ORIGINAL RESEARCH ARTICLE

On the development of UJ-MaGT scientific calculator

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Abstract
Graphing is an important skill/knowledge required by almost every scientist, engineer and other professionals that require analysis of data to make sense of phenomena, relationships, etc. This important knowledge is learned right from secondary school through to advanced level of education and it is developed through the study of functions in mathematics and laboratory exercises in sciences, etc. At the secondary school level, learning to graph by hand is the most preferred and common practice in most countries in the African continent and other parts of the world. However, studies have shown that graphing by hand present numerous difficulties to science students due to its high "procedural load". To reduce the procedural load, an algorithm called UJ-MaGT was developed and tested for effectiveness. Excellent result in time management, simplification and pedagogical change in graph plotting process was achieved with the help of UJ-MaGT. Currently, the algorithm has been incorporated into a scientific calculator.

Key Words: *Graphing, Graphing Difficulties, Graphing Calculator, Science Education, and Graphing Pedagogy*

Introduction

The Problem

Graphing is a very important tool used in the analysis and interpretation of data by researchers and analysts in general; and scientists in particular (American Association of Physics Teachers, 2014; Woolnough, 2000). It helps in visualizing theories, algebraic functions, and phenomena. One cannot learn the complete syllabus of physics or mathematics in secondary school without learning graphing. It is made an integral part of laboratory activities in the curriculum of physics and mathematics courses/subjects in most, if not all, the countries of the world. Most curricula around the world introduce graphing to students right from JSS3 (Grade 9). Students start by learning how to construct graphs and subsequently how to interpret and make sense of graphs. Graph construction using hands is usually emphasized for beginners.

The procedures of construction of graph by hand include drawing and labelling of axes correctly, choosing of suitable scales and scaling the axes correctly, plotting data points, drawing line of best fit, determination of slopes and intercept of the line of best fit, etc. Significant number of research have documented that some of these graph construction procedures present significant challenges to many students. Some of these challenges faced by students include the setting up of scales, plotting points at the correct locations, reading the coordinates of a point from the graph correctly, drawing best-fit line, interpreting of graphs etc. (Ryan, *et al*, 2016; Kola, 2013; Adolphus and Aderonmu, 2013; Roth &McGinn, 1996; and Wavering, 1989; Brasell & Rowe, 1993; Van Zee & McDermott, 1987; Bowen &Roth, 2005; Forster, 2004; Leinhardt, Zaslavsky & Stein, 1990; and Brasell, 1987). Ryan, *et al*. (2016) attribute some of these difficulties to high procedural load associated with graph construction by hand, of which scale setting constituted the highest difficulty. These challenges contribute to poor performances in examinations and loss of interest in learning of concepts involving graph construction (waeconline.org.ng, 2017; Jackson, Edwards, & Berger, 1993; Hattikudur, *et al*., 2012; Kali, 2005)

The solution

Technological solution available includes graphing calculators such as TI-84, TI-Nspire CX, Casio etc. These do not support graph construction by hand and many educators still have reservations on some of the technological advancements in these calculators. They are mostly programable and therefore can be useful tools for examination malpractice; and are very expensive beyond the affordances of students from many developing countries. Study by Brown, *et al*., (2007) revealed that some teachers view the use of graphing calculator as a means of getting to the answer without understanding the mathematical process. A question posted on stackexchange.com (2016) – '…why don't we discard the traditional pencil and paper method of graph plotting in high schools and for freshers at colleges since there are many electronic devices doing the graphing…?' - saw over 90 percent of the respondents write in favour of manual construction of graphs, arguing that it leads to better understanding of what graph is as opposed to the use of electronic devices. Others, however, opined that graph construction using paper and pencil supports active learning which enhances learner's understanding of concepts being studied (Davidwees.com, 2012; McDermott, *et al*., 2014; and Freeman, *et al*., 2004).

