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The Use of Competency-based Statements in Assessing Student Knowledge, Skills, and Abilities: A study in a Network Security Class

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Abstract

Cybersecurity content is typically taught and assessed using Bloom's Taxonomy to ensure that students acquire foundational and higher-order knowledge. In this study we show that when students are given the objectives written in the form of a competency-based statements, students have a more clearly defined outcome and are be able to exhibit their knowledge, skills, and abilities that are being measured with higher accuracy. Students also are able to demonstrate a higher level of both knowledge and confidence in describing their skills. An experiment with two sections of a network security class compared student performance on assessments, with one group receiving Bloom's Taxonomy objective statements and the second group receiving competency-based statements. The results of this study show an increase in performance on the instructional topic, and support applying the approach to cybersecurity workforce development.

Keywords: Competency-based Statements, ABCD model, Computer Science Education, Security+, Cybersecurity education

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The Use of Competency-based Statements in Assessing Student Knowledge, Skills, and Abilities:| A study in a Network Security Class

Jeff Hanson, Blair Taylor, Siddharth Kaza

1. INTRODUCTION

According to the $(ISC)^2$ Cybersecurity Workforce Study (2022), a global cybersecurity workforce gap of 3.4 million people exists. Knowledgeable and skilled workers are needed to adequately fill those vacancies. One method to assess a person's knowledge is by administering a certification exam, of which there are many. Most certification exams are vendor-neutral and vendor-specific, centered on knowledge, skills, and abilities necessary for a job in the information technology (IT) industry, including cybersecurity. These certifications have a set of specific objectives focused on computer and cybersecurity concepts, which are written in the form of traditional Bloom's Taxonomy statements. We believe providing students with competency-based statements would be more effective in helping students know more specifically what skills they need to be proficient in to not only pass exams, but also to be competent in the workplace. Competency is broadly defined as being able to perform a specific task, or being able to demonstrate a skill. The goal of this study was to explore the use and effectiveness of competency-based learning in relation to student exam success rates and to measure improvement in performance when using said statements.

There were two directly related motivations for this study. The first was to observe the effect of providing students with competency-based statements on a performance assessment to determine if using competency statements in place of the traditional objective statements would have a positive impact on students' performance. Second was to compare student written responses after completing a performance assessment measuring student confidence and feelings on objectives vs. competency-based statements provided in directions and expected outcomes.

2. BACKGROUND AND LITERATURE REVIEW

History

The original Taxonomy of Educational Objectives was written by Dr. Benjamin Bloom (Bloom et al., 1956). Bloom categorized and classified the cognitive domain of learning into varying levels according to complexity and outlined six main categories: knowledge, comprehension, application, analysis, synthesis, and evaluation. When writing objectives using the Bloom's Taxonomy method, objectives contain a single verb and its object. The verb describes an observable action, and these objectives can be written at Bloom's six levels of learning, with memorization being the lowest level and creative thinking being the highest. Competency-based statements are more precise statements that define the behavior and actions needed to perform well in a particular job role.

Competency-based education (CBE) differs from the traditional education program by looking at what students learn and what skills they develop during an educational program, while not emphasizing time period restraints. CBE has been steadily gaining popularity nationwide and encompasses a range of practices and policies that vary across settings. The ideas of both CBE and outcome-based education (OBE) have existed for many years and have about as many definitions and designs. Concepts and characteristics of both CBE and OBE have continued to evolve over the years and adapt to the educational landscape, as well as become blended into very similar concepts. This literature review presents an overview of aspects and various implementations of CBE.

According to Curry and Docherty (2017), the roots of CBE can be traced to the monograph "The Principles of Scientific Management" (Taylor, 1911), in which Taylor examines work practices and details his approach to improving workplace efficiency and productivity. Taylor examined practices at a steel manufacturing plant in the early 1900's. He identified procedures that, once implemented, would improve both efficiency and productivity in industrial settings. Focusing on the end product enabled Taylor to develop key principles. One of which is the importance of providing proper training to workers to ensure they acquire the necessary skills and knowledge to perform their tasks efficiently. Taylor believed

that skilled workers would be more productive and contribute to overall organizational success. The fact that Taylor focused on the output and final product of the employees forms the basis of CBE and OBE. This is seen by relating what workers needed to produce in the steel plant (the outcome of products made) to what skills students today need to possess and what they need to be able to do (the skill set).

Application in Education

Elam (1971) summarized the results of a Committee on Performance-based teacher education (PBTE) established by the American Association of Colleges for Teacher Education (AACTE). This committee was given responsibility to "study the many efforts currently taking place in the United States in the area of performance-based teacher education." Elements of PBTE as described by Elam include competencies that are characterized by the knowledge, skills, and behaviors that to be demonstrated need to include specific qualities. First, a competency needs to be derived from explicit conceptions of teacher roles. Second, a competency needs to be stated so as to make possible assessment of a student's behavior in relation to specific competencies. And third, a competency needs to be made public in advance. Assessment of the competency of the student performance is the primary source of evidence. In addition, assessment would consider evidence of the knowledge of the student relevant to planning for, analyzing, and interpreting situations. The student's rate of progress through the instructional program would be determined by competency rather than time or course completion. The learning experience would be guided by feedback, which could be from others or self-evaluative by having the student watch their own recorded performance. Elam theorized that the PBTE movement most likely was a product of the United States Federal Government's "realization that little, or no progress was being made in narrowing wide inequality gaps, and that traditional teacher education programs were not producing educators equipped to teach minority group children and youth effectively" (Elam, 1971, p. 2). Elam stated that these PBTE programs require that future educators are to be held accountable not for passing grades but attaining a given level of competency in performing essential tasks of teaching.

