Increasing Career Competencies Skills in Computer Science Students using Project-Based Learning and Blended Practical in a Cognitive Apprenticeship Framework

Janett Walters-Williams
janett.williams@hamptonu.edu
Hampton University
Hampton, Virginia, USA

ABSTRACT

The digital revolution resulted in an increase demand for a computer network workforce prepared by universities and colleges. The Computer Network field however, is complex and unpredictable, making it challenging to study and teach yet educators must prepare graduates who understand concepts, have practical network skills as well the necessary Higher Order Thinking Skills. This paper presents a case study utilizing a new methodology based on a merger of Project-Based Learning, Hands-on Learning, Simulation Based Learning, in a Cognitive Apprenticeship framework. It seeks to increase students' (i) expertise in Computer Network, (ii) self-efficacy and (iii) Higher Order Thinking skills competency levels. After 4 years of implementation, analysis of results shows, despite the COVID-19 pandemic, that students (i) acquired and increased their domain knowledge, (ii) acquired procedural and processed knowledge while solving problems, in given scenarios (iii) increased their self-efficacy in Computer Networks and (iv) increased their Higher Order Thinking skills.

CCS CONCEPTS

• **Social and professional topics** → **Computer science education**; • **Applied computing** → *Collaborative learning*; • **Networks** → Network simulations; Network design principles.

KEYWORDS

Higher Order Thinking Skills, Computer Network, Cognitive Apprenticeship, Project Based Leaning, Simulation Based Learning

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1 INTRODUCTION

It has been reported that human's thinking when "left to itself, is biased, distorted, partial, uninformed or down-right prejudiced" [35]. The Fourth Industrial Revolution (4IR) has however presented digital transformation that has made technology an integral part of life resulting in a demand to change this way of thinking. This is because the quality of our lives and that which we produce, make, or build depends precisely on the quality of our thoughts [35]. The system that focuses on human life must now change to one where life is full of technology and people think critically as well as creatively. As such, employees are now asking for graduates who not only have technical knowledge and skills (hard skills) but are also able to think critically, solve problems, work well with others, communicate in a clear and effective manner and manage themselves and projects effectively (soft skills) [8, 29]. This means that developing the quality of students' thinking is a must for not only their learning but their lives as well.

The traditional means of learning where students remember specific information used for directed activities or successfully complete examinations is now inappropriate. "Knowledge is not passively received either through the senses or by way of communication. Knowledge is [instead] actively built up by the cognizing subject" [4]. Knowledge therefore cannot simply be 'transferred' from teacher to student. 4IR requires evolution in teaching strategies that produce graduates able to use prior knowledge while acquiring core academic content, necessary soft skills, and learning dispositions that allow them to create, develop thinking skills, work with others, analyse, present and share learning experiences as well as be self-motivated to learn [42]. Personalised learning is not the goal but a means to achieving these outcomes.

Reports from the National Association of Colleges and Employers (NACE), the World Economic Forum (WEF) and Linked-In reveal that to employers acquiring soft skills are just as, or even more important than hard content skills; college graduates however tend to be lacking the desired level of competencies [16, 27, 32]. WEF stated that what is required to provide competent in soft skills are new approaches to skill development. Today's graduates must be able to adapt to shifts in the workplace and be positioned to shape solutions through creative problem solving and open thinking where there is continuous creativity, decision making, and the completion of related actions - compelling the next wave of creative thinking. Mistakes are simply opportunities to learn [24]; graduates therefore should be able construct knowledge with some new experiences based on their pre-existing knowledge.

As 4IR influences people's lives with the Internet, email, IoT, Social Networks and Cloud Computing the demand for the appropriate Computer Network (CN) workforce increases [33]. A course in CN should produce students who have the necessary depth and breadth of knowledge and practical networking (hard) skills to be able to manipulate details as well as apply needed logical problem-solving, creative and critical thinking (soft) skills. The CN field is however complex [28] and unpredictable making it challenging to study and teach [10, 38]. This occurs because CN is interdisciplinary combining Computer Science, Information Technology, Computer Engineering, Mathematics and Telecommunication; resulting in a evolving field that has a broad range of topics, many abstract technical concepts and jargon that are difficult to explain and understand. These complexities affect the teaching and learning abilities of any CN course as the field relies heavily on the theoretical and practical applications of the combined scientific and engineering disciplines. To produce CN graduates with the required hard and soft skills teaching must become student-centred and utilise an experiential learning method that is holistic, encompassing thinking, feeling and perceiving results from synergetic transactions between student and the environment.

This paper seeks to examine the results of a new teaching methodology that is designed to increase students' soft skills while increasing their expertise in CN. Its implementation has been, for the last four years, in an undergraduate CN course in a Historically Black University (HBCU). Section 2 will introduce the teaching methodology while section 3 examines the research methodology. Section 4 presents qualitative evidence showing effectiveness as well as research discussion and conclusion is found in section 5.