UJ-MaGT algorithm is developed with the sole aim of procedural load reduction and support of graph construction by hand thereby sustaining conceptual understanding, retention, and higher order achievements that can be realized from active learning (Ryan, *et al.*, 2016; Berg & Phillips, 1994; McDermott, *et al*., 2014; and Freeman, *et al*., 2004). It assists students in choosing a suitable scale for any given set of data and paper size. A suitable scale by West African Examination Council (WAEC) is a scale that does not comprise odd numbers other than 1 & 5 or multiples and submultiples of odd numbers other than 1 & 5 and can make the data points cover at least one-third (1/3) and, in some instances, one-half (1/2) of the space provided for graph construction (see supplementary material). To use the app, a student needs to understand some few things about one's data and paper. The students must be able to identify the largest and smallest values of his set of data, know the number of centimeters on his paper, know the number of decimal places of his data, understand the trend between his variable. It also helps in converting data sets into its millimeter equivalence thereby making the construction process much easier and within the

WAEC accuracy limit which is plus or minus half of the millimeter box. This is easier because instead of locating a coordinate by tracing its value on the axis, the student just counts the number of millimeters equivalent to the desired number. Similarly, the student can use the algorithm to convert number of millimeter boxes into the corresponding value. This helps students to read the coordinates of right-angle triangle accurately when determining slope and reading intercepts. (See youtube video; https://youtu.be/7s7b2xNoaCM)

Purpose of the Paper

The aim of this paper is to present the various stages of the development of UJ-MaGT scientific calculator for the purpose of provoking interest and guiding future innovators of educational technologies.

Developmental Stages

Formulation

Mathematical equations (1) (2) and (3) (Mafuyai, *et al*., 2013a; Mafuyai, *et al*., 2013b) were formulated. These were formulated on the bases of number theory and guided by the rubrics of both West African Examination and National Examination Councils' (WAEC & NECO) physics practical marking scheme. This was necessary because both WAEC and NECO standards are the minimum most general standards of graphing accuracy required of the students of the member countries of WAEC.

$$K = 2^{m-x} \times 5^{\varepsilon - x} \qquad (1)$$

$$\lambda \approx \frac{NK}{Z-\mu} \qquad (2)$$

$$\text{where } \varepsilon \text{ is determine from } {}^{2Z10^x}/_{N} \gg /5 = P_\varepsilon \quad \text{for which } P_\varepsilon < 5$$

$$\mu = Kv \qquad (3)$$

$$\text{where } v \text{ is determine from } L = Kv + Kw$$

Validation: the work was presented to experts at the 35th Annual National Conference of the Nigerian Institute of Physics for criticism and thereafter, published in the journal of Nigerian Association of Mathematical Physics as cited above. A book chapter was written; detailing how the formulas can be used in graph construction and published in the textbook used for year one physics practical courses in the University of Jos (Ike, *et al*., 2015).

Algorithm and Executable File for Desktop computers

The algorithm/flowchart[1] based on equations (1), (2), (3) and other auxiliary equations was developed. This was converted into a computer programme and executable file using C# programming language by one of the co-authors in this paper. (Figure 1).

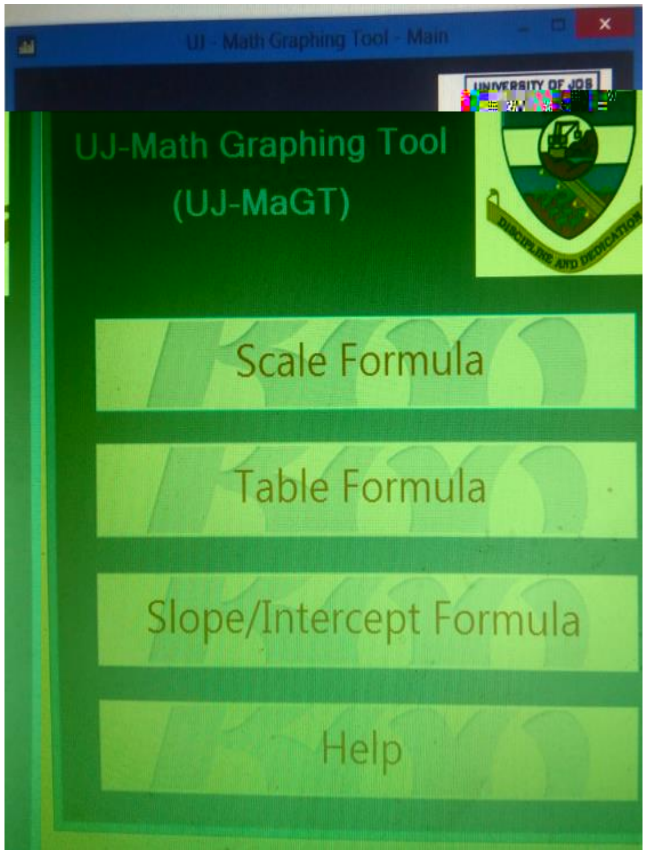
Validation: to validate the programme, approval was sort and granted by the vice chancellor of the University of Jos to install the programme on the University's library computers for students who needed to make use of it in the process of reporting their laboratory experiment. Feedback from the library management[2] revealed that there was a massive increase in the use of library computers

