Investigating the Usefulness of a Micro High Performance Computing System as an Educational Tool

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ABSTRACT

Access to High-Performance Computing (HPC) systems is an increasingly important problem in academia in emerging economies. Computer science curricula often offer courses that require an HPC system as an education supporting tool. This represents a problem in emerging economies due to the extensive financial resources that are required to acquire, host, and maintain it. To tackle this problem we investigate how a micro HPC system can be used in computer science courses to help the students acquire the knowledge and the skills required to utilize a fully-fledged HPC system. In this paper, we use four dimensions of the utilization of a micro HPC system to examine how these are related to one component of the technology acceptance model. In the evaluation of the usefulness of a micro HPC system, we have used design science research as the survey method. Research data were collected to evaluate the hypotheses that the acquisition of HPC skills and knowledge of engineering students in managing, maintaining, programming, and integration relate to the perceived usefulness of a micro HPC system. The results show that a micro HPC system is a useful artifact that can support computer science students in acquiring HPC skills and knowledge. The findings of this study support the usability of a micro HPC system by evaluating the usefulness of the system as an educational tool to support the transfer of HPC skills and knowledge in a resource-constrained environment.

CCS CONCEPTS

• Computer systems organization•Applied computing~Education•Applied computing~Education~Computer-managed instruction

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KEYWORDS

High Performance Computing, Technology acceptance model, Computer science education, Design science research, Usefulness

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1 Introduction

In this era of parallel computing, computer science curricula generally require a parallel computing system as an educational supporting tool. Parallel computing systems that are used in research institutions and academic institutions present a challenge in terms of the total cost of ownership and usually focus on research than teaching. The total cost of ownership of a fully-fledged High-Performance Computing (HPC) system as a parallel computing system represents a challenge in emerging economies due to the number of financial resources that are required to acquire, host, and maintain it. A micro HPC (μHPC) system can be used to tackle challenges in computer science courses that hinder students from acquiring the knowledge and the skills required to manage a fully-fledged HPC system.

The learning of students is enhanced by access to educational artifacts [1][2]. Evidence-based evaluation of an artifact is one of the important processes in the design science research (DSR) cycle [13][36]. In the study of information systems, the socio-technical evaluation of IT-based artifacts is one of the processes in the design cycle that can ensure that the artifact achieves the purpose for which it was designed. DSR involves the evaluation and building of artifacts in the form of models, instantiations, methods, and constructs [14]. The rigorous evaluation of an artifact involves verifying whether the designed artifact has met the expected goals in solving practical problems [16]. To meet the expected goals, the measure of the usefulness of an artifact is desired. According to the Merriam-Webster dictionary, the definition of usefulness reads as follows: "the quality of having utility and especially practical worth or applicability". Perceived usefulness has been defined as one's perception that using new technology will improve or enhance one's performance [22].

This study employed a constructivist approach as a learning theory to enable learners to self-discover the usefulness of the µHPC system. Constructivism is learner-centered and enables the learner to construct knowledge gained from hands-on experience by interacting with the artifact in the social context [56]. In constructivism, the learner is creating their reality by using cognitive activities in the context. Hence the knowledge enables one to adapt the reality, not to copy reality.

Research studies show that evaluation of an artifact's usefulness is shaped by the context in which it is used, and that usefulness is critical in defining a user's overall evaluation of a system [1][9]. Usability, consistency, performance, accuracy, functionality, and completeness are some of the factors that can be used to evaluate IT artifacts [17][35]. In investigating an artifact in a naturalistic environment, we concentrate on the underlying claim of usefulness [19] to be used as an attribute that measures the usability of the artifact. Although substantial work has been done on the design and development of µHPC systems, more work needs to be conducted to ascertain the usefulness of a µHPC system as an educational tool in a variety of learning situations.

In this study, the purpose was to evaluate the usefulness of a µHPC system to support engineering students' HPC knowledge and skills in higher education in Tanzania. The specific purpose of this study is to determine the usefulness of a µHPC system to engineering students to develop HPC management, maintenance, programming, and integration skills and knowledge. We used DSR to investigate the usefulness of a µHPC system by evaluating it as an educational artifact. The evaluation of an artifact in DSR is a crucial process to articulate how well the artifact performs and fulfills the requirements of the user [25]. The research question is "How useful is a µHPC system artifact for students to acquire the knowledge and the skills required to utilize data-center sized HPC systems?"

