

three-year period, and not once did he have issues with students not being able to build and complete the assignment. While overall interest was high, he reported that there were students who found the project to be too much for them and that it decreased their interest in networking. Sarkar (2006), on the other hand, created private networks in his lab. He disconnected the computers from the university's network and distributed the necessary hardware and software to the students to simulate private networks. Students performed practical experiments weekly in the labs. He also reported higher academic success and higher student satisfaction with the course. However, creating actual networks is, for the moment, out of reach for most universities and colleges.

With both PBL and building actual experimental networks being out of the equation for many colleges and universities, other solutions need to be found. Simulation-Based Learning (SBL) can be adapted to computer networking courses (Asadi et al., 2024). The basic premise is that an ICN course consists of both a lecture and a lab. The lab should include some sort of network simulation, which should generate student engagement and enthusiasm for the course. By simulating some of the more theoretical concepts in a lab, the theories become practical, making the lecture material easier to understand. There are many simulation tools available, such as NS2, NS3, OPNET, OMET++, GNS3, MATLAB, and Cisco Packet Tracer. However, due to the easy-to-implement and free-of-charge cost of the Cisco Packet Tracer, most colleges and universities adopted the latter (Asadi et al., 2024).

A main advantage of the Cisco Packet Tracer is that it is virtual. It is a free application that can be downloaded from Cisco. After installing, students can choose from a variety of network devices to create their own complex network. Teacher-led labs may require the students to configure devices according to certain specifications and connect devices according to certain requirements. Students can then "run" the network and see how it behaves. Although the labs are entirely virtual, students believed that the learning that was done in the labs was real (A. Smith, 2012). Since the students can now more easily visualize the concepts taught in the lecture, they performed better on quizzes (Vijayalakshmi et al., 2016).

Another low-cost, easily adaptable application useful for a networking course is Wireshark's packet analyzer. While it was primarily created for troubleshooting networks, it can be easily integrated into an ICN course. Wireshark captures all the packets that enter and exit the computer and displays the information in an easy-to-understand format. Packet details are divided into layers, and students studying networking can examine these details to understand better what each layer adds to the packet and how the different layers work together (Bonaventure et al., 2020; Sasi et al., 2020). A successful ICN course should include both a lecture and an interactive lab.

While care should be taken when choosing the hands-on activities that take place in the lab, the lecture should not be neglected. Different textbooks have adopted various approaches, including bottom-up, engineering, system, balanced-view, visual, and top-down (Chang, 2004). In adopting a textbook, the instructor must first choose the underlying protocol model that the group will study. There are basically three choices to choose from – the OSI Model, the TCP/IP Model, and the Hybrid Model.

The OSI Model was a theoretical model that was adopted by the IOS in 1979. This model consisted of seven layers – physical, data-link, network, transport, session, presentation, and application. The TCP/IP Model was developed around the same time and was created to be a practical implementation of the network being set up by the United States government. This model consists of only four layers: link, internet, transport, and application. Both models have their advantages as well as disadvantages. They can be merged into a Hybrid Model, which is the one that most academic textbooks have adopted today. This Hybrid Model, which is also commonly referred to as the Five-Layer Internet Protocol Stack, consists of the following layers: physical, data, network, transport, and application.

Once the choice of models has been made, the decision of how to present the material needs to be discussed. The two basic options are top-down vs. bottom-up. The bottom-up option starts with the bottom layer and continues up the layers, covering the topics from the physical, data, network, transport, and finally, the application layer. The top-down option starts at the topmost layer and works its way down. This decision is important because the two methodologies teach the same material but in the opposite order.
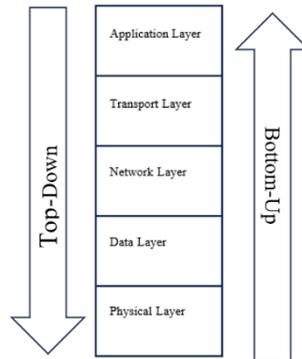

Figure 1. Top-down vs. bottom-up

The decision as to which direction to go should not be made arbitrarily; it should be based on both the instructors and the students. Teachers with an electrical engineering background tend to prefer teaching bottom-up, as opposed to teachers with a computer science background, who prefer top-down (Koo & Kwong, 2005). Students can also be similarly categorized. Those who are more hardware-oriented tend to learn better under a bottom-up approach, while those who are more software inclined prefer a top-down approach (Ciuffoletti, 2021; Koo & Kwong, 2005).

Even with practical labs being added to the course, the lectures also need to have some student interaction built in. Most college and university students were born into the digital world and have been exposed to technology for their entire lives. They are bored by didactic lectures, which not only affect their satisfaction with the course but also impede their learning process. There is an impending need to add interactive activities to the lecture (Balakrishna, 2023).

On the other hand, if they are interested in the class, they are willing to do extra work on their own outside of the classroom. Given the ease of accessing the internet and the plethora of resources that it contains, instructors should utilize this resource to augment the class materials. Moreover, most higher education institutions have integrated Learning Management Systems (LMS) into their schools. Online quizzes can easily be created in these systems. Ideally, quizzes should be written to test their low-order as well as high-order thinking skills since this will indeed reinforce concepts covered in the lecture (Zou, 2011).

