Computer networking concepts enhancement through analogies: a study of information technology students

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ABSTRACT

Computer networks are one of the skills that require mastering concepts, but a weak comprehension of these concepts can cause cognitive and psychomotor challenges for students. Several studies showed that a group of information technology education students at a university struggled with basic network practical exercises, signifying the importance of addressing conceptual understanding. Therefore, this study aimed to enhance students' comprehension of high-level abstract computer network materials. To achieve the desired outcome, a pre-test post-test control group design was conducted on two groups of 29 students each. The results showed a positive impact on strengthening the conceptual understanding of students. Consequently, the experimental class achieved higher test scores compared to the control class, with a difference of 11.6. Data processing also showed higher N-gain values in the experimental class, indicating that analogies had a positive influence on students' conceptual understanding of computer network materials.

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1. INTRODUCTION

Conceptual understanding is at the core of the learning process [1] and is a crucial factor in assisting university students in succeeding in comprehending information technology [2]. Studies on teachers teaching science education showed that those who prioritized conceptual understanding over teacher-centered learning tended to be more successful. An example of a concept, requiring a strong understanding is computer networking, which is a specialized subject within information technology education programs at university [3]. At its core, this learning covers a range of topics, including computer networking hardware types and functions, internet protocol (IP) addresses, subnetting, and routing [4]. The abstract nature of computer networking can be challenging for students to understand, requiring a strong conceptual mastery, making it less popular. Moreover, it poses a significant challenge for teachers striving to facilitate effective learning processes to help students reach their goals [5]. The presence of dedicated teachers is essential for maximizing the abilities of students through appropriate learning processes [6]–[8], thereby necessitating thorough preparation before commencing the teaching process. In some instances, several studies [9], [10] noted that some teachers struggled with constructing a solid conceptual foundation for the subject matter they taught, adversely affecting the procedural skills of students, since conceptual knowledge serves as the cornerstone for procedural skills [11].

Computer networking is a subject that requires theoretical knowledge and practical skills for students to configure networking scenarios [12]. Students who fail to understand these concepts often face difficulties when solving problems in their assigned projects. Consequently, numerous studies proposed innovative learning strategies aimed at enhancing conceptual knowledge of computer networking. Some of these strategies include hands-on laboratory exercises [13], [14], the use of virtual machines [12], [15], [16], and the implementation of problem-based learning (PBL) models [17]–[19]. These three methods have proven successful in improving students' comprehension of computer networking concepts. The presence of hands-on laboratories and virtual machines can assist students in understanding these concepts. Furthermore, students gain valuable experience through network simulation, experiments, and repeated configurations using virtual machines, all of which are considered effective in honing their skills [15], [20].

The success of hands-on laboratories and virtual machines in enhancing understanding of computer networking concepts is not without its challenges. This study has identified several gaps that can cause difficulties for teachers seeking to adopt these learning methods, including limitations in infrastructure, virtualization tools, time constraints, and costs [21]. Enhancing comprehension of computer networking concepts is nearly impossible without access to physical or virtual laboratories [15]. Additionally, the use of hands-on laboratories and virtual machines is most effective for students who possess prior knowledge or prior learning experience in earlier stages [3]. Students with no prior experience in computer networking may still find it challenging to understand these concepts.

A proposed teaching strategy for improving conceptual understanding in computer networking classes with low comprehension levels comprises the use of an analogy-based learning approach. This method comprises linking existing general knowledge known by students with the specific material being taught. Analogies possess significant potential for enhancing the comprehension of scientific concepts [22], [23], as they can describe new ideas by connecting students to familiar concepts [24]. Moreover, the phenomenon can increase the interest and motivation to explore the subject matter further. Vosniadou and Skopeliti [25] noted that analogies could transform disinterest into enthusiasm and knowledge, but teachers needed to exercise caution during this process [26], as some science teachers lacked formal training in their application [27]. To ensure effective use of analogies, teachers should have a strong understanding of the material and the ability to relate it to experiences or common knowledge familiar to students [1].