[1] See flowchart at the University of Jos repository

[2] See appendix for the report from the library.

by students during the academic session. Opinions and suggestions from the students[3] at the end of the session were sort through questionnaires on areas requiring improvement. The algorithm functionality was improved as a result of some of the suggestions made by the students.

Figure1. Interface of the UJ-Math Graphing Tool (UJ-MaGT)



Mobile App

The algorithm was developed into a mobile app (Figure 2) to make it more portable and increase both affordability and availability. Three platforms were made; Android, iOS, and Blackberry (see Android version: https://play.google.com/store/apps/details?id=com.bitrient.magt). The mobile app enabled the validation and assessment of pedagogical impact of the algorithm on graph construction.

[3] See the compiled comments of the students in the University of Jos repository

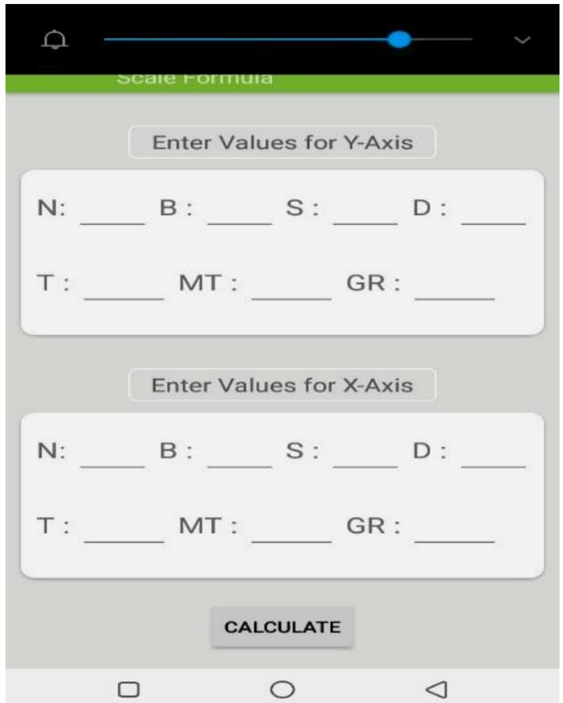


Figure 2: The Interface of the Scale Formula

Validation: to validate, a comparative study sponsored by Tertiary Education Trust Fund (TETFund) institutional-based research (IBR) grant was carried out. The study assessed the impact of the algorithm in improving performance as well as attitudinal and motivational impact (Mafuyai, *et al*., 2018). To assess performance improvement, the work compared two procedures of load reduction methods of teaching in graph construction by hand; the use of UJ-MaGT software and the use of specific guidance (Ryan, *et al*., 2016). First-year undergraduate students who registered for physics practical course consented and enrolled for the study. The group that was taught some specific instructions on graph construction is called "Specifics Instruction Group" (SIG) and the group that was taught how to use UJ-MaGT app (computer software) in graph construction is called "Computer Software Group" (CSG). A pre-treatments test was administered at the beginning of the semester while a post-treatment test at the end of the semester. The scripts were graded in accordance with the West African Examination Council's Physics practical marking rubrics. The result shows that the students' level of competence at the beginning of the semester was fairly similar as revealed by the mean values of their pre-test scores of 4.18 and 4.24 with average completion times of 14.23 minutes and 14.22 minutes for SIG and SCG respectively. The mean values of the SIG's post-test score and time of completion were 4.83 and 13.51 minutes which were not statistically significant ($P>0.01$) compared to the mean values of pre-test scores of both groups. The mean values of the CSG's post-test scores and time of completion were 11.39 and 8.52 minutes which were statistically significant ($P<0.01$) compared to the mean values of pre-test of both groups and post-test of the SIG. Large effect sizes (Coe, 2002) of up to 3 and 1.5 were achieved using UJ-MaGT as against 0.22 and 0.14 achieved by use of specific instruction in graph construction.

