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Towards a Perspective of the Role of Mathematics in Computer Science and Engineering (CSE) Education

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***Abstract*— In the field of Computer Science and Engineering (CSE), many students have very high aspirations but lack mathematical skills. These students do not realize the significance and importance of mathematics in CSE education. Through a review of relevant literature, this paper discusses several relevant areas of CSE and explains why CSE students require mathematics in order to master and have control of the materials/modules taught in these courses. The explanations elaborated in this paper will eventually enable a CSE student to gain success in computing both academically and professionally.**

***Index Terms*— Computer Science, Engineering, Education, Mathematics and Students**

I. Introduction

MATHEMATICS is very fundamental to the study of Computer Science and Engineering (CSE). Throughout the history of CSE education, there has been debate on what should be the suitable mathematical background for CSE programmes/majors [1]. During the last decade this topic became more real, since with the development of computer science and computer engineering, there has been a lot of pressure to make the CSE curriculum less mathematical [2].

Years of teaching experience in University and Polytechnic Education in Ghana has shown that many CSE students who desire to become system analysts, computer programmers, database administrators, computer scientists, computer hardware architects, software engineer etc. do not have the background knowledge needed to succeed in their studies. Unfortunately, such students do not remain in the field of CSE for a long time. This is because a weak mathematical background is simply not helpful in learning how to code mathematical expressions in a programming language, or for example, in converting from octal to binary or hexadecimal number systems. Mathematics is intrinsically tied to the study of CSE from the most elementary courses to the most advanced courses [1]- [3]. As a consequence, students who are strong in mathematics will typically fare well in CSE, both professionally and academically.

The basic argument of the relationship between mathematics and CSE include the following: (a) mathematics is used to model the problem domain, to specify and design high quality software, (ii) mathematics is also used to develop correct and efficient algorithms, and (c) mathematics is a mindset that fundamentally improves one's ability to devise and implement algorithms. Globally, the main benefit CSE professionals gain from mathematics they learn at a university or polytechnic is the experience of laborious reasoning with purely abstract objects and structures [2], [4].

The goal of this paper is not to repeat the importance of the mathematical knowledge for a CSE programme/major in a long run, but to emphasize its necessity while at school, when the student is taking certain required courses, namely, theoretical and practical courses in CSE education.

The rest of the paper is organized as follows. Section II presents our motivation for the study, Section III presents some major CSE courses that require a strong mathematical background and Section IV presents a Research Discussion. The paper is finally concluded with a recommendation in Section V.

II. Motivation for the Study

Our motivation for this study is driven from the fact that, through teaching experience in our various departments, we have witnessed that CSE students do not know the importance and necessity of mathematics in CSE education. We are amazed and appalled about mathematical comments and questions we get from students. Furthermore, students who are admitted into Ghanaian polytechnics to pursue CSE programmes, do not actually know the difference between

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CSE and other related courses such as Information Technology (IT) and Information and Communication Technology (ICT) which are less mathematical. We have also observed that the weak background of some CSE students makes them perform poorly in very important CSE courses such as Discrete Mathematics, Numerical Methods and Computations, Computer Programming, Computer Organization and Architecture, Computer Science Theory, Introduction to Computer Technology, Software Engineering, Circuit Theory, Electronics and System Analysis.