In the application of analogies, connections are established between two things, such as human information processing in the brain and computer information processing in the processor. Furthermore, it is a method for transferring knowledge across domains [28]. A learning approach using analogies can create new learning scenarios for students by mapping the existing knowledge from daily life to the material being studied [29]. According to Colletti *et al.* [30], analogies positively contribute to thinking abilities, particularly in conceptual knowledge. Several studies, including Gray and Holyoak [31], explored the use of analogies in education to help students understand concepts in the studies. In certain instances, analogies have proven effective in facilitating students' comprehension of abstract material by introducing basic concepts and presenting procedural solutions to problems [32].

Investigations on the use of analogies in learning showed that students had a positive perception [33]. This is consistent with previous study [34], stating that analogies play a key role in the learning process for constructing students' knowledge. Furthermore, numerous studies showed the success of analogies in enhancing the understanding of abstract material. However, the mapping model between material and target analogies in the field of computer networking has not been extensively examined. Initial results from a group of students in the information technology education department at one university showed that only twenty seven percent of students qualified for computer network material based on an initial test.

This current study aims to apply the success of analogies in the scientific field to help students understand computer networking materials with a high level of abstraction. Analogies are anticipated to assist students in understanding concepts by simplifying challenging material through familiar content [22]. Based on the explanation, it was hypothesized that analogies could improve the conceptual understanding of information technology education students when handling abstract computer networking materials.

2. RESEARCH METHOD

This study aimed to show the outcomes of using analogy-based learning in the computer network course for students. The objective of analogies was to bridge the gap between abstract computer networking material and the existing knowledge of students. The exploration process was organized into stages, including the design stage to describe the study design, the determining population and sample stage for detailing methods, the determining research instruments stage for planning and testing instruments, and the data analysis stage for analyzing trial data from each instrument.

2.1. Design

In this experimental study, a pretest-posttest control group design was used. The independent variable was defined as analogy-based learning, while the dependent variable was mastery of computer networking concepts. The sample was divided into two classes: experimental, which received the analogy-based learning treatment, and the control class, subjected to conventional learning (direct instruction).

2.2. Population and sample

In this study, the sample consisted of 58 out of 70 second-semester students enrolled in the Bachelor of Information Technology Education program, comprising 62% females and 38% males. The sample selection utilized the purposive sampling method, which comprised specific considerations [35]. In this case, students with backgrounds other than computer network engineering, scoring the lowest on the conceptual understanding test, were selected. From the determination of the sample size, 58 individuals complied to the guidelines of the Isaac-Michael sample size determination table, with a margin of error of 5% [36], [37].

2.3. Instruments

Precise instruments in accordance with each stage of the study were developed [38], serving as an important factor in guiding the investigation, commencing with an initial test. The study utilized three primary instruments, namely a pre-test, learning process observation, and post-test. The pre-test was designed to assess the students' conceptual understanding and consisted of eight essay questions with both verbal and figural components. The learning process observation instrument aimed to measure various aspects, including the comprehensiveness of the taught material, student engagement, classroom ambiance, and the accuracy and depth of analogies used. This instrument consisted of 15 observation items assessed by peers. The post-test instrument included 20 assessment items based on practical instructions, requiring students to configure computer network topologies and present their results.

Before using the three instruments, the instruments were reviewed by four experts-two in education and two in information technology-to ensure content validity [39]. This expert review was very crucial in producing sound instruments [40]. In addition, the expert analysis was crucial in refining the instruments before the validity test, guided by the valid criteria outlined by previous researchers [41], [42]. The content validity scores for the three instruments were shown in Table 1.