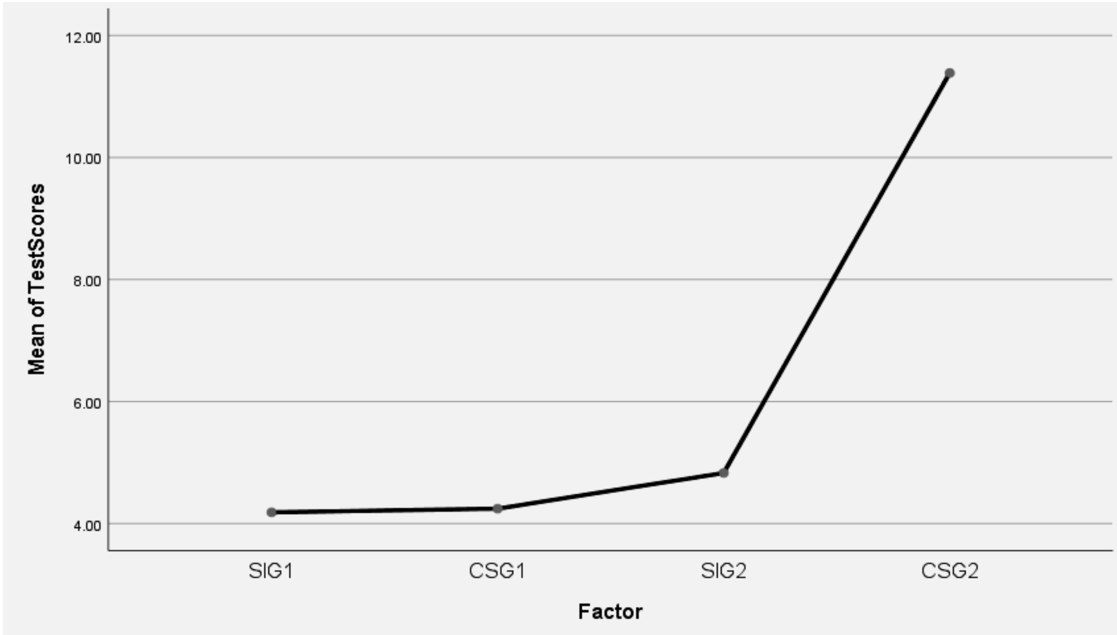


Figure 3[4]: Comparison of Mean Scores for each Group's Test Scores.

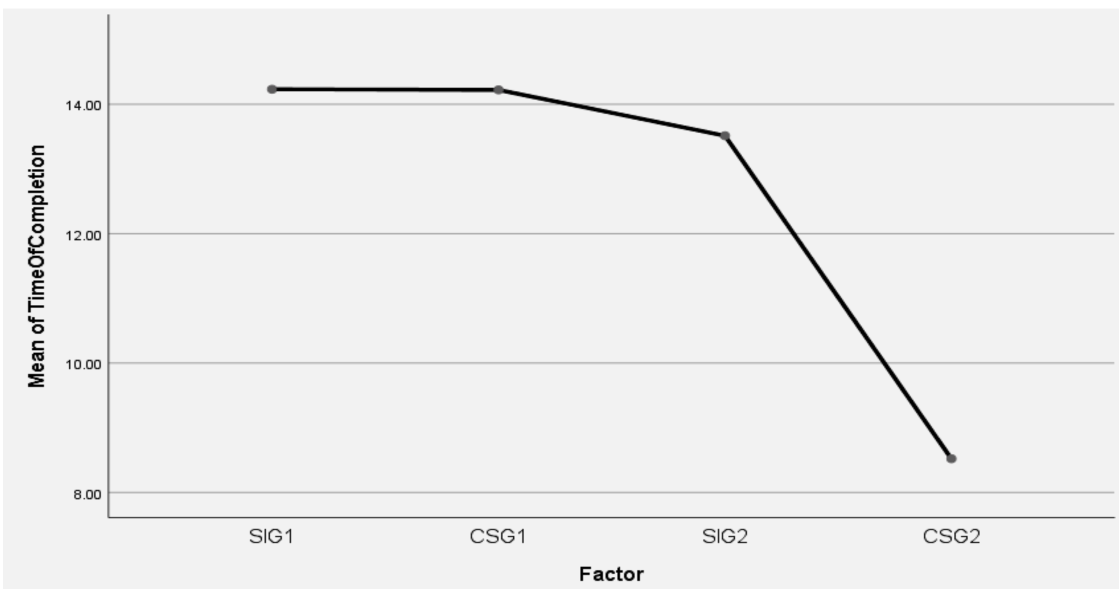


Figure 4[5]: Means Plot for the Time Taken to Complete Graph Construction

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[4]The abilities of both groups in construction of graph at the beginning of the semester were fairly similar (SIG1 and CSG1). However, at the end of the semester, both groups improved in their abilities which lead to increase in mean scores. But the group that used UJ-MaGT (CSG) had the highest mean score (CSG2)