2 LITERATURE REVIEW

2.1 Teaching a Computer Network Course

To survive in this ever-changing workplace CN students are required to have some level of expertise. The accumulation of content knowledge does not automatically equal having expertise as students need the ability and skills to organise this knowledge, add new knowledge as well as analyse new contexts to fit into and increase this knowledge. Once this is done, student experts will be able to use their knowledge to interpret information, analyse situations, and develop solutions to problems. As such, the curriculum must be designed to help novice-level students take the journey to increase their expertise levels.

Possible Solution: The Cognitive Apprenticeship (CA) framework provides the vehicle for this journey as it offers a learning environment that helps novices become experts through guided learning. It emphasises the importance of learning in context such that students will see how different strategies combine with their content knowledge and how they can use a variety of resources in the social and physical environment in relation to this knowledge [23].

CA achieves this by creating a learning environment that consists of four dimensions: (i) *Content Strategies* to acquire relevant concepts and facts associated with a subject using the best knowledge acquisition approaches, (ii) *Teaching Methods* that synthesise, model, coach, and scaffold teaching techniques with methods that promote articulation, reflection, and exploration, (iii) *Sequencing approaches* that support the increasing complexity of tasks combined with tools that develop skills necessary to master a subject, and (iv) The sociology of a *learning environment* that contains policies that create a community of interactive learners. Each dimension has numerous strategies allowing CA to support the three stages of skill acquisition [14]: (i) *Cognitive* where the student develops their knowledge, (ii) *Associative* where any mistakes and misinterpretations learned are corrected while critical elements involved in the skill are strengthened, and (iii) *Autonomous* where the skills are fine-tuned to expert level.

As such CA allows students to explore the nuances of difficult concepts, to engage with simulations of real-life [scenarios], observe, and apply their knowledge as often as they like, and at their own pace. Students can control variables of a system which allows them to explore the causal role of individual parts and receive real-time feedback that can be visualised in multiple ways. In this way, students continuously renegotiate and reinforce their knowledge and understanding of a concept [36] while receiving real-time feedback.

2.2 Receiving Relevant Networking Practical Experience

The CN practical experience is traditionally acquired through a hands-on (HOL) approach which require costly hardware-laden laboratories. As a result, students may work with obsolete or damaged devices due to device cost and maintenance issues [38]. Students may also (1) receive limited device experience due to the limited number of devices restricting student group size as well as practice time. Students may also not have access to parts of the network which are sensitive to security breaches or down times as this would be disastrous. This method is therefore inadequate in providing students with the necessary understanding and skill set [46] as the number and type of devices dictate the number and type of real-life scenarios provided. Non-traditional methods, such as simulations, on the other hand, offer experience which are less costly and more flexible. Students are not working in device-dependent labs but still receive "practical experience of the theoretical concepts [while learning] the complex material in a simple, flexible and relaxed manner" [38]. In so doing simulations-based learning (SBL) overcomes the limitations of learning in real-life situations while developing complex skills and enhancing theoretical concepts [9].

Possible Solution: Despite of the advantages of SBL, HOL remain tremendously important in CN as learning occurs when mental activity is suffused with physical activity [18]. The success of CN students is directly related to their ability to transfer knowledge gained in the academic environment to real-world situations. Acquisition of manipulative skills is only possible through the use of real devices. Therefore, to enhance student learning, the CN must integrate the effective characteristics of both SBL and HOL. This results in students increasing their understanding of concepts while developing their manipulative and technical skills from physical manipulations [7]. Research by the US Department of Education and others [38] have shown that a blend of HOL and SBL produces students who meet more learning outcomes than traditional methods alone[7] as SBL amplifies the real experience in HOL [3].

2.3 Teaching Soft Skills

Soft Skills called 21st Century Skills is a combination of 12 knowledge, life and career skills, habits and traits that are critical to a person's success in today's world [12]. From these, the 4C's (Critical Thinking, Creativity, Communication and Collaboration), problem solving, innovation, decision-making and metacognitive thinking are together called the Higher Order Thinking skills (HOTS)[30]. These skills allow persons to be able to understand concepts, connections and big-picture thinking, analyze and evaluate complex information, categorize, manipulate and connect facts, troubleshoot for solutions, problem solve, ideate and develop insightful reasoning [20] so that they to find answers that do not exist while providing the proper judgement based on determine criteria. HOTS can be divided into four skill areas (Fig. 1): Creative Thinking (CRTS), Critical Thinking (CTS), Problem-solving (PSS), and Metacognitive (MTS). Research shows that HOTS is an important element in education as it "improves students' learning performance, reduces weakness, interprets, synthesises, solves problems, and controls information, ideas and day-to-day activities" [25].