Structure

Over the years, several different terms have emerged in this area of education. Thus, phrases that include terms such as performance-based, competency-based, teacher education, training and vocational education are commonly used, and often used interchangeably. It is stated that an education characterized as competency-based, or outcome based, will include a variety of content items such educational objectives, outcome statements, competency frameworks, task analysis, employability skill lists, and performance and grading checklists (Curry & Docherty, 2017).

In a paper similar to Curry and Docherty (Haynes et al., 2016, p. 4) describes CBE as an "approach to instruction that places emphasis on what students learn and master rather than how much time they spend in school." This definition characterizes specific learning targets for what students should be able to do in order to earn credit. It employs "assessment, support, and monitoring of individual students' progress as they work toward meeting these targets, with requirements that students demonstrate mastery of competencies" (Haynes et al., 2016, p. 4). In addition, Haynes lists both flexible pacing and progression, both extended and accelerated, as part of CBE. The study by Haynes administered surveys to students, teachers, and school administrators to understand the impact of CBE. The goal of the study was to rigorously examine the relationship between CBE practices and changes in such learning capacities, skills, behaviors, and dispositions that enhance student capacity in school. The top practice was students helping each other with schoolwork. This strategy was reportedly used by 86% of CBE schools and 96% of comparison schools. Group work was approximately 50% for each. Haynes (2016) reported that pacing and progression varied with 50% of CBE teachers allowing students to take extra time to review and master a topic, and 29% allowing students to move ahead if they are ready before other students. This study looked at many disciplines, and only mathematics showed a positive change in learning capacities.

CBE grew in popularity in the early 2000's in the health professions. This was the focus of CBE research in medicine in which CBE was identified as emerging in the field of health education to address criticisms of contemporary approaches to training (Frank et al., 2010). The goal of the paper was to provide a definition of CBE. The resulting definition became: "Competency-based Education (CBE) is an approach to preparing physicians for practice that is fundamentally orientated to graduate outcome abilities and organized around competencies derived from an analysis of societal and patient needs. It de-emphasizes time-based training and promises

greater accountability, flexibility, and learner-centeredness."

As stated by Gervais (2016, p. 99) "CBE is defined as an outcome-based approach to education that incorporates modes of instructional delivery and assessment efforts designed to evaluate mastery of learning by students through their demonstration of the knowledge, attitudes, values, skills, and behaviors required for the degree sought." While this definition has some variation with previous definitions, it is consistent with the goal of having students demonstrate mastery of a desired skill set. Competencies are developed based on the feedback and contribution of all stakeholders involved, including teachers and students. Another perspective was defined as CBE settings offer students greater opportunities or personalized learning, autonomy, flexibility, and responsibility for their own learning (Patrick, et al., 2011).
The paper "Exploring secondary teachers' perspectives on implementing competency-based education" (Rogers, 2021) begins by identifying that the more traditional education systems emphasize Carnegie units, seat time, and grade averages on a 100-point scale. In contrast, CBE students must demonstrate mastery and meet specific learning targets before progressing through the curriculum. Rogers examines a five-part definition of competency-based education by the International Association for K-12 Online Learning (formally iNACOL, now the Aurora Institute). The five-part framework defines competencies as needing to include explicit, measurable, and transferrable learning objectives that empower students. The framework states "students advance upon mastery" and "assessment is meaningful and a positive learning experience for students" (Rogers, 2021, p. 2). The framework also states that "students receive timely and differentiated support based on their learning need, and that learning outcomes emphasize competencies that include application and creation of knowledge, along with the development of important skills and dispositions." (Rogers, 2021, p. 2)

An exploratory study reports that the use of CBE is expected to continue to rise (Prokes et al., 2021). This is attributed to the fact that more than 75% of institutions expected to grow CBE programs by 2024. This study describes CBE as consisting of three key elements. The first is competency statements must be tied to measurable abilities and are linked to vocational or career-oriented outcomes. The second element states that CBD requires a prescribed set of materials comprising the structure of a course. The third element focuses on the ability of the student to demonstrate mastery of competencies in multiple methods.

Forms of CBE in Computer Science and Cybersecurity Education

The National Security Agency's (NSA) National Cryptologic School manages the National Centers for Academic Excellence in Cybersecurity (NCAE-C), which creates and manages a collaborative cybersecurity educational program with community colleges, colleges, and universities. The center partners with many United States government agencies, including NICE (formally recognized as The National Initiative for Cybersecurity Education). In 2020 NICE created the Workforce Framework for Cybersecurity (Peterson, et al., 2020) which is described to be a reference for "describing and sharing information about cybersecurity work" (Wetzel, 2023, p. 4). The program and corresponding documents "express work as task statements and describes knowledge and skill statements that provide a foundation for learners including students, job seekers, and employees. The use of these statements helps students to develop skills, helps job seekers to demonstrate competencies, and helps employees to accomplish tasks" (Wetzel, 2023, p. 4).