Table 1. Content validity score of study instrument

No	Instrument	Scoring				Average	Description
		V1	V2	V3	V4		
1	Pre-test instrument (eight items of essay questions)	4	3	3	4	3.5	Valid
2	Learning process observation instrument (15 observation items)	3	3	4	4	3.5	Valid
3	Post-test instrument (20 items of practicum assessment and percentage)	4	3	4	3	3.5	Valid
	Average					3.5	Valid
	Compatibility					87.5%	

Description: V is validator

Table 1 shows that each instrument fell within the "valid" category, with a compatibility level of 87.5%. The next step in instrument development was testing, which was performed on a small group before implementation [43]. This small group test was essential to evaluate item difficulty and implementation based on previous studies [38], [44].

2.4. Data analysis technique

After the collection of test results from projects and presentations of students in each class using the developed instruments, data analysis was carried out using the normalized gain score (N-gain) formula (1), adapted from [45].

$$N - gain = \frac{S_{post} - S_{pre}}{S_{max} - S_{pre}} x\ 100\% \quad (1)$$

Where, N-gain >70% (high); 30% < N-gain < 70% (moderate); and N-gain <30% (low).

N-gain served the purpose of assessing the effectiveness of treatment, specifically the efficacy of analogy-based learning in enhancing conceptual understanding. A value exceeding 70% indicated high effectiveness, while a range of 30% to 70% signified moderate effectiveness. In addition, it was observed that an N-gain below 30% indicated low effectiveness.

For more precise data analysis, a normality test was conducted to ascertain whether the independent and dependent variables adhered to a normal distribution [46]. The Shapiro-Wilk test was used, and normal distribution was established when the significance value exceeded 5% or 0.05. Finally, data analysis comprised the use of an independent sample t-test to determine the impact of analogy-based learning on strengthening the comprehension of computer networking concepts.

3. RESULTS AND DISCUSSION

The results section discussed the learning process implemented by one teacher and one observer in each group, using jointly prepared teaching tools. The material covered included an introduction to IP address, subnetting, and routing practicum using Cisco packet tracer software. Material coverage, duration of learning, number of students, and testing methods were identical between the two groups, with the only difference being the presence of analogies in the teacher's material presentation in the experimental group. The discussion section elaborated on the study contribution, its connection to previous explorations, and the implications in science education.

3.1. Results

Enhancing conceptual understanding in computer networking was achieved by providing treatment to the experimental class through mapping between concepts and common knowledge known by all students, such as the functions and characteristics of IP addresses. The mapping connected the functions and characteristics of IP addresses with those of student identification numbers. Figure 1 shows the functions and characteristics of IP addresses as an identity on a computer [47] and student identification numbers as unique identifiers in a group. It should be acknowledged that the identity being described referred to a unique code not owned by the computer or other students.

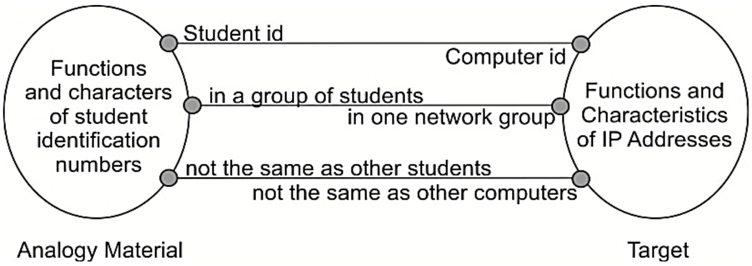

Figure 1. An example of analogy mapping on functions and characters of IP addresses

Another example of mapping took place in the subnetting material, where the concept of dividing IP addresses to accommodate multiple hosts in a network (as the target) was compared to a construction contractor company that calculated material requirements (as the analogy material). The analogy material aimed to ensure the availability of tools and materials for constructing a building according to the demand of customers, while the target was to ensure the availability of IP addresses for multiple hosts. Additionally, the analogy material aimed to minimize wastage of tools and materials, mirroring subnetting's goal of conserving IP addresses in a computer network.