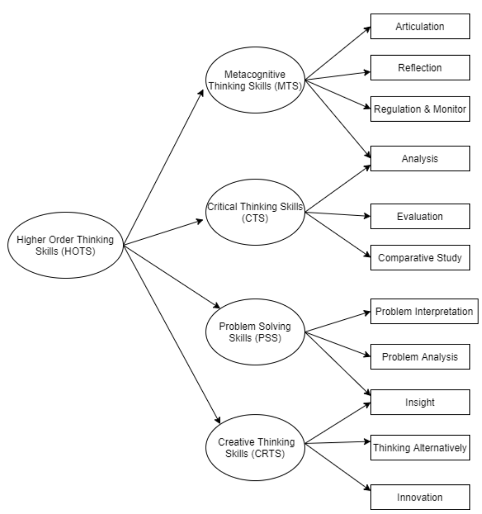

Figure 1: The Four Components of Higher Order Thinking Skills [45].

In the chosen university, the Computing programs are accredited by the Accreditation Board for Engineering and Technology, Inc (ABET). As part of assessment, programs must show achievement in set learning outcomes including critical thinking/problem solving (outcomes 1), creativity (outcome 2), communication (outcome 3), and teamwork/collaboration (outcome 5) [1], - HOTS competencies. The Computing programs are also guided by the ACM/IEEE curriculum that aims to produce graduates who have received adequate preparation in soft skills, such as systematic thinking, collaboration, and creativity. In so doing these graduates will be able to creatively solve new challenges that arise as they meet complex demands in a variety of contexts [2].

Employment reports and surveys show however, that college graduates consistently fall below the desired HOTS competency level [16, 27, 32]. The Pearson Business School 2019 report also states that only 13% of graduates are soft skill ready at the time of employment [47]. Wiley Education Services and Future Workplace 2019 survey found 64% (increase from 54% [2018]) of surveyed employers were concerned with the soft skills deficiency in their companies indicating that the soft skills gap had widened [48]. Employers feel that education has done little or nothing to address this shortage [49]; these skills however are the areas in which colleges are struggling to prepare students. Graduates are taught content and not how to teach, use or understand its importance [49] resulting in the demand for HOTS skills being a serious "challenge traditional [learning] establishments" [6].

Possible Solution: Research shows Project Based Learning (PBL) as highly successful in creating a student-centred classroom that supports students' individuality and creativity as well provide ways to increase their HOTS competency levels [5, 12, 31, 34, 40]. This is because PBL provides opportunities for students according to [15] to:

(1) make decisions through a systematic framework, having problems whose solutions are not limited,
(2) design the process of activities,
(3) build knowledge based on real experience,
(4) find information and solutions,
(5) work collaboratively on projects,
(6) conduct ongoing evaluations of solution
(7) evaluate each other to find mistakes and make changes, and
(8) assess resulting product.

It therefore integrates learning with training allowing students to be more independent in building their own understanding [34] while providing them with opportunities to analyze, categorize and develop the expertise and skills required to address realistic scenarios, as well as enhance their leadership abilities, listening skills, coordination and strategic thinking skills [31]. The realistic scenario projects provided in PBL have clear focus on (i) critical thinking and problem-solving (ii) collaboration and leadership, (iii) verbal and written communication and self-management [26, 29] which are the 4 top competencies required by employers in NACE job surveys [32].

2.4 Offered Solution - CAP-B

Research shows a positive relationship between Problem Based Learning (PrBL) and CA [17, 37] however the research showing the connection between PBL and CA is conducted by the research in [45]. Research has also shown the implementation of a HOL and SBL merger as well as a PrBL and HOL merger [38] but none shows the implementation of the merger of PBL, CA, HOL and SBL. This research seeks to showcase a methodology called CAP-B (*Cognitive Apprenticeship (CA) Framework with Project-Based Learning (P), and Blended Learning (B)*) and its impact on students expertise and HOTS competencies levels.

3 RESEARCH METHODOLOGY

This research employed an exploratory case study approach as student groups were small and it is suitable when finding answers to "how" and "why" questions in research [43]. To achieve data triangulation and enhance internal validity, Creswell's [11] mixed method approach was employed allowing the researcher to conduct

(i) a quantitative study to address the hypothesis and research questions (RQ) and use the data to analyse specific variables relevant to learning outcomes, attitudes, abilities and other constructs [28]; and (ii) a qualitative study to explain any unexpected results, significant or non-significant quantitative findings and the description of the context within which findings were situated. The research also employed hypothesis testing.

3.1 Hypothesis

This research hypothesises that CAP-B is an effective teaching-learning methodology that increases students' self-efficacy (SE) and expertise in CN as well as their HOTS competency level. Based on this hypothesis this study seeks to answer the following RQs.

- RQ1: Does the use of this methodology increase students' SE levels significantly?
- RQ2: Does the use of this methodology increase students' knowledge and expertise levels drastically?
- RQ3: Does the use of this methodology increase students' level of HOTS competencies?