The document lists competency areas that are defined as "a cluster of related knowledge and skill statements that correlates with one's capability to perform tasks in a particular domain" (Wetzel, 2023, p. 11). The NCWF begins by defining several cybersecurity workforce categories, broken down into 33 specialty areas. This ends up becoming approximately 1,000 tasks (actions typically performed), 630 knowledge items (what the cybersecurity professional needs to know), 370 skills, and 175 abilities. These are then used to form work roles and competency areas on which to focus. These competency areas "help learners discover areas of interest, inform career planning and development, identify gaps for knowledge and skills development, and provide a means of assessing or demonstrating a learner's capabilities in the domain" (Wetzel, 2023, p. 11).
The International Atomic Energy Agency (IAEA) published "The Competency Framework, A guide for IAEA managers and staff" in 2024 in which they provide the following definition: "A competency is generally described as a combination of skills, knowledge, attributes, and behaviors that enable an individual to perform a task or an activity successfully within a given job. Competencies are observable behaviors that can be measured and evaluated, and this are

essential in terms of defining job requirements and recruiting, retaining and developing staff." NICE released a new proposed list of framework competency areas for comment in 2024. This list incorporates updates from a previous draft and serves as an example of the ever-changing information on how competency areas are defined and how they can be used in preparing a job-ready cybersecurity workforce as the industry responds to the changing field.

One proposal advocates "the use of competency-based education and mastery learning (CBML) methodologies as an innovative and more effective approach than the current OBE approach" (Watkins, Tobey, O'Brien, 2018, p. 1). in cybersecurity education. The CBML approach here is defined as "a structure that creates flexibility, allows students to progress as they demonstrate master of academic content, regardless of time, place, or pace of learning" (Watkins, Tobey, O'Brien, 2018, p. 4). "This proposal is based on the set of cybersecurity tasks, knowledge, skills, and abilities defined by the job performance models produced by the National Board of Information Security Examiners (NBISE), the competency model developed by the National Institute for Science and Technology and NCWF developed by NICE." (Watkins, Tobey, O'Brien, 2018, p. 5). The proposal looks to design and build CBML curriculum materials using a bottom-up approach. First identified will be the foundational learning objectives. This places emphasis of the CBML model on learner readiness rather than completion. Once the learner has mastered the foundational skills, then they will progress to the next level. The comparison is given that most OBE learning modules might be 45 - 60 minutes long and cover multiple topics, the CBML modules are shorter, possibly 15 - 20 minutes, and focus on only one or two topics. A CBML course could have 50 - 100 learning modules. This is a similar approach to that of CBE.

The Accreditation Board for Engineering and Technology (ABET) defines student outcomes as "what students are expected to know and be able to do by the time of graduation." (ABET, 2021, p. 6). In addition to this definition, the Computing Curricula 2020 describes competency as "comprising knowledge, skills, and dispositions that are observable in accomplishing a task within a work context" (CC2020, 2020, p. 13). This report recognizes that most undergraduate computer science students will seek employment after graduation. In order to secure employment, they will need to meet "standards, practice, and real-world expectations for performance" (CC2020, 2020, p. 54). This further emphasizes the growing need for helping students to build competency in the field of computer science, of which cybersecurity is a specialized field. Raj et al., (2022) proposed that educators can address the skills gap by using a variety of methods, which can be interpreted as being competency-based. Educators can add a practicum component to required and electives courses which can count toward the final grade. Institutions can choose to move introductory courses to closed lab models, apprenticeship-style learning in courses, and require internship experience.

Alammari et al., (2022, p. 1) state that "cybersecurity competencies are a dynamic combination of knowledge, skills, and abilities and focus on performance, meaning that knowledge alone does not guarantee success." In addition, cybersecurity is a multidisciplinary field of study and a cybersecurity framework needs to accommodate different kinds of competencies. This is an affirmation that the field of cybersecurity needs to measure both student success on competencies while also building skills.

The ABCD Model

This new implementation uses terms and concepts from Bloom's create level and merges them with three elements from the book "Preparing Instructional Objectives" (Mager, 1962). Throughout his book, Mager described the importance of determining learning goals that are measurable, observable, and realistic when delivering instruction. The three elements defined are performance, condition, and criterion. This method is labeled the ABCD model and incorporates the following: A is for the audience and is used to refer to those who will be demonstrating what they learned after a period of instruction. B is for behavior, which is described as the precise and tangible evidence that will be shown by learners. C is for the condition, which refers to the circumstances under which the behavior will be done. D represents the degree, which is a standard that has to do with accuracy, or number of mistakes or kind of mistakes that learners are allowed to make before such judgement as to the learning goal not being accomplished.