We sought to test the hypothesis that a µHPC system artifact is useful in acquiring the knowledge and the skills required to utilize data-center sized HPC systems. A µHPC system was used as an intervention to participants who didn't study HPC in their curriculum but not to participants who studied an HPC module already using a data-center sized HPC system. Participants were put into two groups and the measurements recorded before and after the experiments.

The study was designed (1) to study the usefulness of a µHPC system, (2) to assess the utility of the µHPC system as an educational tool, and (3) to investigate the µHPC system's capacity to perform activities of management, maintenance, integration and programming of a fully-fledged HPC system. The results of this investigation showed the µHPC system to be useful to improve computer science and computer engineering education practices.

The remainder of this paper is organized in the following sections. First, the research artifact is presented in section 2. Next, the evaluation context is presented in section 3. Thereafter the methodology is presented in section 4 and in section 5 the results are presented. A discussion in section 6 is followed by the conclusion in section 7.

2 Artifact

In developing countries, the numbers of HPC systems that can be used in academia to support the curriculum do not match the numbers of academic institutions. Most of these HPC systems are primarily installed to support advanced research [57][58]. Nowadays HPC systems serve mainly three purposes, namely advanced research, consultancy, and support of the curriculum. All three HPC purposes normally compete for the available CPU hours of an HPC system. Support for the curriculum sometimes suffers in this competition for CPU hours due to the high priority that is given for advanced research. Support for a parallel computing curriculum using HPC systems is of importance in 21st-century education.

The availability of affordable yet powerful computing artifacts that use off-the-shelf computing devices and open source software has created opportunities, using the Beowulf architecture, to create HPC clusters [4][5][6][7][49]. These computing clusters, which are made up of computing nodes and master nodes (see Table 1), are also called *Beowulf clusters* or *HPC systems*. They use similar processors as those for data-center sized HPC systems [47]. In this study, the research artifact is an HPC system that is used as an educational tool. The *utility* of an HPC system, in this context, means the ability to perform activities required to manage, maintain, program, and integrate HPC systems.

Data-centre size HPC systems that have a high footprint in highly funded research institutions have been reported to be expensive in terms of the acquisition, operation, and maintenance costs [55]. In line with the prohibitive costs of acquisition and maintenance associated with such systems, we evaluated an affordable HPC system as an educational tool. The evaluated artifact is referred to as a *micro HPC system* (*µHPC system*) and is intended to be used to support computer science curricula. The portable and affordable µHPC artifact is made of credit card-sized computing and master nodes [47]. The µHPC system supports, among others, the Python language, which is an open-source parallel programming language [48]. The µHPC artifact is configured and runs using Linux open-source software. The network that glues the four computing nodes and one master node are made of inexpensive switches.

Table 1: Master and Computing Node Technical Specifications [28]

No.	Component	Specification
1.	Architecture	ARMv8
2.	SoC	BCM2837B0
3.	CPU	Cortex-A53 64 Bit Instruction
4.	GPU	Broadcom Videocore IV @ 400
5.	Memory	1 GB SDRAM
6.	USB	4 USB 2.0 ports
7.	Video Output	HDMI
8.	On-board	Micro SD port
9.	On-board	Giga Ethernet, Bluetooth and
10.	Power source	5.1V/2.5A DC power input
11.	Power ratings	700-1000 mA (up to 5.1 W)

3 Evaluation Context

The evaluation of the artifact in a socio-technical context is influenced by the resources available in the environment. In investigating the usefulness of a μHPC system in the context of education, we did not face constraints in terms of access to participants, time, people, and budget. However, the main constraint in this study was the evaluation environment which was in one institution in a computer laboratory room [1] because that is the only academic institution that currently teaches HPC in their curriculum. So it was not possible to conduct multiple evaluations in different institutions.