3.2 Population Sample & Course

The target population for this study was the 3rd- and 4th-year students in a Computer Science department in a South-east HBCU. The population was taken from an undergraduate CN course over a 4-year period (2019-2022) totalling 48 (28 male, 20 female).

The primary objective of the CN course is to provide students with theoretical CN knowledge and practical skills while increasing their SE and HOTS competency levels. It consisted of 16 weeks of lectures, assignments, project, examinations, simulations and hands-on labs all supported by a prescribed text. Labs sessions were divided into weekly hands-on exercises and simulations that were designed to act as the practical component of the lecture. In this way students' practical experience and knowledge were cemented as they utilised abstract concepts that are usually hard to understand [41].

There is a semester-long PBL project that presents real-world problem scenarios. This project had bi-weekly monitoring and there is the testing of results through presentations and reports to determine the achievement of students competencies and an evaluation the project solution achievement. Students also conducted individual assessment while the group members carried out peer assessment.

3.3 Research Instrument

Students' academic progress can normally be assessed using examinations. Assessment of students' growth in their HOTS competency, however, requires alternate techniques. Since these skills are most often performed in problem-solving situations, growth can be assessed through students' performance in situations where students practice and demonstrate intelligent behaviors. Research has shown that students who have good competency level of HOTS are expected to succeed in their studies [44]. In this research students' academic performance were therefore used to determine students competency levels in the skills areas seen in Fig. 1.

Data was collected from ongoing assessment (formative and summative) that provided a "picture album" of each student's ability instead of the random and isolated "snapshot" of the student's knowledge provided by traditional testing. There were six(6) assessment methods:

(1) **Examinations** – continuous evaluation through labs and tests that assessed students understanding of course concepts, and their real-world applications in order to optimize learning. *Pre-assessment Test*, administered in the first week, was used as baseline reference. *Final theory examination* examined students' ability to apply course concepts to different scenarios. *Final simulation examination* assessed practical skills students acquired via simulations throughout the semester.
(2) **Self-Reflection Evaluation** – a qualitative feedback where each student assessed his/her individual performance and level of learning after completing PBL project.
(3) **Project Evaluation** – At the end of the course students showcased and explained CN project solutions in detail with relevance to theory concepts. The submitted project report and solution demo were also assessed.
(4) **Discussion** – forum through which students had dialog on content, shared their ideas, challenged and taught each other, clarified assumptions, experiment, and learnt new knowledge, skills and ideas.
(5) **Direct Observation** - weekly monitoring of students' performance during hands-on activities by researcher.
(6) **Survey** - administered at the end of course to measure students' (i) attitudes and perceptions of the effectiveness of the methodology in promoting learning and (ii) increase in SE and HOTS competencies.

3.4 Research Analysis

Data analysis utilised four statistical tests: Welch t-Test (Wt), Wilcon Signed Rank (WS), Mann Whitney Test (MW) and One-Way ANOVA test. Students grades were also analyzed using Gain Analysis. The criterion for the statistical significance, α, was set at 0.05 for all tests. Wt and MW utilised the 2-tailed hypothesis and ANOVA had an effect size of 0.25.

3.4.1 ***Validity Tests:*** The following validity tests were conducted: (i) *Construct validity* that focused on the degree to which a test accurately measures its intended subject. This was done using examinations. The conclusion was also examined to ensure that it followed logically from suppositions; (ii) *Internal validity* that described the logical flow of the study from hypothesis to evidence to conclusion. For this study examinations were administered per university policy under supervision and results evaluated; and (iii) *External validity* that demonstrated the applicability of the finding to real world. In this study validity was tested as there has been different student groups.

3.4.2 ***Qualitative Analysis:*** Two surveys were administered yearly at the end of the course to ascertain students' views on their CN, SE and skill development. To ensure validity of the data students completed online surveys. Both surveys contained Likert-scale items,

Table 1: Students' Self-efficacy Survey Questions.

Number	Actual Question
1	I did not have much knowledge of the subject matter at the start of the course
2	My knowledge of the subject matter increased drastically at the end of the course
3	I know that I have achieved the course's desired learning
4	I am confident that I can apply theory acquired to practice
5	I understand network concepts well enough to synthesise these knowledge and skills
6	I have developed my ability to think critically when solving problems in different exercises
7	I can do a good job on exercises and tasks assigned in networking
8	I am satisfied with my effort in this course

Table 2: Students' Self-Efficacy Survey Results (%).

Question	Agree/SA	Disagree/SD	Neutral
1	95	5	0
2	97	0	3
3	100	0	0
4	100	0	0
5	86	0	14
6	95	0	5
7	100	0	0
8	100	0	0

ranging from Strongly Disagree(SD) to Strongly Agree(SA). Tables 1 and 2 show and students response for SE survey. Question 8 sought to measure the students' level of course satisfaction. Table 3 and Table 4 shows questions and students' responses for the Skills Development survey.