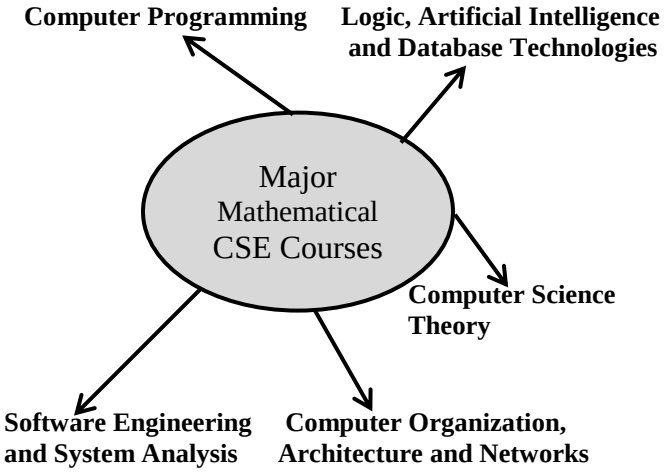

Fig. 1: Some Important Mathematical Courses in CSE Education

III. Some Major CSE Course That Require Students to Have a Strong Mathematical Background

In this section, the paper presents some very important courses in CSE (shown in Fig. 1) that require a strong mathematical background for students to be successful in computing both academically and professionally.

A. Computer Programming

A solid mathematical background is important and fundamental in beginner, intermediate and advanced levels of computer programming courses such as Objected Oriented Programming with Java and VB.Net. In the early stages of computer programming courses, students usually learn how to write solutions using certain data types, operations and functions. CSE students must understand mathematical expressions and the precedence of operators in order for them to correctly code, text and debug programs that involve calculations. CSE students also need basic arithmetic in order to design printed outputs. Such basic arithmetic is needed so that CSE students will be able to produce reports that are orderly, and in line with specified precision [1], [3], [4].

In mathematics, functions are widely encountered. Moreover, functions are integral parts of computer programming in CSE education. CSE students who can grasp the concept of a code performing a well-defined action and/or returning some piece of information have a better chance of understanding the entire process involved in computer programming i.e., whether it is object-oriented, entirely functional or procedural.

The aspect of variables in both programming and mathematics are closely related. Consequently, CSE students must understand algebra very well to be good computer programmers. CSE students must understand the difference between constants and variables, and the different situations in which they are used. Understanding different data types is also very important for CSE students so that they can effectively use data when programming. The process of determining good test data in computer programming is another area which requires strong mathematical skills. Computer programmers are required to understand all the subtleties of numbers and their operations, so that they can develop relevant data for testing a program code [1].

The study of parallelism introduction in programming languages also involves mathematics. For example Backus-Naur Form (BNF) can be used to formally express languages mathematically. Furthermore, language definitions are precise and abstractions are necessary for describing the syntax and semantics of a language. CSE students who are proficient in formal mathematics will be familiar with formal notations and proofs. Such students usually understand the definitions, syntax and formal semantics of programming languages better. Additionally, such students can also practice the use of abstraction, which is a very important skill for solving computing problems by expressing those problems in terms of a particular programming language [1], [3], [4].

B. Logic, Artificial Intelligence and Database Technologies

Logic, Artificial Intelligence (AI), data mining techniques, meta-heuristic optimization search such as ant colony optimization, particle swarm optimization and others are CSE areas that involve mathematics at a very high level. According to Luger and Stubblefield [5], there is an assumption that students going through Logic and AI courses in CSE should have a background of introductory mathematical courses such as discrete mathematics, calculus and graph theory. Such mathematical skills are necessary since abstract concepts such as planning, learning, knowledge and reasoning must be described formally so that they can be represented concretely in a form that can be used in computer programming [1].

In relation to database technologies, relational databases and the mathematical concept of set theories are very closely related. A good understanding of the mathematical concept of set theories is necessary for understanding the subtleties of relational database tables and operations. Set theory operations such as intersection, union and cross product can be applied in database relations [6]. Object oriented databases do not rely so heavily on set theory but are still mathematical because they require a good understanding of concepts such as functions, abstractions, hierarchies and partial orderings [6].

C. Computer Organization, Architecture and Networks

The most appropriate way for CSE students to get a better understanding of low-level hardware, circuits, electronics and systems is to have a required amount of knowledge in calculus. Furthermore, computer system engineers and architects must be well knowledgeable in binary number systems and be able to convert from binary to octal, hexadecimal and decimal number systems. CSE students must therefore be able to understand and use Boolean algebra which is a logic based on the binary number system [1], [2], [7]. This will enable and propel them to understand the computer organization and architecture course very well.