[5] The groups' time taken to construction a graph at the beginning of the semester were fairly similar (SIG1 and CSG1). However, at the end of the semester, both groups improved in their time management which led to decrease in time taken to construct a graph. But the group that used UJ-MaGT (CSG) had the lowest time (CSG2)

Furthermore, students' attitude and willingness to graphing was found using a questionnaire at the end of the semester following the use of UJ-MaGT. Result shows (Figure 5) improved attitude and willingness to engage in topics involving graph construction. In expressing their willingness to enroll for a graph plotting course, 88% said they will enroll if app is available while 12% said they will not enroll if app is available. And 29% said they will enroll if app is not available while 71% said they will not enroll if app is not available.

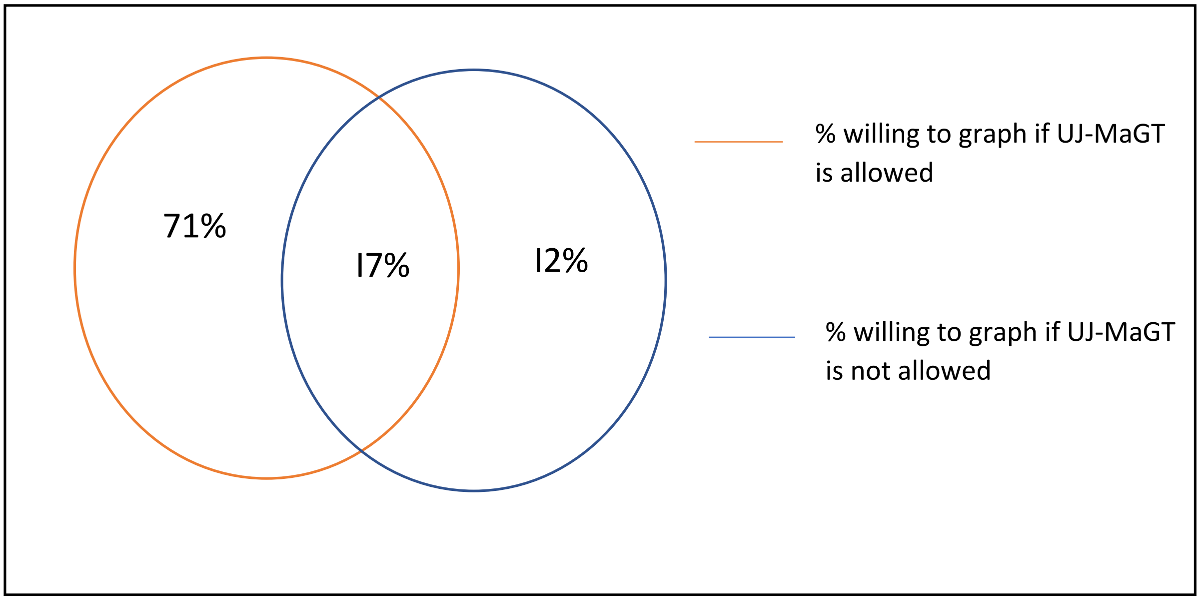

Figure 5: Venn diagram of Participants' Willingness and Attitude to Graphing Using UJ-MaGT

The motivational impact was assessed using modified educational motivation scale. Extrinsic motivation external regulation, extrinsic motivation identified regulation and intrinsic motivation toward accomplishment were the highest aroused type of motivation among the students (Mafuyai, *et al*., 2018).

Protection of Intellectual Property; the algorithm has been protected by the Nigerian copy right law through registration with the NCC[6].

UJ-MaGT Scientific Calculator

The algorithm has been incorporated into a scientific calculator to make it fit for use in secondary schools. The mobile app version of the calculator has been developed (Figure 6) and hardware is under construction through the support of Federal Ministry of Science and Technology.