The following is an example of a Bloom's Taxonomy statement being converted to a competency-based statement. The CompTIA Security+ objective document uses the following phrase: "Explain the purpose of mitigation techniques used to secure the enterprise" and one bulleted item is an access control list (ACL). The word explain is at the understand level of Bloom's

Taxonomy. A competency-based statement following the ABCD model would read as follows: "Working as a Network Security Engineer, you will need to implement an ACL on the edge router to deny all telnet connections and only allow SSH connections inbound to the router from the administrative subnet of 10.10.10.0/24 on all ingress interfaces. Use an out-of-band connection to the router interface to create and edit the ACL. The ACL will need to correctly process 100% of the data going through the router." This competency-based statement makes a reference to all four parts of the ABCD model and provides explicitly clear direction as to what job role is being performed, what needs to be done, how it will be done, and the level of accuracy required.

Literature Review Summary

The papers in the literature review show the common theme that the essence of CBE is rooted in knowledge, skills, and abilities along with competencies. The section gives an overview of different definitions and implementations of CBE. These variations show that CBE is growing and is an ever-evolving practice. There are many similarities between the many implementations of CBE, along with some differences. With this history of CBE discussed here and the benefits seen, the objective in this study was to examine how current simplistic objective statements from an industry exam can be rewritten as competency-based statements and provided to students. Next, measuring if these statements had a positive impact on the student's skills and abilities on performance activities, and ultimately leading to an improvement of scores on certification exam assessments.

3. RESEARCH DESIGN

Research Questions

We explored two questions: (1) Will students better demonstrate their knowledge, skills, and abilities when given competency-based statements than those students who are given objectives in Bloom's Taxonomy? And (2) will students be able to identify their own strengths and confidence when writing about their skills?

Research Testbed

This study used 54 students enrolled in two different sections of the same 300-level course at a four-year public University. Table 1 presents the demographic data for the two groups.

Each class met once a week for a 160-minute session on the same day each week. The 3:00 PM class was randomly chosen by the flip of a coin to serve as the competency group. Therefore, the 6:00 PM class became the control group. All students were pursuing a Bachelor of Science degree in Information Technology. Of the total number, 17 were in their junior year and 37 were in their senior year. Twenty-seven students were in group A, which was the competency group. Group B served as the control group and was also made up of 27 students.

Research Methodology

The study compared results when students are given directions based on a competency-based statement vs. students who are given objectives written in the form of Bloom's Taxonomy. It used an assessment that consisted of both quantitative and qualitative questions. Assessment results from student performance in a simulation activity were analyzed. The study also collected and reviewed quantitative data from student self-analysis through a Likert scale survey and analyzed qualitative data from an open-ended question. The assessment was administered during the eighth week of a 15-week semester course and used the program Packet Tracer (https://www.netacad.com/courses/packet-tracer) which is a network simulation tool. Packet Tracer was chosen due to its ability to simulate fundamentals of computer networks and devices and include aspects of cybersecurity. The timing was purposely selected because it allowed students time to become familiar with the Packet Tracer program, thereby eliminating the ability to use the program as influencing the quantitative results.

Group A			
	Male	Female	Total
Black	5	8	13
White	6	2	8
Hispanic	2	0	2
Asian	3	1	4
Group B			
Black	10	6	16
White	5	1	6
Hispanic	3	0	3
Asian	2	0	2

Table 1: Demographic data

Each group was provided with the same lab activity introduction. This description set the stage for the desired network that needed configuration. The starting file consisted of network devices which the students needed to

configure. Successful completion of the network required the application of IP assignments including subnetting, DHCP and DNS server configuration, and wireless security to be configured. Students had the freedom to design their network however they chose, as long as it met the requirements, thus allowing the students to demonstrate their knowledge and skill set.

The topic of the assessment was a set of specific objectives identified from the CompTIA Security+ exam objectives, version SY0-701 (2023). The competency group received these objectives written out as competency-based statements following the format of the NICE Workforce Framework for Cybersecurity (2022). The Centers for Academic Excellence in Cybersecurity (CAE-C) Community in "*Evidencing Competency Oversight*" has developed a model for effectively and efficiently evidencing competency that defines how to write a competency-based statement based on the four items in Mager's ABCD model. Norwich University is the leading institution for the Evidencing Competency Oversight Project (https://www.caecommunity.org/initiative/evidencing-competency). The control group was provided the objectives directly as written by CompTIA on the exam objective document, which uses verbs and categorizations from Bloom's Taxonomy.

During the assessment students did not see any active scoring. After completion, each submission was checked individually by the principal investigator using a checklist created by identifying 40 skills that needed to be completed in order to satisfy the competencies listed in the statements. Students had flexibility with their solutions to meet the stated requirements. The investigator collected the files and analyzed the score results with the student scores on this 40-point assessment serving as the quantitative data source. Appendix A is the 40-point checklist.

After completing the Packet Tracer assessment, each group answered three survey questions regarding the activity using a five-point Likert scale. The responses were collected and analyzed quantitatively.

