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GeoGebra Geometry Software Evaluation Case Study Using the MUSA Mathematical Model

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Abstract

In this work and in the context of the preparation of the Doctoral Dissertation on the subject "Study of Mathematical Modeling for Creation and Mining of Knowledge with the aim of producing new Evaluation Models - Certification of Resource Management Criteria with the help of IT, conducting a Comparative Study and Application for the Cases: a) In Education Organizations and b) In Self-Government Organizations" will be presented part of the research conducted with a questionnaire sent to 50 respondents, who rated the criteria of the GeoGebra educational Geometry Software. results were entered into the advanced MUSA

Mathematical Model, where the criteria-variables were evaluated by drawing conclusions and improvement actions.

Keywords: Evaluation Model, MUSA, GeoGebra.

Introduction

During the lockdowns due to the COVID19 pandemic, distance education in Greece became an imperative option for Teachers and Students. Quick responses and effective planning became essential as no one was prepared for a social and educational crisis of this scale. New roles and experiences emerged for all involved bodies in the educational firmament (Anastasiadis, 2020). Students are taught beyond the boundaries of the traditional curriculum or traditional classroom through alternative educational activities and practices with reference groups such as other classmates and teachers (Shelly et al., 2012).

For the distance learning process, among others, the geometry educational software GeoGebra was used . GeoGebra is dynamic math software for all levels of education that combines geometry, algebra, spreadsheets, graphing, statistics and calculus in one engine. In addition, GeoGebra offers an online platform with over 1 million free classroom resources created by its multilingual community. These resources can be easily shared through the GeoGebra Classroom collaboration platform, where student progress can be tracked in real-time. The term dynamic geometry is due to Jackiw and Rasmussen, it was originally coined to characterize the key feature that distinguishes software such as Geogebra, Geometer Sketchpad and Cabri Geometry II, etc., which is the continuous and real-time transformation of geometric objects often called "dragging". During the transformations the software preserves all the relationships that were defined as essential constraints of the original construct and all the relationships that are mathematical consequences of them (Finzer & Jackiw , 1998). Mathematics educators claim that the dynamic geometric software that has been developed is the most important development in geometry since the time of Euclid (Leung , 2008; Pitta & Christou , 2009).

GeoGebra is a community of millions of users located in almost every country. It has become the leading provider of dynamic mathematics software, supporting science, technology, engineering and mathematics (STEM) education and innovations in teaching and learning worldwide. GeoGebra's math engine powers hundreds of educational websites around the world in different ways, from simple demonstrations to full online assessment systems. As open software, it can be used at all levels of education, from elementary to university, offering possibilities to modify the environment depending on the level and content of the teaching. It is translated into Greek and is provided free of charge. It can be used in the following branches of Mathematics: Geometry, Algebra, Analysis, Statistics, Probability, Discrete Mathematics, Linear Algebra, Number Theory, Complex Analysis and Analytic Geometry.

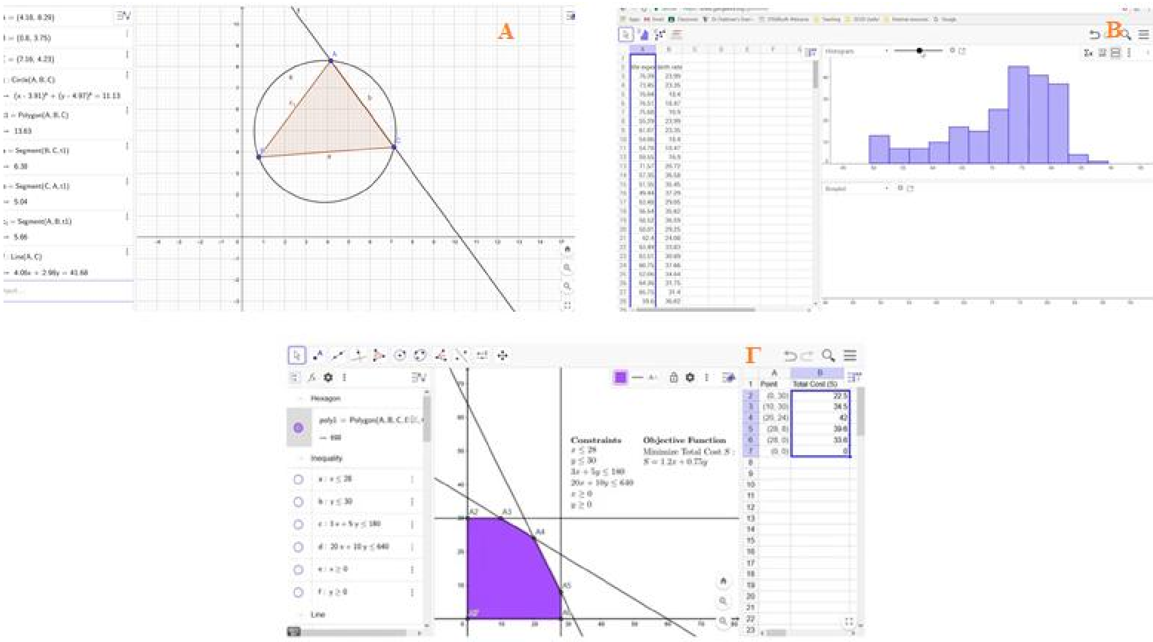

Figure 1. GeoGebra Work Environment in multiple fields of mathematics. A) Field of Analytic Geometry, B) Field of Statistics, C) Field of Optimization Problems

In 2021, GeoGebra became part of the BYJU'S family with hundreds of millions of students on their learning platforms. Applications, classroom resources, GeoGebra Classroom and other features of GeoGebra will continue to be available to the public for free. GeoGebra continues to operate as an independent unit within the BYJU'S group under the leadership of the original GeoGebra founders and developers.