Students were also observed by researcher for eleven weeks during their hands-on labs and the results recorded on a Likert-like scale: *Unsatisfactory* - students made little or no connections between the topics and activities carried out in simulations with the hands-on labs; *Emerging* - students made appropriate but somewhat vague little connections between the topics and activities carried out in simulations with the hands-on labs; *Proficient* - students made appropriate connections between the topics and activities carried out in simulations with the hands-on labs and *Exemplary* - students made appropriate powerful and original connections between the topics and activities carried out in simulations with the hands-on labs (Table 5).

3.4.3 ***Quantitative Analysis:*** This method focused on analysing students' declarative and procedural knowledge as well as their retention level. To determine the level of growth in their declarative knowledge, examinations were administered throughout the course time and comparison done. The researcher established internal validity by conducting these exams under university exam conditions. Procedural knowledge was assessed using weekly hands-on assessments, simulation assessment and a PBL project. Overall retention assessment was examined using students' performance in both declarative and procedural knowledge.

4 RESULTS AND DISCUSSION

4.1 RQ1 - Self Efficacy

Researchers have repeatedly provided evidence that SE can be seen through the students' academic performance [13, 39]. It is one of the most important factors in the students' academic success where high scores in SE are more likely to result in higher levels of academic performance [21, 50]. This shows examination of students' academic performance reflects their SE as there is a strong correlation between the two: the higher the academic performance the stronger the SE. For this research assessment was augmented with three outcome variables: (i) declarative knowledge that examined students' retention of CN facts, principles and their interrelationship (ii) procedural knowledge that looked at knowledge/skills students acquired while executing simulated and hands-on activities and (iii) retention that examined how much declarative and procedural knowledge students had retained at the end of the semester.

The examination of Table 6 shows the positive change in students' overall academic performance from the pre-assessment test to the final examination. Examination of the pre-assessment test (Mean=55.8[2019]; 5.6[2020]; 42.2[2021]; 40.9[2022]) shows low student performance. This is in line with Question 1 seen in Tables 1 & 2 where majority of students did not feel they had much networking knowledge at the beginning of the course. Final Examination result (Mean=97.7[2019]; 83.9[2020]; 82.6[2021]; 88.5[2022]) show great increase from the pre-assessment. Based on the correlation, the conclusion can be made that students having completed the course with these scores have a greater sense of SE that when they began. This conclusion is supported by the survey results in Table 2 where Questions 3, 4 and 7 show 100% of students believed that they had the confidence to apply theory to practical network tasks at the end of the course.

4.2 RQ2 - Network Expertise Assessment

4.2.1 ***Declarative Knowledge:*** For all 4 years there are score increases (Fig 2) from pre-assessment (Mean=55.8[2019]; 5.6[2020]; 42.2[2021]; 40.9[2022]) to midway with midterm (Mean=92.3[2019]; 58.4[2020]; 63.5[2021]; 84.9[2022]) to final exam (Mean=97.7[2019]; 83.9[2020]; 82.6[2021]; 88.5[2022]). This implied that there is constant increase in students' declarative knowledge. Grades were further analysed using aforementioned tests, results shown in Table 6. Examination of p-values revealed that for all tests they were

Table 3: Students' Skill Development Survey Questions.

Number	Actual Question
1	The course provided the opportunity to practice the skills required in the course
2	The course allowed me to synthesize fundamental knowledge and skills
3	The simulations in the course helped to improve my practical skills
4	The course gave me a deeper insight into the field
5	The course presented skills in a helpful sequence
6	The course developed my abilities and skills for the subject
7	The course developed my ability to apply theory to practice
8	The course provided guidance on how to become a competent professional

Table 4: Students' Skills Development Survey Results (%)

Question	Agree/SA	Disagree/SD	Neutral
1	100	0	0
2	95	0	5
3	100	0	0
4	100	0	0
5	100	0	0
6	100	0	0
7	100	0	0
8	100	0	0

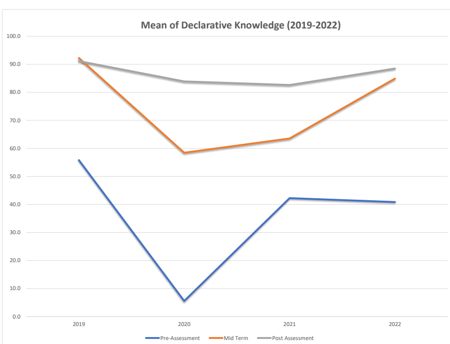

Figure 2: Students' Declarative Knowledge (%).

smaller than α, which indicated that the final examination scores were statistically larger than those of the pre-assessment. The large values from the effect size for all 4 years also supports these findings indicating large differences in scores between the two examinations. Examination of the skewness of both scores showed that pre-assessment was potentially symmetrical however final examination had an asymmetrical left/negative skew with a long-left tale. This supports the position of the calculated means and showed that students' overall performance moved leftward to higher scores.