The final question required an open-ended written response to a prompt to describe their skills with regards to the assessment. Each group was presented with the same prompt. Student responses to this question were collected and analyzed qualitatively. Students were allotted a 45-minute session in which to complete both the Packet Trace file and answer the survey questions. Appendix B is the document provided to the control group. Appendix C is the document provided to the competency group containing all directions and questions.

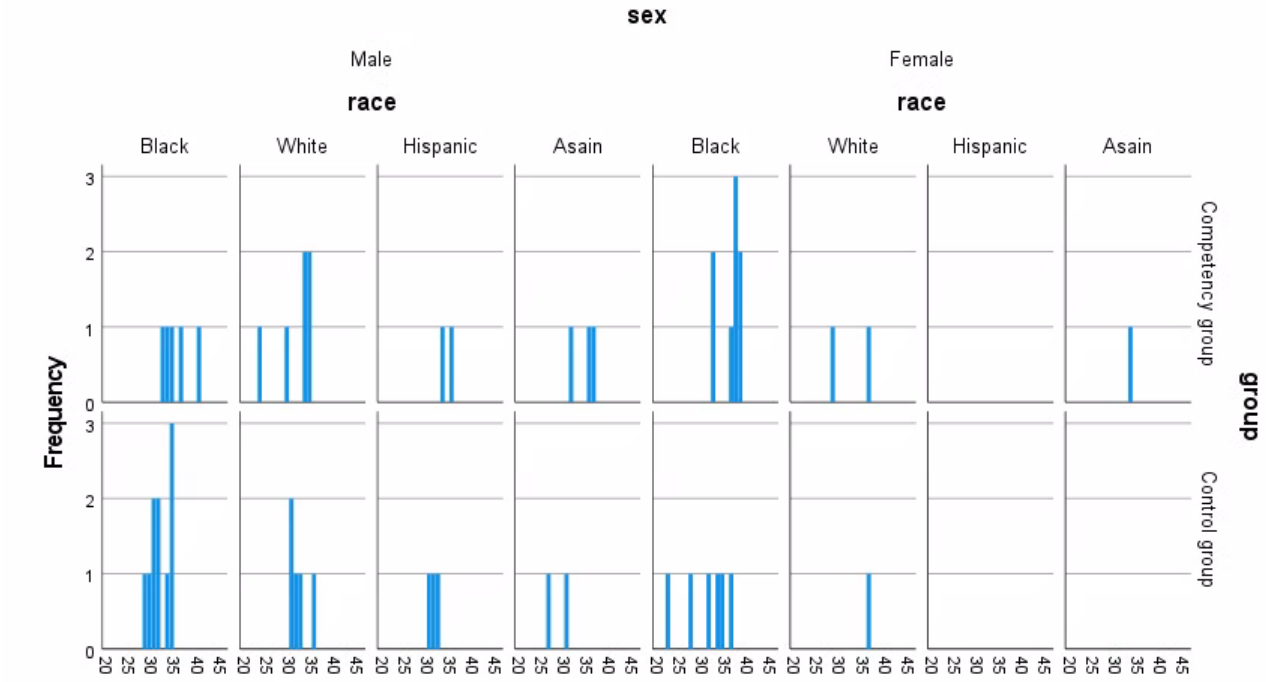


Figure 1: Packet Tracer score results based on race and sex for each of the two groups

4. EXPERIMENTAL RESULTS

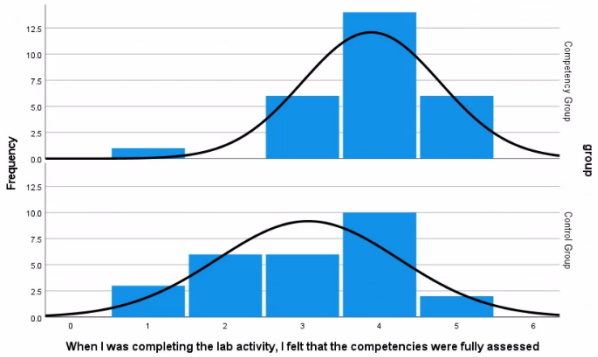


Figure 2: Frequency and normal distribution for question 1

Quantitative Data Analysis

The goal of the study was to determine the effectiveness on a performance assessment when providing students with competency-based statements for the assessment. The activity was completed by 27 students in the competency group receiving competency-based statements, and 27 students in the control group receiving objectives in the form of traditional Bloom's taxonomy statements.