In the section concerning the implementation of subnetting results with the dynamic host configuration protocol (DHCP) server, mapping was accomplished through the analogy of a mother responsible for providing food to her hungry and crying children. In this scenario, the DHCP server assumed the duty of distributing IP addresses to clients requesting IP, similar to how a mother fulfilled the nutritional needs of a child. Meanwhile, in the routing material connecting clients from one router to clients on another router (as the target), mapping was executed through the analogy of an outsider seeking a specific address through the neighborhood leader (as the analogy material).

After students had received a series of theoretical and practical materials across several class sessions, a final test was administered. This test included instructions for creating a project aimed at building a network topology by implementing subnetting results on multiple interconnected routers. The completed project was then presented for evaluation, comparing post-test results from each group (experimental and control) with pre-test scores to determine N-gain values, guiding the assessment of treatment effectiveness. The comparison of conceptual test scores between the two groups could be seen in Figure 2.

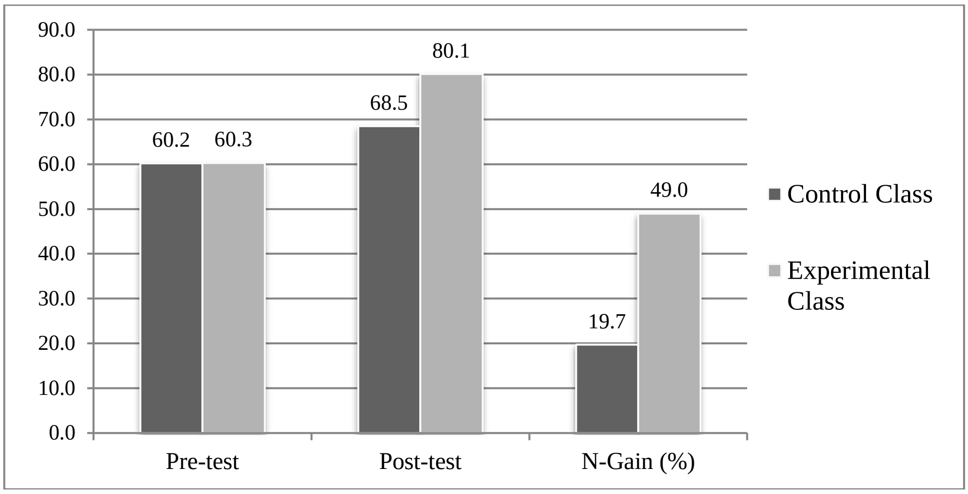

Figure 2. Comparison of conceptual test results for the control and experimental classes

Figure 2 provides several sets of information, including: i) pre-test results for conceptual understanding in networking material for the control and experimental classes showed balanced scores with a mean of 60.2% for the control class and 60.3% for the experimental class; ii) post-test results for conceptual understanding showed a significant difference with a mean of 68.5% for the control class and 80.1% for the experimental class; iii) N-gain for the control and experimental classes fell into the low and moderate categories at 19.7% and 49.0%, respectively. This indicated that the analogy-based learning model had an effect on enhancing concepts in learning computer networking. To enhance the accuracy of the results, further data analysis was conducted, including the normality test and t-test. Table 2 shows statistics related to the test groups, including N value, mean, median, standard deviation, standard error of the mean, and the results of the normality analysis using the Shapiro-Wilk test for the test data.