Application of Gain Score Analysis supports the findings of significant positive changes in students' academic performance. This showed that 71% of all students, over the 4 years, registered increase of 70% and above. Gain analysis also showed a yearly increase (gain% =57.3[2019]; 82.8[2020]; 10.4[2021]; 79.7[2022]) in the number of students who had large gains which corresponds to a drastically large improvement in academic performance. There were 38% of the students in 2019 who had no gain; this disappeared however in 2020, 2021 and 2022.

It can therefore be concluded that CAP-B helped students to retain much of the theory and its applications, thus being able to answer questions more accurately at the end of the course – increase in declarative knowledge.

4.2.2 ***Procedural Knowledge:*** Comparison of the scores for pre-assessment with those for final simulation and hands-on project shows that both Wt and ANOVA produced p-values $< \alpha$ (Table 7). This indicates that the difference between these two sets of scores averages and that of the pre-assessment is large. This was also supported by effect size data that show the differences between these scores average and that of the pre-assessment being also large. This leads to the conclusion that there has been a significant increase in students' skill level by the end of the course. The student survey results in Table 4 supports this findings, as 100% of students indicated that the course developed their practical skill levels and the increase is due to the use of both SBL and HOL.

Examination of performance in (i) final simulation (Mean=87.4% [2019]; 86.9% [2020]; 80.6% [2021];89.0% [2022]) and (ii) hands-on (Mean=87.2% [2019]; 71.8% [2020]; COVID[2021]; 92.5% [2022]) projects showed not much difference in the mean. This can lead to the assumption that students were able to attain the same skill level in both hands-on and simulations. This shows that the results from the simulation are functionally equivalent to the hands-on results. At the end of the course students were asked the question *"Please identify what you consider to be the strengths of the course"*. 90% stated that having simulations practice and then replicating in the hands-on projects helped them learn the material better. It can therefore be concluded that the skills learnt in the simulation environment were transferred to the physical environment and authentic learning had occurred.

This conclusion is supported by the direct observations conducted throughout the course. Table 5 shows that through continuous monitoring students were, by week 8, making appropriate connections between topics and skills learnt in simulations and those used in the hands-on activities. By week 12, 100% of the students were at the proficient or above levels showing that simulation

Table 5: Students' Skills Development Survey Results (%)

Week	Unsatisfactory	Emerging	Proficient	Exemplary
3	36	9	3	0
4	36	7	5	0
5	28	11	9	0
6	15	19	14	0
7	11	22	15	0
8	8	22	16	2
9	0	18	21	9
10	0	9	19	20
11	0	7	21	20
12	0	0	17	31
13	0	0	9	39

Table 6: Declarative Knowledge Analysis Results: Pre-assessment (P) and Final Exam (F).

Year	Test	p-value	Effective Size	Skewness
2019	Wt	1.16E-03	1.05	-
	WS	5.3E-03	0.80	-
	MW	2.08E-02	0.42	-0.11(P) -2.32(F)
	ANOVA	4.6E-04	0.75	-0.11(P) -2.32(F)
2020	Wt	1.73E-06	4.12	-
	WS	3.91E-03	0.87	-
	MW	3.996E-04	0.84	-0.56(P) -1.47(F)
	ANOVA	7.79E-10	3.21	-0.56(P) -1.46(F)
2021	Wt	3.75E-04	1.36	-
	WS	3.91E-03	0.87	-
	MW	3.96E-04	0.84	0.65(P) -1.12(F)
	ANOVA	1.98E-05	1.08	-0.65(P) -1.17(F)
2022	Wt	2.48E-07	5.21	-
	WS	1.95E-03	8.70E-01	-
	MW	1.77E-04	8.4E-01	-0.12(P) -0.41(F)
	ANOVA	8.24E-10	2.7E+00	-0.12(P) -0.41(F)

skills are transferable to the physical environment. This indicated that SBL with HOL increased students procedural knowledge.

4.2.3 ***Retention Level:*** Examination of both declarative and procedural knowledge shows an increase in students' scores. For the studied university the acceptable pass rate is C and to determine students' overall grade (Table 8) was based on their Examinations, Assignments, Labs, Observation and Discussions. From Table 9 it can be seen that the p-values $< \alpha$ indicating that the difference between pre-assessment and students overall grades is large. This is supported by large effect sizes showing that the differences between these scores average was also large. Although MW did not show much the statistically significant change shown in the others result in the conclusion that students were able to retain much of the theory and necessary skills for CN at the end of the course.

4.3 RQ3 - HOTS Level Assessment

To determine the effectiveness of CAP-B in producing students with HOTS competency levels desired by employees this study evaluates students' performance in the four (4) main areas as named in Figure 1. These skills were developed using mainly Simulations, Hands-on Exercises and the PBL project.