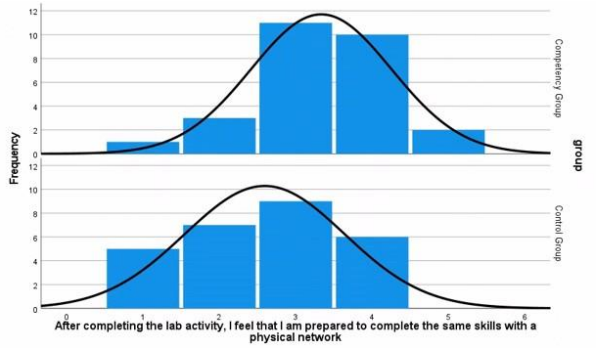


Figure 3: Frequency and normal distribution for question 2

The hypothesis for the quantitative portion of the study was that students will demonstrate their knowledge, skills, and abilities at a higher level of accuracy when given a competency-based statements in place of a Bloom's Taxonomy objective statement. Figure 1 charts Packet Tracer score results based on race and sex for each of the two groups. In analyzing the quantitative data by performing a t-test analysis on the scores, the results show a difference that is statistically significant between the two groups. The average score within the competency group (M=33.89, SD=3.512) is greater than the average score of the control group ($M = 31.11$, $SD = 3.117$), $t(52) = 3.074$, $p = .003$. Scores were higher in the competency-based group for both black males and females, and white females. White males in the control group scored slightly higher than the competency group white males. The significant difference between the scores persisted across both genders. The data from the Packet Tracer assessment are consistent with the hypothesis that competency-based statements positively impact student performance.

Results from the survey questions utilizing a Likert scale were evaluated using mean and a median for central tendency and frequencies for variability (Boone & Boone, 2012). The mean and the median for questions one and two are greater for the competency group when compared to the control group. The median for question three is reported to be the same for each group at 3, while the mean for the competency group is 3.33 and for the control group it is 2.59. Further analysis using a Mann-Whitney U test on the data for question three produced a p-value of 0.02, therefore giving statistically significant evidence at α = 0.05 to permit rejecting the null hypothesis and show that the competency group portrayed a higher level of confidence in their knowledge, skills, and abilities in each of the three questions. Figure 2 shows the frequency and normal distribution for question one.
Figure 3 shows the frequency and normal distribution results for survey question two, and figure 4 is for question three.

Appendix D lists the survey questions and the mean, median, and standard deviation Likert scale calculations for both groups.

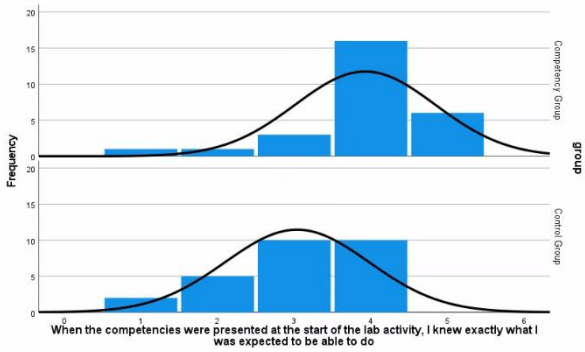


Figure 4: Frequency and normal distribution for question 3

Qualitative Data Analysis

Analysis was performed on the open-ended question following presumption-focused coding (Ado 2019). In the analysis, data relevant to this

study include specific terms listed in the statements given to each group. These terms are subnetting, network, IP addresses, DNS and DHCP servers, wireless security, passwords, SSID, MAC filtering, and encryption. Coding searched for key terms and how the participant described applying the processes that included those key terms in the activity. The application of subnetting, the configuration of either or both a DNS and DHCP server, securing of a wireless network, and configuration of network devices were specifically searched. These terms are seen in the CompTIA objectives, and the frequency of their use was used to determine the participant's confidence level with their knowledge, skills, and abilities for the topics. An automated word-frequency analysis was performed looking for the top 20 words appearing in the responses written by each group. Comparing the word-usage results showed that in each instance the frequency was higher in the competency group than it was seen in the control group. The top word in both groups was network, referenced 58 times within 24 responses from competency group and 54 references in 22 control group responses. Configure, representing a skill, produced 54 references from 24 competency group responses and 44 references within 19 control group responses. Appendix E shows the word occurrences for the competency-based group, and appendix F shows word occurrences for the control group. A majority of the students used many of the key words in their responses, and a few included the job role. One student wrote "As a junior network engineer, I have the skills of troubleshooting, configuring IP addressing, and connecting and securing wired and wireless networks. Using all of these skills I will be able to provide adequate services on configuring networks, including DHCP and DNS servers." These results indicated that the competency group used technical terms at a higher rate than the control group, and within a higher number of student responses. This is evidence that the competency group demonstrates a higher level of proficiency and confidence with regards to their knowledge, skills, and abilities.

5. CONCLUSION

Competency-based statements provide students with a better understanding of what they need to know and be able to do. This study demonstrates their effectiveness in assessing students' knowledge, skills, and abilities of students through performance assessments, as well as measuring their opinions and attitudes through written responses. Statically significant evidence from the study showed increases in the three data points. First, the overall average score on the Packet Tracer assessment was higher for the competency group than for the control group. Second, the students in the competency-based group rated themselves higher on the Likert scale questions than the control group. And third, the competency group displayed higher skills and proficiency when writing about their abilities, as seen in the word-frequency analysis. These gains in knowledge, skills, and abilities help produce individuals better prepared for the workforce. While educators may need to invest time into updating current objectives or writing such statements, the results show that using competency-based statements positively affects students and employers.