Currently, computer networks are proliferating and becoming more widely used. There are several problems associated with computer networks. Some of these problems include: load analysis, data formats, routing, efficiency, recovery and security. A good background of graph theory which is mathematically related, is critical in routing of networks. Consequently, CSE students need a strong mathematical background in order for them to understand concepts of data encryption and data compression in computer networks which both involve mathematical functions and transformations [1], [2], [8], [16].

D. Software Engineering and System Analysis

Software testing, software metrics, code complexity and proofs involving the correctness of programs are some of the topics typically covered in software engineering courses. These academic topics provide CSE students with insight into the problems inherent in software development and design. Topics involving metrics, complexity and proofs have been evidenced to be heavily inclined and involved with mathematics. For example, in software metrics and evaluations, a lot of mathematics is used to determine and evaluate the performance of different softwares [9]-[11].

Furthermore, a professional software engineer must perform concrete feasibility studies and work with budgets. Software engineers are therefore required to complete their projects on time, within budget and with less cost constraints. Consequently, a fundamental knowledge of accounting, business management, project management, statistics and prediction, often with the aid of software and graphing packages is very necessary. Each of the above mentioned areas involve mathematical skills and concepts such as variables, dependency issues and time [9]-[11].

In the process of planning and analyzing projects, system analysts and software engineers make use of many tools [12]. Some of these tools include data flow diagrams and Program Evaluation and Review Technique (PERT) charts. It is therefore desirable to have a good knowledge of graph theory in order to understand how to visualize, determine and design graphs using these tools [9]-[11].

E. Computer Science Theory and Mathematical Courses

When studying computer science theory, CSE students study formal mathematics as it relates to CSE. In fact, most of these courses are pure mathematical courses that are sometimes taught by other lecturers in the mathematics department of an institution. As shown in Fig. 2, such courses include: calculus, linear algebra, discrete mathematics, engineering mathematics and mathematics for computer scientists. In these courses, students learn about concepts related to logic, sets, operations, proofs, theorems, reductions, recursive definitions and graph theory [13]-[15]. Computer science theory also involves topics such as finite automata, stacks and NP-completeness.

The topics covered in computer science theory are all mathematical in nature. Consequently, CSE students who have a weak mathematics background find such learning materials difficult to understand and investigate. In relation to pure mathematical courses such as the ones mentioned above, they are mandatory and standard for most CSE programmes. It is therefore important for students to have the necessary and appropriate background for these courses before embarking on a CSE programme.

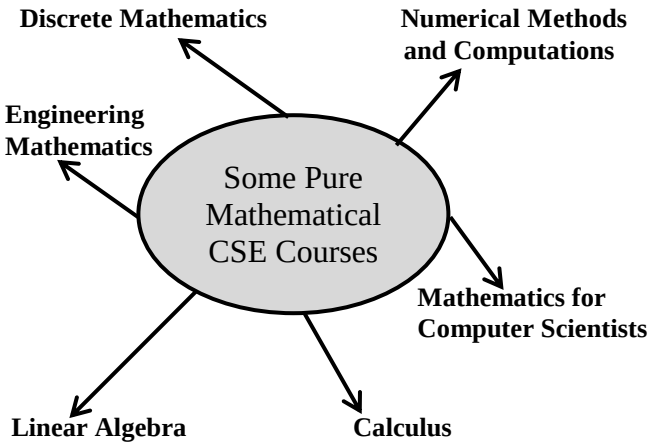

Fig. 2: Some Pure Mathematical Courses in CSE Education

IV. Research Discussion

From the above sections of the paper, it can be realized that a strong mathematical background is very important and necessary in CSE education. In order for Polytechnics and Universities in Ghana to achieve their mission and vision towards education, specifically CSE education, successful assurance of the mathematical background of applicants who apply for CSE programmes of study is very important/vital and has a role to play.