3.1 Evaluation Goal and Strategy

Artifacts in DSR can be evaluated in terms of the improvements in the design or utility of the artifact [26]. For this study, the selected goal was to summatively evaluate the usefulness of the μHPC system as an educational tool. The selected evaluation strategy was naturalistic and ex-post as the complete artifact was evaluated while being used. The experiment was carried out in natural settings that contributed to high external validity. The results can be transferred to similar settings or can be generalized.

3.2 Research Model

One of the influential theories regarding the investigation of the usefulness of the information system is the Technology Acceptance Model (TAM). TAM is one of the popular models that model how users come to use and accept technology [22]. According to Davis [22], TAM has two primary factors that influence the intention of the user to use new technology. The factors are perceived usefulness and perceived ease of use. In this study, we are measuring the usefulness of μHPC system. TAM suggests that users' beliefs and attitudes influence their rejection or acceptance of information as a tool to evaluate the usefulness of a μHPC system in enabling students to acquire the knowledge and the skills required to manage, maintain, program, and integrate data-center sized HPC systems. In line with that, usefulness as an attribute is the determinant for the usage of an ICT system [23]. The evaluation was performed by investigating whether a relationship exists between the perceived usefulness of a μHPC system during HPC program intervention and the use of the μHPC system in an education context. We also investigated the existence of relationships between other factors that contribute to changes over time due to our intervention. Finally, we wanted to know if educational standing and prior learning of students enrolled in an HPC module affects the perceived usefulness and ease of use of the μHPC system.

3.3 Research Question

All evaluation studies should begin, as the starting point, with identification of the question for the research [18]. In this study, we started with the research question that guided this evaluation [14]. Consistent with Fig. 1, our research question for this study investigates useful of the μHPC system artifact.

3.3.1 Research Sub-Questions. The following are research sub-questions of this study.

SR1: How can a μHPC system be used to help students learn the skills and knowledge required to manage data-centre sized HPC systems?

SR2: How can a μHPC system be used to help students learn the skills and knowledge required to maintain data-centre sized HPC systems?

SR3: How can a μHPC system be used to help students learn the skills and knowledge required to program data-centre sized HPC systems?

SR4: How can a μHPC system be used to help students learn the skills and knowledge required to integrate components of data-centre sized HPC systems?

3.3.2 Initial Hypotheses. The following are the initial hypotheses of this study.

$H1_O$: The perception of students that studied HPC using a μHPC system to learn the skills and knowledge required to manage HPC systems will not change over the period of intervention.

$H1_A$: The perception of students that a μHPC system can be used to learn skills and knowledge required to manage HPC systems will change over the period of intervention.

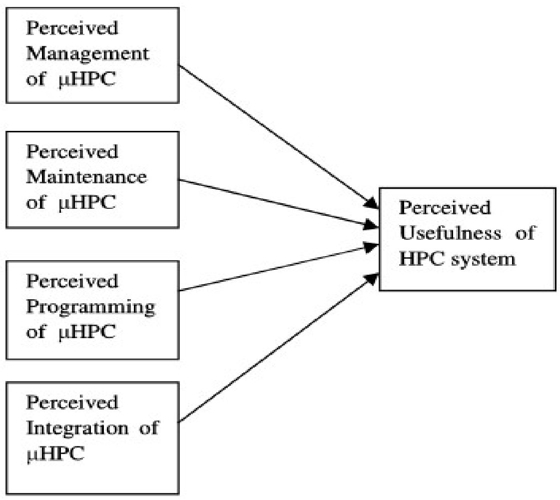

Figure 1. μHPC acceptance model (adapted from [22] and [34])

The other hypotheses map to final research sub-questions:

$H2_O$: The perception of students that a μHPC system can be used to learn skills and knowledge required to maintain HPC systems will not change over the period of intervention.

$H2_A$: The perception of students that a μHPC system can be used to learn skills and knowledge required to maintain HPC systems will change over the period of intervention.

$H3_O$: The perception of students that a μHPC system can be used to learn skills and knowledge required to program HPC systems will not change over the period of intervention.

$H3_A$: The perception of students that a μHPC system can be used to learn skills and knowledge required to program HPC systems will change over the period of intervention.

$H4_O$: The perception of students that a μHPC system can be used to learn skills and knowledge required to integrate components of HPC systems will not change over the period of intervention.