6. FUTURE RESEARCH

The sample size was relatively small with 54 students, which can be a limitation and influence the results. All students completed the same pre-requisites; however, those grades were not evaluated for this study. Student prior knowledge can influence performance, as well as the control group having a class time later in the evening. Future studies will be implemented with a larger population to measure the effectiveness of competency-based statements on a larger scale and a longer time period. In addition, groups will be flipped with the competency group having the later time. Conducting the study with a similar course at other institutions would provide valuable data. These future studies could also evaluate the effectiveness of providing students with competency-based statements before the learning process, then administer an assessment afterwards. A future longitudinal analysis study could be designed to measure student opinions on competency-based education after a year of employment. In future studies, the word 'or' will be replaced with the word 'nor' on the Likert scale for clarity.

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APPENDIX A

40-point checklist for the Packet Tracer assessment

Group: Competency Objectives

Total score: _____ / 40

	Yes	No
1. Applied a private class C network:	☐	☐
2. Borrowed 2 bits for subnetting:	☐	☐
3. Configured acceptable static IP address on Internet port on WAP:	☐	☐
4. Configured correct subnet mask on Internet port on WAP:	☐	☐
5. Configured correct default gateway on Internet port on WAP:	☐	☐
6. Configured correct DNS address on Internet port on WAP:	☐	☐
7. Configured correct static IP address on local port on WAP:	☐	☐
8. Configured correct subnet mask on local port on WAP:	☐	☐
9. Configured correct DNS address on local port on WAP:	☐	☐
10. Configured a DHCP pool on the wireless access point:	☐	☐
11. Set the maximum number of users to less than 50:	☐	☐
12. Configured the SSID for a WLAN:	☐	☐
13. All other Wireless LANs are off:	☐	☐
14. Turned off broadcasting of the SSID:	☐	☐
15. Configured WPA2 Personal security:	☐	☐
16. WPA2 password meets complexity requirements:	☐	☐
17. All Guest wireless networks are disabled:	☐	☐
18. Configured a wireless mac address filter for the PC:	☐	☐
19. Configured a wireless mac address filter for the laptop:	☐	☐
20. Configured a wireless mac address filter for the smartphone:	☐	☐
21. Changed the admin password on the WAP:	☐	☐
22. Remote management of the WAP is disabled:	☐	☐
23. Configured acceptable IP settings on www.sports.com:	☐	☐
24. Configured acceptable IP settings on www.lacrosse.com:	☐	☐
25. Configured acceptable IP settings on www.basketball.com:	☐	☐
26. Configured acceptable IP settings on www.football.com:	☐	☐
27. Configured acceptable IP settings on DNS server:	☐	☐
28. Configured correct A record for sports.com om the DNS server:	☐	☐
29. Configured correct A record for lacrosse.com om the DNS server:	☐	☐
30. Configured correct A record for basketball.com om the DNS server:	☐	☐
31. Configured correct A record for football.com om the DNS server:	☐	☐
32. PC is a DHCP client:	☐	☐
33. PC is configured properly for wireless connection to the WAP:	☐	☐
34. Tablet is a DHCP client:	☐	☐
35. Tablet is configured properly for wireless connection to the WAP:	☐	☐

36. Smartphone is a DHCP client:	☐	☐
37. Smartphone is configured properly for wireless connection to the WAP:	☐	☐
38. R1 port to LAN with web servers is correctly configured:	☐	☐
39. R1 port to LAN with DNS server is correctly configured:	☐	☐
40. R1 port to WLAN is correctly configured:	☐	☐

APPENDIX B

Objectives and Questions given to the control group

Lab Activity: Use the topology provided in Packet Tracer to configure the network so it fully functions, including the wireless network, the DNS server, the DHCP server on the wireless access point, and the web servers. The html files are already configured on each of the four webservers. Use a private class C network. All needed devices are provided in the topology.
Objectives:

1. Apply subnetting to a network scenario
2. Configure network devices with IP addresses
3. Configure DNS services
4. Configure a wireless access point with appropriate standards and technologies
5. Configure DHCP services
6. Apply network hardening techniques for wireless security

Questions:

1. Once you have completed the lab activity, answer the following questions by circling your selection.

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
When the objectives were presented at the start of the lab activity, I knew exactly what I was expected to be able to do	1	2	3	4	5
When I was completing the lab activity, I felt that the objectives were fully assessed	1	2	3	4	5
After completing the lab activity, I feel that I am prepared to complete the same skills with a physical network	1	2	3	4	5

2. You are applying for a job as a junior network engineer with a local company that provides IT services. On the application you are asked to explain what skills you have when it comes to configuring and securing a wireless network and connecting to a wired network, and configuration of both DHCP and DNS servers. Provide a written statement to the question in the space below.

APPENDIX C

Competencies and Questions given to the competency group

Lab Activity: Use the topology provided in Packet Tracer to configure the network so it fully functions, including the wireless network, the DNS server, the DHCP server on the wireless access point, and the web servers. The html files are already configured on each of the four webservers. Use a private class C network. All needed devices are provided in the topology.

Competencies:

In this lab activity you will be performing the following tasks in a Packet Tracer network demonstrating skills required by a Network Operations Specialist.

Subnet a class C private network address to meet the requirements for the full topology, (number of networks and hosts needed), and configure all devices with appropriate addressing.

Configure the wireless access point as a DHCP server for the wireless clients and connect the access point to the local area network (LAN).