In summary, the literature shows that PBL is becoming more recognized as an effective pedagogical strategy in teaching computer networks since it promotes stronger student engagement and the development of practical skills. SBL has also received much attention since it provides students with a risk-free environment to explore intricate networking concepts. Various simulation tools have been assessed for their instructional usefulness and applicability to a networking course. Additional resources, such as homework, quizzes, and labs, have been examined, which are crucial for reinforcing theoretical knowledge. However, despite these advances, there remains a need to combine these strategies into a cohesive and scalable instructional model. This case study addresses this gap by

proposing and evaluating a new model for improving a computer networking course by combining PBL, SBL, simulation tools, and traditional structured resources.

MATERIALS AND METHODS

The JCT offers an undergraduate degree in computer science. Courses in programming, physics, mathematics, and theory make up the program. In 2010, a computer network course was added to the list of compulsory courses for the major. The course would be offered every spring semester starting from the freshman year. The class consisted of a three-hour lecture to be taught over a thirteen-week semester. Introduction to Computer Science (a C++ programming course) is the only prerequisite. At the conclusion of the semester, there was a final exam that determined their final grade. The choice to adopt one of the most well-known networking books at the time had an impact on the decision to adopt the hybrid model and teach the model using the bottom-up approach.

To assess our courses, we use both a quantitative and a qualitative evaluation scheme. From a quantitative perspective, we use the final course score to determine how well the students mastered the material, and from a qualitative standpoint, we use student feedback. While some of the feedback may be informal, such as emails or general comments made after class, the majority of the feedback is formal and collected via the student evaluation forms. At the end of each semester, the student portal automatically provides students with an anonymous voluntary evaluation form. For each course, students rate their instructor and their overall assessment of the course on a scale from 4 to 10. Many also choose to elaborate in the area provided for comments.

The course evaluations from 2010 showed that students were not happy with the new course (see Table 1 for the results of the 2010 survey). They had a hard time understanding the material being taught. They were frustrated that there was no recitation, which would add practical examples to help them understand and review the theoretical concepts that were taught in the lecture. They were disappointed that there was no follow-up to check if they were on the right track or not. Most importantly, they felt that it was unfair to have their entire grade based on just one exam.

In 2012, the course was given a makeover in hopes of both improving student success and student satisfaction. While the textbook remained the same and the Hybrid Model was still taught using the bottom-up method, the course hours and course evaluation changed. An extra hour was added to the course in the form of a one-hour recitation. Students now had the opportunity to review the lecture materials, solve practical problems, and ask questions.

Homework was also added to the course requirements. The final grade evaluation shifted to 80% final exam and 20% homework. Students were required to complete four homework assignments; each had ten to twenty questions and was given a two to three-week deadline. Some questions were based on what they had already been taught, including defining terms, identifying which activities occur in which layer, describing what the network does in certain situations, and requiring mathematical calculations. Other questions required them to research the internet and learn something new. There were three main objectives for the homework. The first was to reduce the weight of the final exam. The second was to find a means for students to review and reinforce the materials taught and to provide feedback to them on their progress. The third was to make the course more enjoyable for the students. It was assumed that having students do independent research on material that was not covered in class would spark their interest and make the course more exciting.

Yet still, student satisfaction remained low. The end of the semester, voluntary surveys revealed that they still had problems understanding the theoretical concepts taught in the lecture course (results of the 2012 survey can be seen in Table 1). Many felt that the homework was too long and hard to answer, and they were frustrated by the questions that covered topics not taught in class. Some of the more common quotes were:

- *I still don't understand anything taught in the lecture, even after the recitation.*
- *The recitation does a good job covering a specific topic, but doesn't cover most.*
- *There is no connection between the lecture, recitation, and homework. I can't answer the homeworks (sic).*
- *The assignments were too hard. We did way easier stuff in class.*
- *I got stuck on the questions that we needed to research on my own. I never got the right answer on those.*
- *After a whole semester, I still do not understand the internet or networks in general.*
- *I see the trees but not the forest. I understand everything that was taught but I just don't see the big picture (how it all comes together).*

The last comment was the most prevalent one among the students and also the most worrisome one for the faculty. It was therefore decided to temporarily suspend the course for the 2021/2022 academic year and spend the year revising the course. We spent the first six months exclusively researching networking courses in other higher education institutions. What we found interesting was that our problem with the course was not unique. A plethora of research has been done on the ICN course, and many have identified the same problems we were experiencing. The lecture was complex and theoretical; students were bored and disengaged. The students could not see how to practically apply the material to an actual network, nor to the internet, which, before taking the ICN course, they had thought they were experts on.

All of the research that we saw included the same solution: create a student-centered environment and have them engage in more active learning and less passive lecture listening. The question was which method to employ. We considered PBL but decided that it would not cover enough of the topics that we wanted to teach in the time constraints that we had. We then thought of implementing private networks; however, after learning about SBL, we decided to first try a simulation tool and see if that works. That left us with the choice of which simulation tool to choose from among the various tools available. We debated between Wireshark and Cisco Packet Tracer. Originally, we thought of using both for the course, but ultimately, we decided on just Wireshark.