$H4_A$: The perception of students that a μHPC system can be used to learn skills and knowledge required to integrate components of HPC systems will change over the period of intervention.

4 Methodology

In this study, an overview of the research methodology is articulated by describing the method used, study design, questionnaire, place of the survey, response rate, participants, and data collection. Also, data analysis, reliability and validity, and ethics are described.

4.1 Method

In DSR, evidence-based evaluation of artifacts is a very important activity in the design cycle [13]. The rigorous evaluation of the existing and new artifacts is important to ensure that they meet the expressed objectives [16]. There are many methods for validation, evaluation, and communication of artifacts in a design science paradigm [27][45]. These include the technical action research method [13][15][30][31][32][33] which is used in validation where the researcher plays the role of developer, investigator, and helper in the process of validation. The focus of this study is to investigate the effects of a μHPC artifact intervention within a design science paradigm [29]. In DSR, the completeness and effectiveness of the designed artifact are attained when the constraints and requirements of the problem it was meant to solve are satisfied [17]. Researchers have identified several methods for artifact evaluation: experimental, observational, analytical, descriptive, and testing [17]. Other researchers [40] have divided evaluation into demonstration and evaluation activities.

The other categorization of evaluation is artificial and naturalistic evaluation [41]. The method used in this study is ex-post DSR. Experimental ex-post evaluation of the designed artifact allows one to make assumptions about the direction of the design of the artifact [1]. The method used is quasi-experimental using questionnaires as the data collection method [20] and the analysis using statistical methods [12]. IT artifacts can be evaluated in terms of some of the following attributes: completeness, fit to an organization, reliability, accuracy, usability, functionality, and consistency [13]. For this study, we used the operational definition of usefulness as "the subjective probability that prospective users trained with μHPC will find it easy to maintain, use, learn, program, manage and integrate the computing system" [8].

4.2 Research Design

The survey design for this study is quasi-experimental, and there are a lot of useful benefits of using that for evaluation in DSR [13]. In DSR, the researcher creates and evaluates artifacts intended to solve the particular problem of the organization [13]. The instrument used in this study was a self-administered questionnaire to analyze and identify the usefulness of the μHPC system. The questionnaire was based on a different tool that was designed to measure the perception of a personal work station [42], which we adapted for use in this study. We have used [27] as the framework for communicating the results of this study.

4.3 Place of Survey

The survey was conducted in a higher education institution in Tanzania while students were in recess. The choice of the site was due to fact that naturalistic, ex-post evaluation requires a site where the artifact can be deployed. The choice of the institution was based on the availability of an HPC system and the availability of HPC modules in the curriculum. Evaluation of the research outcome in the context of the institution that the artifact was implemented help to articulate the role of the artifact and the relevance of the research [24].

4.4 Participants

Participants who had an engineering studies background at the higher education institution in Tanzania served as the sample for this study of usability evaluation. According to the literature on usability evaluation, a sample of only five participants can be used to identify 50% to 85% of the problem [50][53]. The other literature [52] shows that only 12 participants are enough to obtain the measure of the perceived usability of the system with a usability scale questionnaire. According to the study reported in [51], a sample of 20 users was sufficient to find the usability problems to an accuracy of least 95%. Based on that, our study also sought eighty-eight participants who were at different education levels. The final sample consisted of both male and female students who were randomly selected and assigned to one of two groups based on their education level. The first group consisted of 35 computer engineering students who previously took the HPC module in their normal curriculum using the available HPC system. The group served as the control group in the study. The second group consisted of 53 computer engineering students who had not taken a course on HPC and constituted the experiment group.

At the end of the μHPC course, eighty-three participants (68 males and 15 females) completed and returned the questionnaires for the current study.

Ethical consent for the study was obtained. The data collected for this study were anonymized and remained confidential and secure. The participants were fully debriefed before the experiment as the methodology did not require us to conceal any information from participants. To maintain confidentiality the questionnaires were administered only by researchers in the computer laboratory. Although their lecturers were around, they were instructed not to be in the computer laboratory at the time. Participants folded their question papers in half as they were filing out the laboratory. No one except the researchers was allowed to examine the questionnaires.