Table 2. Group statistics and data normality test results between control and experiment classes

	Class	N	Mean	Median	Std. dev	Std. error mean	Shapiro-Wilk Statistic	df	Sig.
Final_test	Pre-test experimental class	29	60.28	60.00	6.502		.949	29	.173
	Post-test experimental class	29	80.10	82.00	7.599	1.411	.962	29	.366
	Pre-test control class	29	60.17	60.00	8.058		.942	29	.111
	Post-test control class	29	68.48	68.00	7.184	1.334	.962	29	.368

*. This is a lower bound of the true significance.
a. Lilliefors significance correction

Table 2 shows the statistical data for each class and the results of the normality test, indicating that both classes exhibited a normal distribution. The sig. values for the pre-test and post-test in the control class were 0.111>0.05 and 0.368>0.05, respectively. Similarly, the Sig. values for pre-test and post-test in the experimental class were 0.173 (greater than 0.05) and 0.366 (greater than 0.05). The next stage comprised testing the influence between variables, specifically the dependent (analogy-based learning) and the independent variable (mastery of computer networking concepts) through an independent sample t-test. The results obtained were then shown in Table 3. In Table 3, the independent sample t-test resulted in a Sig. (two-tailed) value of 0.000 (less than 0.05), indicating that the dependent variable affected the independent variable [48]. In other words, the analogy-based learning model influenced the enhancement of concepts in the material studied.

Table 3. Independent sample test

Class	Levene's test for equality of variances		T-test for equality of means				
	F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference
Equal variances assumed	.134	.716	5.984	56	.000	11.621	1.942
Equal variances not assumed	5.984	55.825	.000	11.621	1.942	5.984	55.825

3.2. Discussion

This section thoroughly discussed various aspects related to the results of the study process, starting from the initial condition of the students, the classroom learning process, as well as the situation and results of the final test in the form of a project to measure the conceptual understanding of students. The results showed that the initial abilities of both classes were relatively similar, with a mean of 60.2 for the control class and 60.3 for the experimental class. This similarity arose because students had not deeply explored computer networking material at the undergraduate level. The respondents primarily relied on prior knowledge from their earlier educational levels, which covered computer networking in a general sense, such as the types and functions of network devices, topologies, and an introduction to IP Addresses. The students in both classes did not possess the knowledge required for subnetting, implementing subnetting results on routers with the DHCP Server, or routing across multiple routers using Cisco packet tracer software. During their learning process, students were supported by theoretical material guidelines and practical instructions provided by the teacher as references for completing the exercises. However, in practice, 87% were unable to complete the practical exercises successfully when they encountered changes in the instructions. This occurred due to the low conceptual understanding of the material being taught [10].

The presence of uneven distribution in students' concept understanding served as a confounding variable [49], contributing to a high rate of failure to complete the practicum. To address this issue, variables were controlled by providing identical teaching materials to all students and forming study groups outside the classroom. This assisted in placing students with lower knowledge levels into groups with those who understand the material.

To enhance conceptual understanding, a treatment was implemented in the experimental class, comprising the integration of analogies into the learning process. The objective of using analogies in this study was to establish connections between daily knowledge and the complex domain of computer networking. These analogies served as a pragmatic framework for comprehending the core subject matter. In specific sub-topics, such as the message broadcast mechanism in computer networks, the IP leasing model derived from the DHCP server concept, routing commands between routers, analysis of communication messages between computers through the PING use, and various other sub-topics, analogies were used to facilitate comprehension. The selection of these analogies was guided by their compatibility with the target material, taking into account structural resemblances and the degree of familiarity with the knowledge of students [50], [51]. Furthermore, Hartsell [52] emphasized the significance of establishing effective analogies in constructing a robust understanding of the material.

After acquiring both theoretical and practical knowledge, students were assigned the task of configuring a network following provided topological instructions. The assignments included designing a network topology for five addresses using the Cisco packet tracer simulator, subnetting to fulfill host requirements, configuring a DHCP server, setting up routing procedures, and testing connections between hosts in different networks. Subsequently, students presented their work for evaluation of the configuration's completeness and comprehension of the concepts, as evaluated by the developed instruments. The data analysis of the final project completion test in both classes showed that N-gain in the experimental class, averaging 49.0% (categorized as moderate), significantly surpassed the control class, with a value of 19.7% (categorized as low). This observation described the influence of the distinct treatments administered to each class, resulting in a mean difference of 29.3%.