The decision to make the course more hands-on led us to add an extra hour to the course. Originally, we thought of changing the recitation to a lab, but then we realized that the recitation was quite important. The recitation provides an opportunity for students to ask questions as well as a means for review. The recitations were changed to include questions and examples from the entire lecture and not just cover specific topics. Moreover, the recitation and lecture would be taught back-to-back by the same lecturer. This would allow the lecturer to integrate the recitation within the lecture. Now, there was no clear separation between the lecture and review. The instructor could finish a topic and go on to review questions before beginning the next topic. It also had the extra benefit of breaking the monotony of the course. Well-placed questions, sometimes in the form of games, would break the tedium of dry lectures. The first time that the course was offered, the lecture/recitation ran for the entire four hours straight. We realized immediately that this was a mistake; the class was too long, and somewhere in the middle, they got tired. Therefore, we decided that the next time we would run the class, we would break the course into two parts – each part consisted of just two hours and was scheduled on different days.

Since the recitation was not being replaced, we tacked on an extra hour for the lab. Each lab included a Wireshark activity. Wireshark is a relatively easy application to learn and use. The first lab was an introduction to Wireshark, where the purpose of the lab was to familiarize the students with the five layers of the model and demonstrate to them how the layers work in tandem. It also served as a basis for them to learn how to run Wireshark, capture packets, and analyze the data. The remaining labs were focused on teaching specific layers and the protocols associated with those layers. While the lab instructor was present for all labs, the expectation was that the instructor would only answer questions and offer assistance, if needed. Students were encouraged to use the skills they acquired in the first lab, combined with their knowledge from the lecture, to capture packets, analyze the data, and answer questions. Students were grouped into pairs, and each team worked independently to

correctly solve the questions. Their answers were graded by the LMS, and feedback was immediate. Their average for the labs became their final score for the lab section of the course and was worth 10% of their overall grade.

Just like the lecture, we realized that the scheduling of the labs was not ideal. On the one hand, there was only one hour appropriate for the course lab, and on the other hand, most labs take more time to get into and complete. We therefore changed the class schedule for the next time that the course was offered, so that each lab ran for two consecutive hours, but met once every other week.

From our research, we also learned that students with a programming background were more likely to appreciate a top-down approach rather than a Bottom-Up one. Our concern was that the students were not seeing the "big picture" because we were starting from something small that they did not necessarily understand and expanding on it, instead of starting from something that they already understood. The idea of starting from the message that was being sent on the network and seeing what each layer added until the message actually went onto the wire seemed much more attractive. We then realized that we would need to switch the course textbook. The new textbook chosen also used the Hybrid Model but implemented a top-down approach.

The last problem that needed to be addressed was the homework. We questioned whether to keep the homework, change it, or replace it. The major issue was the number of complaints that the instructors were getting. Students not only voiced objections in anonymous surveys but also complained during labs and recitations. They felt that they were too long, too difficult, required too much time to complete, and were disconnected from what was taught. They were especially resentful of questions that entailed researching the internet to find the correct answer, since the assumption was that if the answer was important enough, it should be covered in class. We were also doubting how much help the homework really offered. Students did not necessarily understand the material any better after submitting the assignments. Questions that were included in the assignments and then appeared once again on the final exam were no more likely to be answered correctly than questions that were seen for the first time on the exam. High student dissatisfaction coupled with low student performance led us to the decision to remove the homework.

We decided to replace it with quizzes. The quiz factor would be worth 10% of the final score. Three quizzes were closed-book and given in weeks four, seven, and ten of the semester. Each quiz was comprised of ten multiple-choice questions, where some of the questions tested their ability to recall what was taught (low-order thinking skills) while other questions were more thought-provoking and required logical reasoning (high-level thinking skills). Our rationale behind the quizzes was four-fold. First, we wanted to make sure that the students reviewed the course material consistently; our aim was for them to review the material every three/four weeks, learn it well, and not wait till the end of the semester to start studying. Second, we wanted to provide feedback in a timely manner. Our aim was to create a means for students to realistically assess their mastery of the material. Third, we wanted to provide feedback to the instructors. It is important for instructors to see students' achievement in real-time so that they can adjust their lectures/recitations if needed. Fourth, we were hoping that the experience of taking the quizzes and the familiarity with quiz-like questions would make it easier for them to take the final exam.

RESULT AND DISCUSSION

RESULTS

The first ICN course was offered in JCT in 2010 as a response to the growing need to train computer science students in the field of networking. From its very inception, the course faced issues of high student failure, low student grades, and low student satisfaction with the course. We therefore set out

to both improve student outcomes and improve student perceptions. The 2010 version of the course contained just one three-hour lecture, and the final grade was based 100% on the final exam.

In 2012, the course was revised. Due to the fact that the course was a requirement for the Computer Science major, dropping out of the course midsemester was not a viable option for most students. This was an advantage to the faculty because it allowed them to see the problems that most students faced and address these problems. At the time, the solution of adding an extra recitation to a lecture-based course was popular, and therefore, the recitation was adopted. Homework was added to the course, and therefore, the final grade was now calculated based on 80% final exam and 20% homework.

Still, the course faced the same issues, those of low satisfaction and low student achievement. It was therefore decided to discontinue the course for an entire year, research similar courses, and design an improved course. The new and improved course was launched in the spring of 2023. The new course now has three components: lecture, recitation, and lab. The recitation, while not a new faction, is built into the lecture. The hands-on lab was new. Homework is replaced by three quizzes. Course delivery changed from bottom-up to top-down, but otherwise, course content remained almost the same.