It is also very important for Polytechnics and Universities in Ghana to analyze the actual differences between CSE and other computing related programmes, so that students who are admitted into CSE programmes will understand and realize the importance and requirements of mathematics in CSE in comparison to less mathematical computing programmes such as IT, ICT and Management Information Systems (MIS). Computer Science Theory and Mathematical Course require a stronger mathematical background since they are purely mathematical within a CSE curriculum. Globally, CSE education is on the rise as a result of the importance of

computing/ICT in an economy. In Ghana for example, CSE education is offered in most of the public universities and polytechnics. An illustration of some of these institutions is depicted in Table I. As shown in Table I, University of Ghana and KNUST dominate CSE education at all educational levels in Ghana.

A person well-trained in CSE knows how to deal with algorithms. He/she knows how to construct algorithms, manipulate them, understand them and analyze them. This knowledge prepares him for more than just writing good and effective computer programs. The study of algorithms in CSE is a general-purpose activity which will be a definite aid for even understanding other subjects such as chemistry, physics and electronics.

Certainly, there are phenomena about computers which are now being actively studied by Computer Scientists and Engineers, which are hardly mathematical. But if we restrict our attention to the study of algorithms, it can be realized that algorithms are really mathematical. Algorithms were initially studied by mathematicians before the advent of computer science and engineering. Therefore it is right to argue that the central aspect of computer science and engineering is really part of mathematics [1], [2].

The "success" of any CSE student will depend on how strong he/she is oriented mathematically. There is no doubt about the importance of mathematics in CSE education. Once the right students are admitted into a CSE programme, it makes lecturing such students easier and the rate at which student trail (fail) CSE courses will drastically reduce.

TABLE I: CSE PROGRAMMES OFFERED BY PUBLIC TERTIARY INSTITUTIONS IN GHANA

S/N	Tertiary Institution	CSE Programme Offered
1	Accra Polytechnic	HND Computer Science
2	Kumasi Polytechnic	HND Computer Science
3	Sunyani Polytechnic	HND Computer Science
4	Koforidua Polytechnic	HND Computer Science
5	Ho Polytechnic	HND Computer Science
6	University of Ghana (UG)	BSc Computer Science, BSc Computer Engineering, MSc/MPhil/PhD Computer Science, MSc/MPhil/PhD Computer Engineering
7	Kwame Nkrumah University of Science and Technology (KNUST)	BSc Computer Science, BSc Computer Engineering, MSc/MPhil/PhD Computer Science, MSc/MPhil/PhD Computer Engineering
8	University of Cape Coast (UCC)	BSc Computer Science, BEd Computer Science
9	University of Education (UEW)	BEd Computer Science
10	Ghana Institutte of Management and Public Administration (GIMPA)	BSc Computer Science
11	University of Mines and Technology (UMAT)	BSc Computer Science and Engineering
12	University of Energy and Natural Resources (UENR)	BSc Computer Science, BSc Computer Engineering

V. CONCLUSION

Innovative scientific applications deal with analysis, measurements and experiments. Additionally, most areas of science and engineering deal with data (image, graphical alphabetic and numeric), mathematical models, simulations, constants and formulations which are relevant for understanding the application domain. Business applications manipulate and store large amounts of data. Consequently, mathematical calculations and computations in these applications typically involve aspects of the company that deals with different types of variables.

At a low level, everything about a computer is related to numbers, arithmetic and logic. Computers usually perform operations such as addition and comparison of two values. It should therefore not be a wonder that, CSE which is the study of how to use machines based on numbers to solve real word problems requires a good understanding of mathematics.

Using relevant literature, this paper outlined the necessity and importance of a strong mathematical background in CSE education. The paper also stressed on the necessity of mathematics to CSE students while in school studying. The explanations presented in this paper will eventually enable CSE students gain success as computing professionals.

This paper therefore recommends that Polytechnics and Universities in both Ghana and abroad should embark on training programmes that will stress on and justify the required background of mathematics in CSE in order to select the right candidates/applicants to pursue CSE programmes. Such training programmes should involve parents, management of institutions, CSE teaching staff/lecturers, prospective CSE students and continuous CSE students.

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