The success of analogies in enhancing students' conceptual understanding and addressing misconceptions in abstract computer networking material was influenced by the teacher's precision in selecting analogical materials derived from events or things generally well-understood by students [53], [54]. Analogies served as a foundation for students to learn, reason, and adapt the knowledge to new domains [55]. Furthermore, the concept played a significant role in reducing the cognitive and psychomotor burdens faced by students in understanding abstract computer networking material [56], as shown by Agustini *et al.* [57] in the study where Subak concept was used as analogy source to address misconceptions in abstract material and facilitate students in understanding computer networks. Subak is one of the agricultural irrigation systems widely known in Bali community. In addition, it has a resource management model recognized by UNESCO as one of the local wisdoms. Subak was used as analogy source because it had a unique resource management model similar to the concept of computer network systems in managing limited resources to ensure optimal and effective use. In research by Jammoul *et al.* [58], characteristics of road traffic were discussed as analogy source to facilitate students in understanding traffic in simple computer network topologies, providing practical benefits in the study of communication networks.

Misconceptions were quite common in both computer networking and also in fields of science comprising abstract material [59]. Analogies often served as an alternative for teachers to examine and address the phenomenon of misconceptions [31]. The exploration by Lian *et al.* [60] used analogies to overcome the phenomenon of misconceptions in teaching object-oriented programming (OOP), known for the difficulty due to the abstract nature. Additionally, Saxena *et al.* [61] successfully used analogies to facilitate students in understanding the concepts of software engineering. Analogies were acknowledged for the ability to reduce the cognitive load on students and prevent misconceptions in comprehending abstract material.

The success of analogies extended beyond the context of information technology, as other fields, including physics, also showed their effectiveness. The study by Xue *et al.* [23] tested this approach with a group of students studying atomic structure, using the Solar System as analogy source. Consequently, the results showed improvement in content understanding and transferability skills in the context of atomic structure. Analogies proved to be an effective communication tool for constructing students' knowledge structures and solving problems in the learning process [62].

The issue of misconceptions faced by students studying science presented a unique challenge for teachers [63]. A typical example of this scenario was described in an article by Toledo *et al.* [64], discussing the difficulties teachers encountered in reinforcing the conceptual understanding of students studying basic computer programming courses. This challenge was addressed through numerical examples, cooking recipes, and game-analogies familiar to every student. Another study, conducted by Pedro and Edinson [1] showed success in minimizing student misconceptions about abstract material by introducing analogies as a solution. This approach improved students' learning outcomes compared to conventional teaching methods and was also supported by the majority of students' perceptions, claiming that analogies provided assistance in understanding concepts in abstract material.

The success showed by this current study and previous exploration on the use of analogies in strengthening conceptual understanding and addressing misconceptions in abstract material could be a crucial recommendation for teachers in the field of science education. Furthermore, Tise *et al.* [65] described several studies and practitioners who successfully used analogies to improve students' conceptual understanding. Despite the success in overcoming misconceptions, analogies could also cause a threat to students, leading to further misunderstandings in comprehending the material being studied [66]. This showed the importance of teachers' expertise in minimizing the risks through appropriate mapping between analogy sources and the target material being taught [67].

4. CONCLUSION

In conclusion, the results and data analysis showed that the analogy-based learning model had a positive impact on improving the conceptual understanding of students who were enrolled in computer networking learning. The results of the final test for conceptual understanding showed a significant disparity, with a mean score of 68.5 and 80.1 for the control and experimental classes. N-gain for the control and experimental classes fell into the low and moderate categories at 19.7% and 49.0%, respectively. However, the efficacy of analogies in enhancing conceptual understanding presented some set of challenges. Analogies played a crucial role in foundational knowledge domains but could not achieve their full potential except when accompanied by simulations or practical exercises. Simulations and hands-on exercises provide students with valuable opportunities to apply and assess the acquired concepts.

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