A student's final grade now reflects three components: the final exam is 80%, quizzes are 10%, and labs are 10%. Students' achievements are more accurately reflected by this new scale. The new scheme includes a lab grade, which reveals how much theoretical knowledge a student can apply to a real-world example. The quizzes which are administered every few weeks, are designed to evaluate a student's comprehension of a certain topic or concept within a topic, whereas the final exam examines a wider variety of concepts, frequently establishing connections between different topics or concepts. Both the understanding of a concept in isolation and understanding the concept in relation to a wider scheme are crucial for determining how well the material has been mastered.

The overall makeup of the students taking the course did not change significantly from 2021 (the last time that the course was taught under the old format) to 2023 (the first time that the course was taught under the new format). Nor was there any significant change from 2023 to 2024. In 2021, 290 students took the course. There were five different lectures and tw12elve recitations. In 2023, 331 students took the course. There were eight lectures, 15 recitations, and 24 labs. In 2024, 285 students took the course. There were seven lectures, 11 recitations, and 24 labs.

Our research is focused on comparing the course that was offered before the changes were implemented to the course that is offered after the changes were implemented. Originally, we evaluated the results from the years 2021 and 2023. We knew that 2021 represented a typical year of the old course and were hoping that the results of 2023 would reflect a typical year of the new course. When we repeated the course in 2024 and realized similar results to those of 2023, we concluded that 2023 could indeed be used as typical. Moreover, given that the 2021 and 2023 groups' fundamental dynamics were similar – the same kind of students were enrolled in the courses, the faculty was essentially the same, etc. – we concluded that the variations between the two courses' outcomes would be directly related to the ways in which they were taught.

Since our research is both qualitative and quantitative, the first thing we looked at was whether students' opinions on the course changed. The instructors noticed a decline in students' complaints. This isn't to say that there weren't any complaints at all; generally, the day after the quiz, there would be the general complaint of it being too hard, too long, and of the right answer being marked wrong. However, both the volume of complainers and the intensity of the complaints were remarkably low. In 2023, we had two major issues that we solved in 2024. The first was the length of the lecture/recitation. They felt that four continuous hours was too long, so we changed it so that the course would be divided into two halves and taught on two different days. The second was the length of the lab. They complained that one hour was not enough time to finish the lab. We therefore changed the lab to meet every other week for two hours.

The course content did not change and continued to be both theoretical and complex. Some of the lectures continued to be boring. However, by using the top-down approach, they found it easier to comprehend and apply course concepts to a real network. The labs allowed the students to see the protocols "in action," and attendance at the labs was almost 100% for every session. Overall, students were happier with the course than they had been before the laboratories were added, and their enthusiasm during the lab portion of the course helped make up for some of the less interesting lecture material.

At the end of each semester, students are encouraged to fill out an anonymous survey for the course. Key questions are asked, and they are to rate their answers between 4 and 10, 4 being the score for being very dissatisfied and 10 being the score for being very satisfied. We included the past six years of surveys to measure our success. Overall student satisfaction averaged a 7 in the 2017/2018 academic year, a 7.3 in the 2018/2019 academic year, a 7.5 in the 2019/2020 academic year, and once again a 7.5 in the 2020/2021 academic year. For the 2021/2022 academic year, there was no survey. Student satisfaction averaged 8.6 in the 2022/2023 academic year and 8.9 in the 2022/2023 academic year. Results are summarized in Table 1, and a clearer comparison is shown in Figure 2.

Table 1. Results of the student survey on how satisfied they were with the course

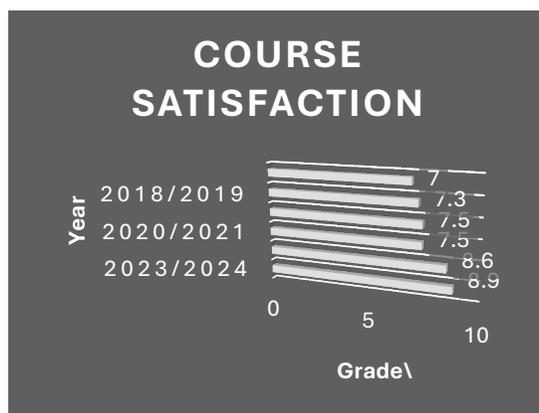| Year	Score
2017/2018	7
2018/2019	7.3
2019/2020	7.5
2020/2021	7.5
2022/2023	8.6
2023/2024	8.9

Figure 2. Student evaluations of the course

Student satisfaction increased slightly each year, but the largest gain occurred in 2022/2023. We attributed the increase to the significant enhancements made to the course. Some of the more common quotes from 2024 were:

- *The recitation made the lecture easier to understand. I liked the games. We should have more.*
- *The lecture is still very long.*
- *The quizzes are too hard but fair.*

- *The quizzes forced me to study every week. I usually wait till the end, but I had to study each week. It is going to make studying for the test easier.*
- *The labs were great. My favorite part. I liked the fact that the lab instructor let us do the work on our own but helped us when we needed.*
- *I really did not understand anything until I got to the labs. Then it became clearer.*

The most memorable quote from 2023 was:

- *This is my second time taking the course. At first I was really bummed because there was an extra hour to it and also since everything changed I would need to redo the entire course instead of just studying for the final exam (I am a senior and need it to graduate). In the end, I am happy that I redid the course. The new way is much better. Not only do I think that I will pass this time, but I also understand everything.*

We also compared their final exam scores to see if there was a difference in student outcomes. We once again took 2021 as a typical year with typical exam outcomes and compared it to 2023. There were twenty-five multiple-choice questions on the tests for both semesters. The exams covered the following six topics:

- Overview
- Layer 1
- Layer 2
- Layer 3
- Layer 4
- Layer 5

By calculating the average number of students who properly answered the questions in each of the six groups into which we divided the exam questions, we were able to compare how well the students performed in each of these subjects. Just 61% of students in 2021 correctly answered questions about the overall overview of networks, compared to 67% in 2023 when the course was changed. Additionally, Layer 1 showed some improvement, with 65% of respondents correctly answering questions about this layer in 2023 compared to 61% in 2021. Layer 2 and Layer 3 did not show significant improvements at all. In 2021, 58% of respondents correctly answered questions about Layer 2 compared to 59% in 2023; 53% answered questions about Layer 2 in 2021 compared to 54% in 2023.

Nonetheless, Layer 4 and Layer 5 demonstrated considerable advancements. Only 51% of respondents correctly answered questions regarding Layer 4 in 2021; by 2023, that number had increased to 65%, a 14% rise. The substantial change in how Layer 5 was taught was the other advantage of the updated course. There was not much time left at the end of the semester to teach the final layer in the original course. Although it was briefly taught, it was not covered in enough depth to be able to include questions about this layer on the final exam. Layer 5 is covered in great length in the updated course, and there were four questions on the topic in the final exam.

After running the course a second time in 2024, we can see that the student achievements of the second time are similar to those of the first time in 2023. In 2024, 67% answered correctly the questions pertaining to the overview (similar to 2023), 66% answered the questions pertaining to Layer 1 (up 1% from 2023), 59% answered correctly the questions pertaining to Layer 2 (similar to 2023), 68% answered the questions pertaining to Layer 3 (up 14% from 2023), 68% answered the questions pertaining to Layer 4 (up 3% from 2023), and 62% answered the questions pertaining to Layer 5 (down 1% from 2023). On the one hand, we were comfortable feeling that the results of 2023 were not a fluke, that they represented true results of the updated course. On the other hand, we noticed an improvement between 2023 and 2024 in Layer 3, with the assumption that the few changes that we made in 2024 are reflected in this grade improvement. Exam results are summarized in Table 2, and a clearer comparison of results can be seen in Figure 3.

**Table 2. Comparison between the percentage of students
who answered the questions correctly based on the topics of the course**

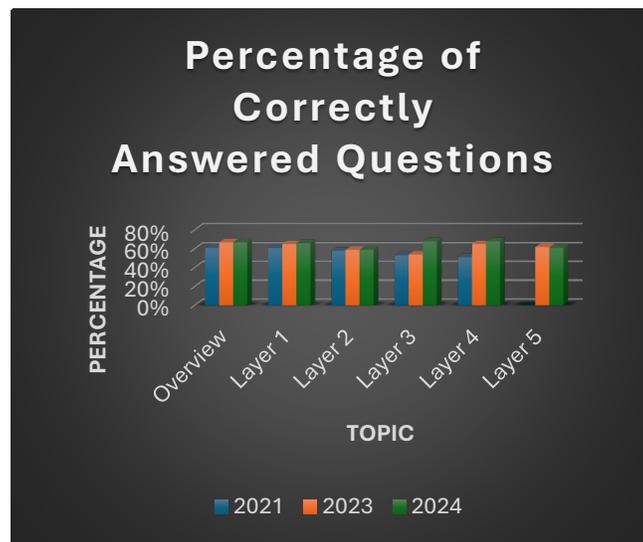| Topic	2021	2023	2024
Overview	61%	67%	67%
Layer 1	61%	65%	66%
Layer 2	58%	59%	59%
Layer 3	53%	54%	68%
Layer 4	51%	65%	68%
Layer 5	-	62%	61%

**Figure 3. Comparison between the percentage of students who
answered the questions correctly based on the topics of the course**

Two noteworthy accomplishments were made with the updated course. When the updated course was implemented in the spring of 2023, student satisfaction increased noticeably. Additionally, students showed that the course revisions, mainly the switch to top-down and including a hands-on lab, which implemented the Wireshark application, improved their understanding of networking.

DISCUSSION

One could describe a computer networking course as both boring and dull (Balakrishna, 2023; Zou, 2011). The main reason for this is that the course covers a lot of theoretical topics that might be perplexing and challenging to understand (Prvan & Ozegovic, 2020; Woolcott & Bui, 2023; Zou, 2011). The fact that the majority of the content is taught via lectures only serves to further complicate matters. Since they were raised in the digital age, today's college and university students anticipate quick and simple access to content. They also anticipate being entertained as they learn. Their learning achievement is not supported by the teacher-centered learning environment (Balakrishna, 2023). These issues affected the ICN course at the JCT. We concluded that we would need to completely redesign the course if we wanted our students to succeed.