4.3.1 ***Metacognitive Skills (MTS):***. Developing MTS require students to progress through three distinct phases: (i) *Planning* where students decide on what they need to learn and how they are going to learn; (ii) *Monitoring* where students examine their progress and the activities they employed to achieve learning; and *Evaluation* were students reflect and analyse how well they achieved learning. The students in the study MTS levels were measured based students' performance in not only examinations but in also difference skill sets as seen below.

Articulation (Communication) Skills: Researchers through the years, have stated that students who have increased their MTS levels will be much better at understanding what they read and consequently this shows in how they solve problems as well as how they articulate their responses[19]. This means that high communication skills reflect high MTS levels. In this study students were evaluated in all three fluencies of communication – digital, writing and speaking using oral presentations, discussions, PowerPoint and written reports. In 2019, there were 2 written reports, however discussion forums were added in 2020 and PowerPoint in 2021. Evaluation shows an increase in the number of As - writing [pass rate: 0% (2019); 33% (2020); 62% (2021)], digital [presentations (pass rate: 100% all 4 years] and oral [pass rate: - (2019); 33% (2020); 62% (2021)]. This shows a reflection of research literature - an increase each year in the number of A's for students' communication skills.

Regulation & Monitoring Skills (Reflection): This was measured using surveys and direct observation. Analysis shows that 95% of the students expressed that their knowledge of CN was limited at the beginning of the course and 100% expressed that by the end of the course they had learnt a great deal. All students expressed that by the end of the course they could apply theory to practice and 95% stated that they could synthesise CN concepts and knowledge while thinking critically when solving problems. Students (100%) also felt that the course not only provided them with the necessary

Table 7: Procedural Knowledge Analysis Results: Final Simulation (F) and Hands-on Project (H).

Year	Test	p-value	Effective Size	Skewness
2019	Wt	9.04E-03	0.78	-
	WS	1.66E-02	0.69	-
	MW	6.27E-02	0.34	-0.11(S) -0.64(H)
	ANOVA	6.30E-03	0.56	-0.11(S) -0.64(H)
2020	Wt	3.31E-10	12.24	-
	WS	9.09E-03	0.87	-
	MW	4.01E-04	0.83	-0.56(S) 0.28(H)
	ANOVA	1.78E-15	7.48	-0.56(S) 0.28(H)
2021	Wt	COVID	COVID	COVID
	WS	COVID	COVID	COVID
	MW	COVID	COVID	COVID
	ANOVA	COVID	COVID	COVID
2022	Wt	8.13E-01	0.11	-
	WS	1.03E-01	0.52	-
	MW	2.90E-02	0.49	-0.71(S) -2.63(H)
	ANOVA	5.09E-01	0.16	-0.71(S) -2.63(H)

Table 8: Students' Retention Level Results (%).

Grades	Pre-Assessment	Overall Finals
A+, A, A-	19	40
B+, B, B-	0	56
C+, C	3	14
Fail	88	0

abilities and skills but also helped them to develop these skills. From monitoring students' performance (Table 5) it can be seen that students' skill competency increased as they progressed throughout the course with 100% being either proficient or exemplary at the end. This supports the findings in the surveys.

4.3.2 ***Creative Thinking (CRTS):***. Developing creative thinking in students require them to be able to look at problems or situations from a fresh perspective or angle while using the right tools to assess and develop a plan for a new solutions. It also looks at if they are able to create new objects and develop innovative ideas and methods by elaborating upon, refining, analysing, and evaluating existing ones [22]. The students' CRTS skills levels were measured based students' performance in both examinations and the skills below.

Innovative Thinking: This skill set focuses on the ability to come-up with new ideas and novel approaches to solve problems. In this study this skill was developed using the PBL project where students were required to design and implement their own CN to solve a given problem. In so doing students developed their innovative skills as they completed their research on the problem with the aim of developing the necessary understanding that would lead to the development of ideas. The project also allowed students to further develop the skill set as they designed and developed a solution based on their perception and understanding. Evaluation shows an increase in the pass rate for solution designs from 2019 to 2022 based on [Final Simulation CN [pass rate: 100% all 4 years] and [Hands-on CN [pass rate: 100% (2019, 2020 & 2022); COVID-19 (2021)]].

Insight Skill (CRTS & PSS): This is considered a wisdom-based skill that focuses on the ability to see beneath the surface of a problem and identify processes or knowledge already available that can be used in designing a solution. Students' performance was determined though the evaluation of the PBL project report [pass rate: 100% all 4 years], which shows how students determined what from their collection of knowledge could be used to help design a solution and make the required recommendation. Evaluation was also done based on students' performance in their Final Simulation CN [pass rate: 100% all 4 years] and [Hands-on CN [pass rate: 100% (2019, 2020 & 2022); COVID-19 (2021)]]. Overall students showed that they have developed their insight skills through the course.