All the students who had studied the HPC module had been selected using a purposive sampling method. The other students that had not studied the HPC module had been selected from the pool of students that had studied other pre-requisite modules of the HPC modules.

The experimental group was taught HPC using a μHPC system as an intervention for 9 weeks. The training course was supplemented with practical HPC exercises. The learning outcomes of the training were to enable students to gain skills and knowledge that are needed to manage, maintain, program, and integrate HPC systems. The study was organized in several sessions with each session targeting a specific learning outcome. The training took place in a computer lab room of the computer engineering department of the institution.

4.5 Questionnaire

The usefulness of the μHPC system was measured with a questionnaire developed for use in this study. The questionnaire was adopted and modified from the design behavior questionnaire to suit the variables of interest in our study [22][37]. The pre-study questionnaire consisted of section A, consisting of 19 questions, and section B consisting of 17 questions, with a combined total of 51 variables. In section A, the questions were designed to fit into two categories: the demography and status of the participants. Also, there were five-point Likert scale questions related to HPC in general and curriculum modules in the broader HPC paradigm. The Likert scale questions addressed issues like experience, ownership, usage, access, components, and preference of HPC systems. In section B, there were five-point Likert scale questions related to constructs that measure opinions of respondents on issues relating to: configuration, programming, management, maintenance, integration, usage, solving societal challenges, relationship with other modules in the computer engineering curriculum, and technical platforms for learning.

The post-study questionnaire consisted of section A consisting of 17 questions measured by 5-point Likert scales, and sections B and C each consisting of 10 questions also measured by 5-point Likert scales, with a combined total of 37 variables. The questions in section A related to the same HPC systems issues as the pre-study questionnaire.

The questions in sections B and C were related to constructs that measure opinions of respondents on issues of the usefulness of HPC systems and ease of use of a μHPC system respectively. The items which showed relevance to our study were initially proposed in the study that theoretically derived the items from research on the adoption of innovations, self-efficiency theory, and the cost-benefit paradigm from behavioral decision theory [22]. We used these selected items as the baseline for measurement and customization to evaluate the usefulness of the μHPC system. Section B covers topics such as usage of cluster-based HPC systems, installation of any operating system and applications in an HPC system, the configuration of the network for a cluster-based HPC system, integration of a cluster-based HPC system, learning skills and knowledge to manage an HPC system, deploying the parallel computing programs in an HPC system, deployment and configuration of a cluster-based HPC system, running of parallel applications in an HPC system, and benchmarking the performance of such systems.

4.6 Response Rate of Participants

All participants who were in attendance when questionnaires were distributed participated in the study. Before the intervention, there were 88 participants, made up of 35 in the control group and 53 in the experimental group. The pre-study questionnaires were distributed to the experimental group and the control group was given questionnaires before the intervention. The second (post-study) questionnaires were distributed to 83 participants made up of 35 in the control group and 48 in the experimental group. Five participants did not return the questionnaires during the post-study.

4.7 Data Collection

The data collection method used was mainly a paper-based questionnaire together with some qualitative data. The experiment was conducted as follows. We administered a pre-study questionnaire to gauge the perceptions of all participants in their respective groups, i.e., the experimental group and control group. The questionnaire gauged the understanding and experience of HPC to all participants in the two groups before the study. We used the issues that were raised in the pre-study questionnaire to formulate the hypotheses of this study. The participants in the experimental group used the computer laboratory room during the entire intervention period. Before the intervention, we briefed the participants on the purpose of the research study and how the training would proceed in the scheduled period of 9 weeks. We explained that both positive and negative feedback was welcomed when responding to questionnaires and they were free not to participate in the questionnaire sessions at any given moment without giving reasons.