[6] See appendix for the copy right certificate

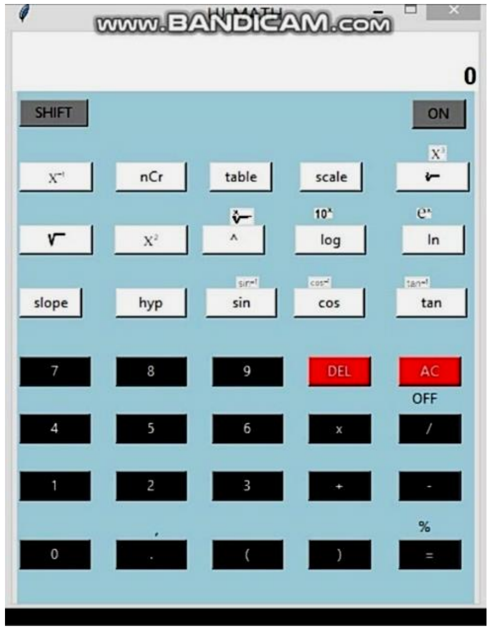

Figure 6: Interface of the Mobile App Version of the UJ-MaGT Scientific Calculator.

Validation: to validate the scientific calculator, a TETFund IBR grant has been secured to undertake a validation study among secondary school students.

Protection of Intellectual property; National office for Technology Acquisition and Promotion (NOTAP) has been consulted and processes are on for filing for patent.

Discussion

Roth and McGinn (1996) opined that teachers should not be mere implementors of classroom technologies but be involved in the development of the technology. This is necessary because the technology could be designed to optimize pedagogical gains and minimize chances for misused. For example, graphing calculators are programable and therefore, a potential tool for malpractice. UJ-MaGT Scientific Calculator on the other hand was designed with no such possibility. Furthermore, in the context of Nigerian and African quest to develop a science and technology-based economy, development of UJ-MaGT Scientific Calculator offers hope to young African Scientists/and entrepreneurs. This can serve as a source of inspiration and motivation for them to innovate and create solutions to problems using Science, Technology, Engineering, and Mathematics (STEM) knowledge they have acquired.

Conclusion

This work has presented and made clear the processes leading to the development of UJ-MaGT Scientific Calculator which could be adopted easily by any other innovators of educational technology. The most important steps include identification of a problem, available solutions and their limitations, creating a new solution, validation of the new solution, and protection of intellectual proper.

Acknowledgement
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Appendix

Nigerian Copyright Commission

ncc

Copyright Registration

Registration No. AW0097

The Nigerian Copyright Commission has been notified of a work with the following particulars:

Author of Work: MAFUYAI MABUR YAKS

Title of Work: UJ-MATH GRAPHING TOOL

Type of Work: ARTISTIC WORK

Year of Creation: 2016

Owner of Copyright: MAFUYAI MABUR YAKS

Issued 18 Day of July 2017

MICHAEL AKPAN

For: Director General

NIGERIAN COPYRIGHT COMMISSION

UNIVERSITY OF JOS
THE UNIVERSITY LIBRARY

Vice-Chancellor
Professor Hayward B. Mafuyai
University Librarian
Stephen A. Akintunde
{Dip Lib; B.Sc (Hons), PGC (IM), M.Sc, PhD}

P.M.B. 2084,Jos,Nigeria
073-453734
Fax: 073-611928
E-mail:librarian@unijos.edu.ng

August 27, 2015

REF: /UJL/33G

To: Mafuyai Mabur Yaks

RE: PERMISSIONTO INSTALL MAFUYAI GRAPHIC TOOL (MaGT) IN THE LIBRARY COMUTERS OF THE UNIVERSITY WITHIN MAIN CAMPUS.

With reference to your memo on the above subject dated **20th May, 2015**. I hereby submit my report on the use of the software in the library as requested by the course lecturer.

The MaGT graph was installed on a total of 61 computer systems in the Bauchi Road Campus Library. Take-off was initially slow with low patronage as most of the students did not know what to do and how to use the software.
Eventually, the use of the MaGT software stabilized, and the Systems Unit of the library had to install the software on more computer systems due to popular demand.

Users of the graph come in groups as assigned by the course lecturer. Their graphs are pl[illegible]