Apply sufficient wireless protection that includes SSID configuration, non-broadcasting, MAC address filtering, encryption, and password configuration.

Configure the DNS server for name resolution for the existing webservers on the network.

Verify full network connectivity for all devices.

Questions

1. Once you have completed the lab activity, answer the following questions by circling your selection.

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
When the competencies were presented at the start of the lab activity, I knew exactly what I was expected to be able to do	1	2	3	4	5
When I was completing the lab activity, I felt that the competencies were fully assessed	1	2	3	4	5
After completing the lab activity, I feel that I am prepared to complete the same skills with a physical network	1	2	3	4	5

2. You are applying for a job as a junior network engineer with a local company that provides IT services. On the application you are asked to explain what skills you have when it comes to configuring and securing a wireless network and connecting to a wired network, and configuration of both DHCP and DNS servers. Provide a written statement to the question in the space below.

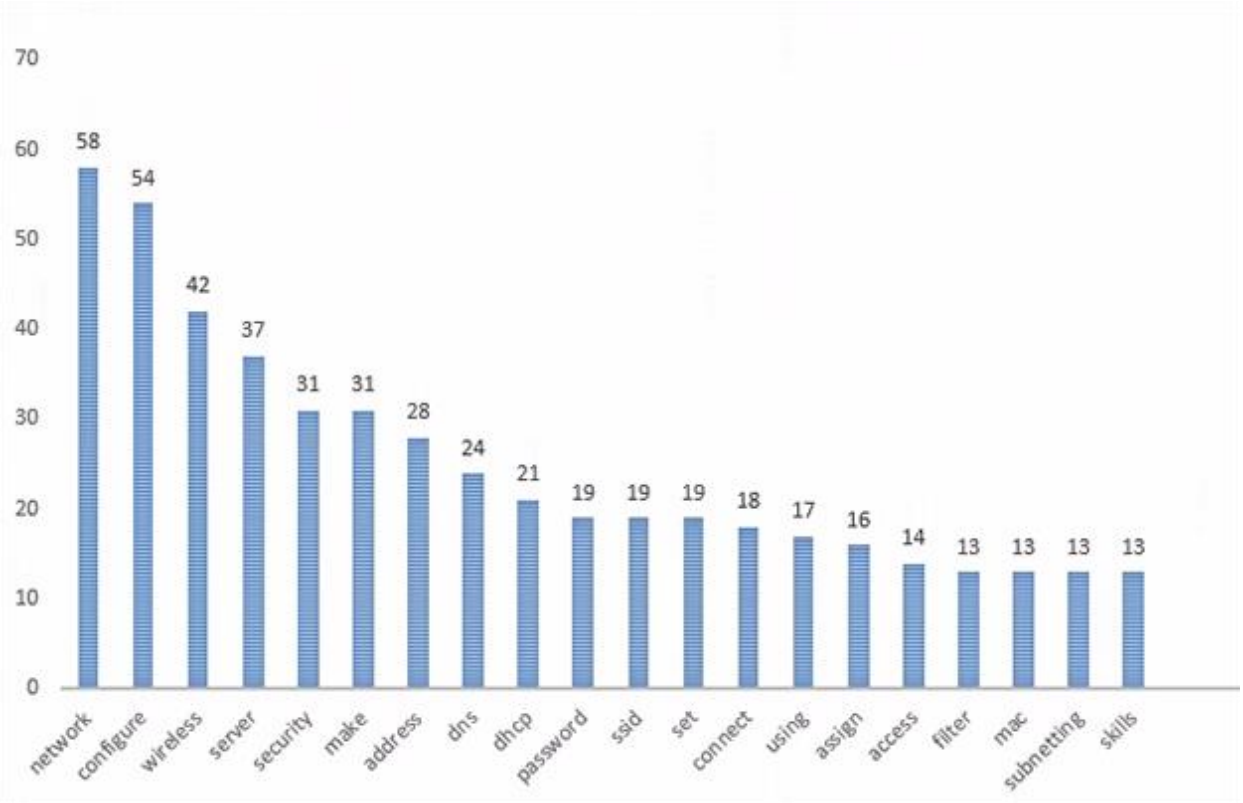
APPENDIX D

Likert scale calculations of the mean, median, and standard deviation for both groups

	Mean	Median	Standard Deviation
Competency group: *When the competencies were presented at the start of the lab activity, I knew exactly what I was expected to be able to do*	3.93	4	.917
Control group: *When the objectives were presented at the start of the lab activity, I knew exactly what I was expected to be able to do*	3.04	3	.940
Competency group: *When I was completing the lab activity, I felt that the competencies were fully assessed*	3.89	4	.892
Control group: *When I was completing the lab activity, I felt that the objectives were fully assessed*	3.07	3	1.174
Competency group: *After completing the lab activity, I feel that I am prepared to complete the same skills with a physical network*	3.33	3	.920
Control group: *After completing the lab activity, I feel that I am prepared to complete the same skills with a physical network*	2.59	3	1.047

APPENDIX E

Word occurrence data for the competency group



APPENDIX F

Word occurrence data for the control group