As a result, the course was suspended for the whole 2021/2022 academic year. During this time, we looked at related networking courses and created a brand-new, enhanced networking course. A move

from a bottom-up to a top-down approach was the first modification implemented. Since the course's audience consists solely of computer science and software engineering students, it made the most sense to teach networking to them using a top-down methodology. Students with strong software skills prefer a top-down approach (Ciuffoletti, 2021; Koo & Kwong, 2005). Every JCT student has some prior experience with computer programming before they take ICN. Many took computer programming courses in high school, and those who did not were required to take a prerequisite course, Introduction to Programming, in the summer session that precedes freshman year. In the fall, all freshmen take the Introduction to Computer Science course, which is an introductory programming course that teaches C++. ICN is only offered in the spring semester and has a prerequisite of Introduction to Computer Science.

It is fair to assume that the students entering the ICN are proficient enough in programming to favor a top-down methodology. Furthermore, the bulk of JCT's teaching staff have degrees in computer science or software engineering, and since faculty members with a strong emphasis on software would naturally favor a top-down method of teaching computer networks (Koo & Kwong, 2005), we went with the top-down approach. The course was expanded to include a lab. Students had a hard time bridging the gap between what they were theoretically taught in class and the practical implications. We originally thought of adding some form of PBL to the course since it has been proven that PBL is instrumental to solving such problems (Savery, 2006). In particular, we looked at the course of Linge and Parsons (2006), who successively added a PBL component to their networking course. However, we realized that we would not be able to implement such a large-scale project in our course. The lab was only one hour a week, and it did not seem possible that our students could successfully complete a PBL-type project in that short period of time. We then considered building a small network. Creating private networks gives the students the opportunity to test out the theories that they learn in class and helps them better understand complex concepts (Chang, 2004; Sarkar, 2006).

While we did not completely negate the possibility, we decided to first see if we could implement an SBL-type project. Many different simulation tools are available and are used successfully by various higher education institutions to teach a networking course (Asadi et al., 2024). The two that we became most interested in were the Cisco Packet Tracer and Wireshark. Each had its own advantages. The Packet Tracer allows students to set up a virtual network on the computer and test how packets run on the network. It is a viable simulation tool to show how networks work (A. Smith, 2012; Vijayalakshmi et al., 2016). Wireshark is a packet sniffer; it captures real packets flowing across the network to which the computer is attached and displays the packet information in a manner that is easy to analyze. Students can learn about the network by analyzing these packets (Bonaventure et al., 2020; Sasi et al., 2020). In the end, we chose to go with Wireshark, although we are still considering including some Cisco Packet Tracer elements into the lab for 2025.

The hands-on labs were scheduled to be held for one hour each week; however, we found that one hour was not sufficient to complete a lab. As a result, the time window was changed to allow the lab to operate for two hours every other week. The students were pleased with how simple it was to utilize Wireshark. The first week was an introduction; they learned how to use the Wireshark application – how to open Wireshark, start and stop a capture, open a packet, and divide it into its layer form. The subsequent weeks were spent using Wireshark. Although working in groups of two was the original plan, many experiments required students to work in groups of four. There was a lab instructor present to answer any questions that they had; however, most of the time, instead of seeking the instructor for aid, they decided to rely on one another to finish the tasks.

The high attendance of the labs and the manner in which the students rated the lab on the survey at the conclusion of the semester both demonstrated how much the students loved the labs. Although only 80% attendance is necessary, the majority of students attended every lab. A lab frequently ran longer than expected since the students were unaware that the class was truly over. Many students even downloaded Wireshark on their laptops so they could continue working on it at home.

The profound degree of thinking that would occur during these practical exercises was an extra advantage that we did not anticipate when designing the labs. The initial goal of the practical exercises, which required them to examine packets, was to improve their comprehension of the various network protocols and their interrelationships. We didn't expect them to start asking many what-if questions during these sessions when they were allowed to experiment and reflect. Their curiosity led them to ask questions that expanded on what they had learned in class, as well as to do research on their own on the internet.

Our expectations of what they were to do outside of the classroom were revised. We got rid of the homework assignments and gave them quizzes instead. We found that the homework did not necessarily help them understand the course content and only bred contempt for the course. Interactive quizzes are great resources for reiterating what was covered in class (Zou, 2011), so we added three to the course. In contrast to the assignments, the quizzes received positive feedback and performed well on the survey. The quizzes were deemed fair by the students, who also said they reinforced important ideas and provided a decent review of the subject matter. Students did not need to cram before the final exam since they spent the semester studying the material in a timely fashion.

While we were very pleased with the improvement in student satisfaction, we were disappointed that there was not much of a change in the final exam grades, as we had anticipated a larger gain. The introduction, which included a general summary of what computer networks are and what they can achieve, Layer 4 and Layer 5, were the only topics in 2023 that saw any notable distinction. To their advantage, Layer 1 increased by 6%, Layer 4 increased by 14%, and there was still time in the updated course to fully instruct Layer 5. In 2024, we saw Layer 3 with an increase of 15% (from 2021) in its advantage. We are currently investigating how to improve students' comprehension of the other two layers, and we anticipate using the results of our study the next time the course is offered.

The responses from the students, however, were the most noteworthy benefit of the modifications. Students were satisfied with the course, and the number of complaints decreased significantly. The course was fun and fascinating for them, but more importantly, they reported that it improved their understanding of the internet and the digital world that they live in.