The participants were also asked not to talk about the study among each other until both sessions had been completed. After that, all participants from the experimental group gathered around one of the µHPC systems at which we gave a brief demonstration of the system, and explained the features of the system (i.e., storage, computing, interfaces, and portability). During the study, we made sure that each participant had access to the system and also performed all activities using the µHPC system. All participants were given instructions that guided the activities which were scheduled to be performed on the µHPC system. The instructions detailed five activities that the participants had to perform with the system during the intervention period. These tasks in those activities were designed to ensure that participants had sufficient experience with the system to be able to evaluate its usefulness. After all participants in the experimental group finished all tasks, we administered a post-survey questionnaire to participants and the control group. The post-survey questionnaire had 3 sections. These sections, which use Likert scales, measured the perceived usefulness and ease of use of the µHPC system after the intervention, but only to the experimental group.

4.8 Reliability and Validity

In our study, we considered the accuracy and appropriateness of our measured variable in terms of reliability and validity. Reliability ensures that the measurement method of the variable(s) gives consistent results. Validity indicates how sound the study is and ensures the extent at which the instrument measures the right elements that it purports to measure. Since a prerequisite of validity is reliability, we consider reliability first [38].

4.8.1 Reliability. Internal reliability and inter-rater reliability are two types of reliability in social science research that are most frequently encountered. In this study, we tested the data collection tool to establish the internal reliability (internal consistency) of the measured variables from captured data of the responses of participants. We used standard statistical software, SPPS, to calculate reliability using statistical coefficient Cronbach's Alpha (α) which ranges from 0 to 1, with a higher value indicating higher internal reliability. The calculation of Cronbach's Alpha achieved 0.781 with the 51 variables in the questionnaire. According to [39], the soundness of Cronbach's Alpha is when $\alpha \geq 0.70$, and since the Cronbach's Alpha is above the threshold. Cronbach's Alpha of 0.781 indicates the high level of internal consistency for our scale in our questionnaire.

4.8.2 Validity. The questionnaire tool was validated in terms of content by submitting the questionnaire to experts in HPC, The HPC experts who volunteered to participate were chosen and recruited from the computer studies department where the HPC module is taught. The rating measures of each construct were based on two criteria: (a) clarity of phrasing of sentences, and (b) the applicability of the content. We considered content validity for pre and post questionnaire tools. Content validity focuses on measuring all components of usefulness variable and only those components alone [54]. To ensure that content validity is pure and comprehensive, we referred to the items in the questionnaire which relate to the usefulness construct. This was done by ensuring that questions are crafted to be representative, not similar to other items in the questionnaire, and cover the depth and breadth of the measured construct. In terms of the measurements, we used five-point Likert Scales (as indicated in subsection 4.5). The collected data consist of score ratings of each participant regarding the perception of the usefulness of the µHPC system as an educational artifact. Usefulness is subjective where each person has their interpretation. Hence ratings were scored as ordinal data. Our findings lack external validity as they are valid in one environment but we were unable to run more experiments in different environments.

4.9 Measures

We are interested to measure one dependent variable and four independent variables.

4.9.1 Dependent Variable. We are interested to measure the perceived usefulness of the µHPC system. Participants were asked "Having access to the µHPC system enabled me to learn skills and knowledge on how to use cluster-based HPC system" as a single item measure for our dependent variable.

4.9.2 Independent Variables. The independent variables for our study are perceived management of the µHPC system, maintenance of the µHPC system, programming of the µHPC system, and integration of the µHPC system, collectively known as predictors.

4.10 Data Analysis

In this study, we analyzed the dataset to establish the usefulness of the µHPC system. The dataset for this study consisted of the survey data from the participants. The quantitative data from the questionnaires were managed and organized using SPSS software. The main analytical method employed in this study was the t-test, and paired sample t-tests were performed to measure responses of the pre and post-survey instruments.

5 Results

The study served four purposes. The four purposes were to examine how a µHPC system can be used by students to learn the skills and knowledge required to (i) manage, (ii) maintain, (iii) program, and (iv) integrate components into data-center sized HPC systems.

The coding scheme used for this study is displayed in Table 2. Based on Table 2, the total number of participants (N=83) returned the questionnaires. The majority of participants (79.5 percent) were in degree courses and 20.5 percent were in non-degree courses (8.5 percent from diploma level, 10.8 percent from General Course and 1.2 percent from other courses). The majority of participants were male. All females who participated were studying at degree level.