4.3.3 ***Problem Solving (PSS) & Critical Thinking (CTS):***. Students who are developing their PSS should be able to identify and understand given problems or situations, collect and analyse relevant information, then select and implement a relevant solution. Learning PSS allows students to learn how to collaborate procedurally and systematically, develop their creativity, expand their thinking processes, increase their intellectual abilities, individual motivation and individual activity in the learning process [15]. Students should then be developing their CTS when they collect hypothetical problem solutions, process, interpret, rationalise and analyse these possible pathways rationally and objectively while understanding the connections between them. The final result should be a reasoned recommendation and application of the best solution.

Analytical Thinking: This skill focuses on the ability to collect, observe, research and interpret a problem in order to develop solutions. In this research this was developed as students worked on the PBL project. Here students used their old and new knowledge joined with researching to brainstorm and produce possible solutions (PSS); analyse and prioritise these solutions (CTS); evaluate

Table 9: Retention Level Analysis Results: Pre-assessment (P) and Overall Grade (O).

Year	Test	p-value	Effective Size	Skewness
2019	Wt	1.94E-03	0.98	-
	WS	2.86E-02	0.80	-
	MW	0.2608	0.42	-0.11(P) -2.32(F)
	ANOVA	1.89E-03	0.65	-0.11(P) -1.40(O)
2020	Wt	3.66E-10	12.09	-
	WS	9.03E-03	0.87	-
	MW	4.01E-04	0.83	-0.56(P) -1.34(O)
	ANOVA	-2.22E-16	9.25	-0.56(P) -1.34(O)
2021	Wt	3.41E-05	1.77	-
	WS	2.64E-03	0.83	-
	MW	3.24E-04	0.71	-0.65(P) -0.25(O)
	ANOVA	1.724E-06	1.28	-0.65(P) -0.25(O)
2022	Wt	1.23E-07	5.08	-
	WS	1.95E-03	0.87	-
	MW	1.08E-05	0.84	-0.12(P) -0.50(O)
	ANOVA	1.23E-09	2.68	-0.12(P) -0.50(O)

these solutions and select the best solution [report [pass rate: 100% all 4 years]]. Students also developed this skill during their lab simulations [pass rate: 100% all 4 years] as they are required to produce an appropriate solution for the given scenarios. This proficiency change is reflected in the number of A's produced [Number of A's: 67% (2019); 78% (2020); 77% (2021); 90% (2022)].

Evaluation: This skill is used to assess a solution to understand how well it achieved it goals. It can also be used to identify any challenges that arises in solution development and the creation of recommendations of tools and devices to overcome these challenges. In this research evaluation was done using students' Final Simulation CN [pass rate: 100% all 3 years], their Hands-on CN [pass rate: 100% (2019, 2020 & 2022); COVID-19 (2021), and their weekly Lab Simulations [Number of A's: 67% (2019); 78% (2020); 77% (2021); 90% (2022)].

Problem Solution Implementation: Once the appropriate solution has been selected students continue to work on improving their PSS by implementing the solution. They received this opportunity in the PBL project with the creation of their Final Simulation CN [pass rate: 100% all 3 years], Hands-on CN [pass rate: 100% (2019, 2020 & 2022); COVID-19 (2021), as well as in their weekly Lab Simulations [Number of A's: 67% (2019); 78% (2020); 77% (2021); 90% (2022)].

5 CONCLUSION

CN is a complex and challenging course to teach and CAP-B is designed as a methodology to help produce graduates that meet employers requirements. As such, it has been designed to improve students expertise in CN, their SE and HOTS competencies. The methodology has been utilise in the chosen HBCU since 2019. The purpose of this case study was to identify if these goals are achieved at the end of teaching CN.

From the quantitative analyses it is revealed that CAP-B has increased students' SE, declarative and procedural knowledge as well as retention levels regardless of their prior knowledge background. With this methodology students were able to understand different types of networking concepts, apply the learnt skills in different environments as well as solve problems arising from different scenarios and environments. This conclusion was again supported with qualitative analyses, that showed there is a strong correlation between the amount of time spent doing simulations and Hands-on practices and the increase in students' expertise level. Based on surveys students perceive that this blend of simulation and hands-on helped them to understand the concepts and acquire necessary skills. For these students the use of simulations helped them to achieve tasks done in the hands-on exercises. Analysis also showed that students level of competency in HOTS, reflected in their academic performance, also increased in all four areas meeting the requirements for ABET, ACM and employers.

Based on analysis of 4-years of data, this study has concluded that using CAP-B has resulted is a significant increase in students SE, academic performance and HOTS competency levels. Data will continue to be collected to continue further analysis. Further research will be conducted to test the transferability of CAP-B to other courses that can utilise both HOL and SBL.

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