CONCLUSIONS

Whether it is a required course for a computer science or software engineering degree or an introductory course for a computer networking degree, the ICN course is crucial for both colleges and universities. Students may find the course dull and difficult to understand because of the abstract technical nature of the material. We had such issues with our students at the JCT that we had to suspend the course for the 2021/2022 academic year. Throughout the year, we revised our own course and conducted research on related ones. During the 2022/2023 school year, we introduced our updated course, and we discovered that the modifications were effective. We continued to make modifications for the year 2023/2024 and found our results to be consistent and even slightly better than those of the previous academic year.

Exam results showed that students understood how a computer network operated on a deeper level. In the updated course, they were also able to cover more ground. We are currently examining what needs to be altered to improve the course's performance for the next time it is given, because we were dissatisfied that their scores for some of the layers were not noticeably higher under the updated version. Nevertheless, the substantial progress the students made in comprehending the course material, plus the fact that we were able to cover Layer 5 in considerably more detail, leads us to believe that our revised course is on the right track for meeting our goals. For the future, we are looking into other activities that can be included in the hands-on labs.

JCT is not unique in the difficulties faced in the ICN course. The issues that arose in our networking course are similar to those that arise in other computer networking courses that are offered as part of

undergraduate degrees in colleges and universities around the world. As a result, we think that the problems we raised in this case study and the remedies we proposed will help any ICN course in any higher education institution.

REFERENCES

Asadi, S., Allison, J., Khurana, M., & Nilashi, M. (2024). Simulation-based learning for computer and networking teaching: A systematic literature review and bibliometric analysis. *Education and Information Technologies*, *29*, 15655-15690. https://doi.org/10.1007/s10639-024-12476-7

Balakrishna, C. (2023). The impact of in-classroom non-digital game-based learning activities on students transitioning to higher education. *Education Sciences*, *13*(4), 328. https://doi.org/10.3390/educsci13040328

Bonaventure, O., De Coninck, Q., Duchêne, F., Gego, A., Jadin, M., Michel, F., Piraux, M., Poncin, C., & Tilmans, O. (2020). Open educational resources for computer networking. *ACM SIGCOMM Computer Communication Review*, *50*(3), 38-45. https://doi.org/10.1145/3411740.3411746

Chang, R. K. C. (2004). Teaching computer networking with the help of personal computer networks. *ACM SIGCSE Bulletin*, *36*(3), 208-212. https://doi.org/10.1145/1026487.1008052

Ciuffoletti, A. (2021). Teaching networks to digital humanists. *IEEE Transactions on Education*, *64*(3) 253-260. https://doi.org/10.1109/TE.2020.3035071

Clark, B. A. (2017). *Project based learning: Assessing and measuring student participation* [Master's project, University of Nebraska Lincoln].

Fraire, J. A., & Durán, J. E. (2021). Revising Computer Science networking hands-on courses in the context of the future internet. *IEEE Transactions on Education*, *64*(2), 133-138. https://doi.org/10.1109/TE.2020.3015673

Hmelo-Silver, C. E., & Barrows, H. S. (2006). Goals and strategies of a problem-based learning facilitator. *Interdisciplinary Journal of Problem-Based Learning*, *1*(1), Article 4. https://doi.org/10.7771/1541-5015.1004

Jeyamala, C., Anitha, D., & Pandeeswari, S. T. (2021). Enhancing student learning and engagement in the course on computer network. *Journal of Engineering Education Transformations*, *34*, 454-463.

Koo, S. G. M., & Kwong, S. W. (2005, October). Teaching computer communication networks: Top-down or bottom-up? *Proceedings Frontiers in Education 35th Annual Conference, Indianapolis, IN, USA,* S2H-S2H. https://doi.org/10.1109/FIE.2005.1612250

Li, A., Bilgic, E., Keuhl, A., & Sibbald, M. (2022). Does your group matter? How group function impacts educational outcomes in problem-based learning: A scoping review. *BMC Medical Education*, *22*, Article 900. https://doi.org/10.1186/s12909-022-03966-8

Linge, N., & Parsons, D. (2006). Problem-based learning as an effective tool for teaching computer network design. *IEEE Transactions on Education*, *49*(1), 5-10. https://doi.org/10.1109/TE.2005.852600

Martins, V. F., Sampaio, P. N. M., Cordeiro, A. J. A., & Viana, B. F. (2017, June). Problem-based learning methodology applied within a data network infrastructure design course a real case implementation. *Proceedings of the 12th Iberian Conference on Information Systems and Technologies*, *Lisbon, Portugal,* 1-6. https://doi.org/10.23919/CISTI.2017.7975684

Mertala, P., López-Pernas, S., Vartiainen, H., Saqr, M., & Tedre, M. (2024). Digital natives in the scientific literature: A topic modeling approach. *Computers in Human Behavior*, *152*, 108076. https://doi.org/10.1016/j.chb.2023.108076

Prensky, M. (2001). Digital natives, digital immigrants. *On the Horizon*, *9*(5), 1-6. https://doi.org/10.1108/10748120110424816

Prvan, M., & Ozegovic, J. (2020). Methods in teaching computer networks: A literature review. *ACM Transactions on Computing Education, 20*, 1-35. https://doi.org/10.1145/3394963

Pupik Dean, C. G., Grossman, P., Enumah, L., Herrmann, Z., & Kavanagh, S. S. (2023). Core practices for project-based learning: Learning from experienced practitioners in the United States. *Teaching and Teacher Education*, *133,* 104275. https://doi.org/10.1016/j.tate.2023.104275

Ricaurte, M., & Viloria, A. (2020). Project-based learning as a strategy for multi-level training applied to undergraduate engineering students. *Education for Chemical Engineers*, *33*, 102-111. https://doi.org/10.1016/j.ece.2020.09.001

Roessingh, H., & Chambers, W. (2011). Project-based learning and pedagogy in teacher preparation: Staking out the theoretical mid-ground. *International Journal of Teaching and Learning in Higher Education*, *23*(1), 60-71.