Table 2. Participant Demographics

Coding Scheme	Education Level	Frequency	Percent	Male	Female
1	Degree level	66	79.5	51	15
2	Diploma level	7	8.5	7	0
3	General course	9	10.8	9	0
4	Others	1	1.2	1	0
	Total	83	100.0	68	15

To test our hypotheses, we tested whether or not significant differences in the participants' perceptions after learning skills and knowledge required to maintain, manage, program, and integrate HPC systems, can be attributed to the µHPC system. For this purpose and due to the sample size, we decided to choose the t-test as an analysis tool. Paired sample t-tests were performed to measure responses to the pre-survey instrument and post-survey instrument. Subsequently, paired sample t-tests were conducted to determine the usefulness of the µHPC system to learn the skills and knowledge required to utilize HPC systems. By observing the common practice, we tested our hypotheses by setting the significance level to 0.05.

There was no significant observable change of perception of students about the usefulness of the µHPC system to learn the skills and knowledge required to manage and maintain HPC systems over the period of intervention. The difference was not significant, $p > 0.05$ with $p = 0.392$ and $p = 0.747$ respectively.

However, there was a significant observable change of perception of students about the usefulness of the µHPC system to learn the skills and knowledge required to program and integrate components of HPC systems over the period of intervention. The difference was significant, $p < 0.05$ with $p = 0.0004$ and $p = 0.048$ respectively.

The findings of the whole sample are summed up by results of perceptions as measured using t-test analyses on the four hypotheses for the usefulness of the µHPC system to students in Table 3. For details of the initial hypotheses refer to sub-section 3.3.2.

Table 3. Results of Hypothesis Test

No.	Hypothesis	The Paired Sample t-Tests		Supported / Not Supported
		t	p	
1.	$H1_O$	0.865	0.392	Supported
	$H1_A$			Not Supported
2.	$H2_O$	0.325	0.747	Supported
	$H2_A$			Not Supported
3.	$H3_O$	3.855	0.0004	Not Supported
	$H3_A$			Supported
4.	$H4_O$	2.044	0.048	Not Supported
	$H4_A$			Supported

6 Discussion

As mentioned earlier, the cost of installation and maintenance of a data-center sized HPC system that supports computer science curricula in academic institutions of a developing country is high compared to an equivalent µHPC system. Hence there was a need to perform an experiment to investigate the usefulness of a µHPC system which can be used by engineering students to acquire HPC knowledge and skills.

The usefulness of a µHPC system to support the transfer of HPC skills and knowledge required to utilize HPC systems was investigated through the administration of an HPC training course that used a µHPC system and compared the results using t-tests. The findings from the study indicate that the perceptions of students about the maintenance and management of the HPC system did not change over time. Meanwhile, the perception of students on the issues of programming and integration of the HPC system did change over time. The usefulness of the artifact is the determinant for the usage of an ICT system [23]. The evaluation of hypotheses has supported the existence of a relationship between the perceived usefulness of a µHPC system during HPC program intervention and usage of the µHPC system in an education context.

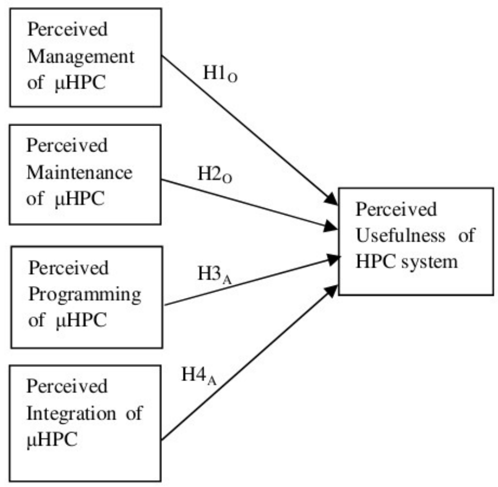

Figure 2. µHPC acceptance model results of students

The possible reasons for the usefulness of a µHPC system were examined by testing hypotheses. Fig.2 shows mixed results. The hypotheses that measured participants' perceived usefulness of the µHPC system, i.e., $H1_O$, $H2_O$, $H3_A$, and $H4_A$, were supported by collected data and tested using t-tests between the constructs of the questionnaires. In general, the support for $H1_O$, $H2_O$, $H3_A$, and $H4_A$ consequently answer the main research question for this study. This supports our µHPC acceptance model that the perceived usefulness in terms of maintenance, integration, programming, and management of a µHPC system can influence the perception of the usefulness of the HPC system.