Sarkar, N. I. (2006). Teaching computer networking fundamentals using practical laboratory exercises. *IEEE Transactions on Education*, *49*(2) 285-291. https://doi.org/10.1109/TE.2006.873967

Sasi, G., Thanapal, P., Balaji, V. S., Babu, G. V., & Elamaran, V. (2020, January). A handy approach for teaching and learning computer networks using Wireshark. *Proceedings of the Fourth International Conference on Inventive Systems and Control*, *Coimbatore, India,* 456-461. https://doi.org/10.1109/ICISC47916.2020.9171197

Savery, J. R. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-Based Learning*, *1*(1), Article 3, 9-20. https://doi.org/10.7771/1541-5015.1002

Smith, A. (2012). Development of a simulated Internet for education. *Research in Learning Technology*, *19*.

Smith, K., Maynard, N., Berry, A., Stephenson, T., Spiteri, T., Corrigan, D., Mansfield, J., Ellerton, P., & Smith, T. (2022). Principles of Problem-Based Learning (PBL) in STEM education: Using expert wisdom and research to frame educational practice. *Education Sciences*, *12*(10), 728. https://doi.org/10.3390/educsci12100728

Song, Z., Shah, N., Guo, J., & Zhu, Q. (2022, March). Applying project-based learning to improve computer networks courses: An experience report. *Proceedings of the IEEE Global Engineering Education Conference*, *Tunis, Tunisia,* 148-156. https://doi.org/10.1109/EDUCON52537.2022.9766750

Sukackė, V., Guerra, A. O. P. d. C., Ellinger, D., Carlos, V., Petronienė, S., Gaižiūnienė, L., Blanch, S., Marbà-Tallada, A., & Brose, A. (2022). Towards active evidence-based learning in engineering education: A systematic literature review of PBL, PjBL, and CBL. *Sustainability*, *14*(21), 13955. https://doi.org/10.3390/su142113955

U.S. Bureau of Labor Statistics. (n.d.). Computer network architects. *Occupational outlook handbook.* https://www.bls.gov/ooh/computer-and-information-technology/computer-network-architects.htm

Vijayalakshmi, M., Desai, P., & Raikar, M. M. (2016, December). Packet Tracer simulation tool as pedagogy to enhance learning of computer network concepts. *Proceedings of the IEEE 4th International Conference on MOOCs, Innovation and Technology in Education, Madurai, India,* 71-76. https://doi.org/10.1109/MITE.2016.024

Vogel, J., & Bouhnik, D. (2024). Prize-based learning in an introductory computer course – A case study, *European Journal of Education*, *59*(4), e12792. https://doi.org/10.1111/ejed.12792

Woolcott, G., & Bui, V. (2023). Design and implementation of a smart learning environment for teaching computer networking. *European Journal of Open, Distance and E-Learning, 25*(1) 162-179. https://doi.org/10.2478/eurodl-2023-0013

Wu, S., & Na, T. (2013). Education informatization and university teaching reform. *International Conference on Education Technology and Information System* (pp. 53-57). Atlantis Press. https://doi.org/10.2991/icetis-13.2013.13

Zhang, X., Zhang, B., & Zhang, F. (2023). Student-centered case-based teaching and online-offline case discussion in postgraduate courses of computer science. *International Journal of Educational Technology in Higher Education*, *20*, Article 6. https://doi.org/10.1186/s41239-022-00374-2

Zou, Y. (2011, December). Study on teaching reform of computer networks course. *Proceedings of the IEEE International Symposium on IT in Medicine and Education*, *Guangzhou, China,* 579-582. https://doi.org/10.1109/ITiME.2011.6130904

AUTHORS

Joyce Vogel is a lecturer at the Jerusalem College of Technology, where she teaches courses in both Computer Science and Software Engineering. Her primary research interest lies in improving pedagogical methods for teaching computing subjects, with a focus on developing more effective and engaging ways to deliver technical content. She is passionate about enhancing student learning experiences in the ever-evolving field of computer science education.

Joyce holds a Bachelor of Arts degree and a Master of Arts degree in Computer Science from the City University of New York, Queens College campus.

Dan Bouhnik received a BSc degree in Computer Science from the Jerusalem College of Technology in 1981, an MSc in Computer Science from Bar-Ilan University in 1988, and a PhD in Computer Science from Pacific Southern University in 1991. He is the author of several books used to teach advanced computer science.

He is currently an Associate Professor and serves as the Rector of the Jerusalem College of Technology. His main research interests include Information Science, Knowledge Management, Information Security, and Big Data issues and their effect on society.