It was determined that significant change did not occur in terms of skills and knowledge required to manage and maintain HPC systems. The possible reason for this is the fact that participants did study computer networking, computer architecture, and system administration in their curricula prior to HPC training. The same knowledge and skills are used by the µHPC system as an educational tool. The knowledge of computer networking, computer architecture, and system administration is required in the HPC cluster that uses a Beowulf architecture [5][6][7]. Also, the processors used in the µHPC system are similar to processors used in data-center sized HPC systems [47][49].

Interestingly, the perception of usefulness from participants who used the µHPC system to learn HPC skills and knowledge changed after the training intervention. A possible reason for this is that majority of participants did not study parallel programming and did not study the integration of HPC systems prior to the HPC training intervention that used the µHPC system. The participants did not practice the integration of the fully-fledged HPC system in their normal curriculum. This demonstrates the usefulness of a µHPC system in computer science curricula. This caused the changes in the perception of students in regard to the usefulness of the µHPC system artifact. This is consistent with the findings that affordable and portable HPC systems can be used by students to learn the knowledge and skills required to write parallel programs and to integrate components of an HPC system [47][49]. This is the indication of the usefulness of a µHPC system since the same open-source Python parallel programming language is used to write parallel programs [48], and also off-the-shelf general-purpose hardware components are used to integrate data-center sized HPC systems [4][5][6][7].

As reported earlier, the results of this study suggest that a µHPC system is a useful educational artifact and can be used to acquire the knowledge and the skills required to manage, maintain, integrate components and write parallel programs that can be used in data-center sized HPC systems. This is consistent with the finding that having an HPC system is one thing but the most important thing is to build knowledge to manage, maintain, and utilize the HPC system [46].

7 Conclusion

This research investigated the usefulness of a µHPC system artifact as an education tool used for students to acquire the knowledge and skills required to utilize data-center sized HPC systems. It was originally assumed that the perception of students that studied HPC using a µHPC system to learn skills and knowledge required to manage, maintain, program, and integrate HPC systems would not change over the period of intervention. The µHPC artifact was designed as the educational platform that allows students to assemble and disassemble its components; perform maintenance activities; manage the artifacts, and write parallel programming code. The usefulness of a µHPC system was investigated by designing an experiment that contained both experimental and control groups of students. The HPC course as an intervention was applied to the experimental group for a period of 9 weeks and was administered using a µHPC system. The control group was made up of participants who prior to the experiment had studied HPC in their curriculum. By comparing the results of the two groups using ex-post DSR, a quantitative evaluation was performed. These findings lend support to the assumption that a µHPC system is useful to engineering students in enabling them to develop the skills and knowledge required to manage, maintain, program, and integrate data-center sized HPC systems.

Despite the contribution of this study in expanding knowledge of HPC education, the findings of the study should also be considered in light of its limitations. The first limitation was the one that involves the conditions under which a µHPC system operates, which is different from the special environment to which data-center sized HPC systems operate. The second limitation was the confinement of the sample size to one institution. This study focused on a moderate size group of computer and telecommunication engineering students. For generalization, other researchers could recruit larger populations of participants across a greater number of academic institutions that offer HPC courses. The small sample size is an opportunity for further research that includes a larger sample size. Besides, the assessment of the usefulness of the µHPC system used survey measurement as the method of data collection. Future research should include multiple data collection methods, i.e. interviews, as well as multiple informants from different institutions. Lastly, the time of the intervention of the µHPC system was during the recess of the institute. This time might have excluded some students who had the experience of HPC before the intervention. The study did not include students who had graduated from the institute who had the experience of HPC, as it was impossible to reach them.

However, the results indicate considerable potential even though the data were collected in one institution over three months of intervention. Nevertheless, the results indicated that the μHPC system has considerable useful potential in education. The current study did not evaluate other attributes of usability of μHPC systems which may be of interest in an education context, and this would form the focus of a future study.

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