This paper makes a reference to the Mathematical Model MUSA (MUlticriteria Satisfaction Analysis) and then presents the user satisfaction evaluation of the above mathematical software, which was used for the distance education of students of various educational levels and presents its advantages and disadvantages as well as the results.

Methodology

For this work, a bibliographic research was used, of the mathematical models of evaluation of criteria certification and use - management of resources: TAM (*Technology Acceptance Model)* , UTAUT (Unified Theory of Acceptance and Use of Technology) and MUSA (MUlticriteria Satisfaction Analysis) as well as the mathematical software GeoGebra .

The data collection was carried out after a survey conducted on 50 teachers, students and civil servants who had experience in educational software using questionnaires for their evaluation of the educational tool Geo Gebra and how satisfied they would be with its application in the context of a Maths course.

Research questions

The research questions, which will be investigated through the study, are the following:

- Does the introduction of New Technologies in Educational Organizations and Public Organizations create problems for users and how are they dealt with?
- With the rapid development of information and communication technologies (ICT), their acceptance or rejection remains an open question.
- Is it possible, through the evolution of Mathematical Models, to derive a new improved model, which with the help of Information Science to produce intelligent software that will evaluate the management and Certification Criteria of human and non-human resources in Educational Organizations?
- How can we categorize users based on their capabilities and perceptions?
- What is the role of gender, age and technological readiness in the process of adoption and acceptance of New technologically based services?
- What are the problems faced by teachers, students and civil servants when using teleconferences and how can they be solved?
- Which of the criteria-variables included in the fundamental models can be incorporated into a new mathematical model?

MUSA method

The MUSA method played an important role in the development of separation model standards. It has been developed to measure and analyze customer satisfaction (Grigoroudis et al., 2002). This method is used to evaluate a set of marginal satisfaction functions in such a way that the global satisfaction criterion becomes as consistent as possible with customer judgments. Thus, the main goal of the method is to aggregate the individual judgments into a collective value function (Grigoroudis et al., 2002).

The success of MUSA is characterized by many applications in various fields such as the banking sector (Grigoroudis et al., 2002), agricultural marketing (Siskos et al., 2007) and the transport-communication sector (Grigoroudis & Siskos 2003; Aouadni et al., 2014), website quality (Grigoroudis & Siskos, 2009). Joao et al. (2010) proposed a method that aggregates individual customer satisfaction criteria into a total value function, but uses a dummy variable regression technique with additional constraints. For the same input information, the results of the proposed method are more stable than those of MUSA, and the observed differences allowed us to have deeper insights into how to deal with the information provided by the participants in a survey. Furthermore, unlike MUSA, they proposed applying more than one regression technique, starting with a dummy variable regression technique that uses the least squares approach and then iteratively applying a robust regression method such as M regression. Other publications interested in improve MUSA , such as MUSA-INT proposed by Angilella et al. (2014) , also consider positive and negative interactions between criteria, as does the UTAGMS-INT multi-criteria method. In addition, MUSA-INT considers a set of utility functions representing customer satisfaction, adopting the robust normal regression methodology (Angilella et al., 2014).

In our study, we are interested in improving the algorithm of the MUSA method in the field of educational software evaluation. This method applies a heuristic method to search for near-optimal solutions. This algorithm is based on the near-optimal solution because the optimal solutions are not the most interesting, given the uncertainty of the model parameters and the preferences of the decision maker (Van De Panne, 1975) and the fact that the number of optimal or near-optimal of solutions is often very large. Therefore an exhaustive search method (eg reverse simplex, Manas-Nedoma algorithm) requires a lot of computational effort.

Professor Ioannis Siskos (Siskos, 1985) showed that the algorithm (inverse simplex, Manas Nedoma algorithm) has many limitations such as large computer memory storage, long computation time, lack of strong robustness and difficult implementation. Therefore, it is very difficult to find the optimal (or near-optimal) solution with reasonable computation time and good quality.

The MUSA method is a normal regression used to evaluate a set of marginal satisfaction functions to such an extent that the global satisfaction criterion becomes as consistent as possible with the individual's judgments (Grigoroudis , E. , & Siskos , Y. 2002). Each teacher is asked to express their overall satisfaction with the software in terms of a set of discrete criteria on a predetermined satisfaction scale. The MUSA method is used to minimize the sum of the variances of the teachers' opinions about the software and that resulting from the multi-criteria evaluation (Koilias , C ., Tourna , E ., & Koukouletsos , K . 2012).

The main elements of the MUSA method for the problem of the present study:

j = (1, ..., M) is the set of teachers, i = (1, ..., n) is the number of criteria, q = (1, ..., n_i) is the number of secondary criteria, U: The global satisfaction of the teacher in relation to the software, m = (1, ..., a): Total satisfaction number, u^m: The m global level of satisfaction, V_i: The satisfaction of the teacher for the software according to criterion i (i = 1, 2, ..., n), k = (1, ..., a_i): Number of satisfaction level for the i-criterion, v_i^k: The k-level satisfaction of criterion i, U*: Value of function U, u*: The value of the level of satisfaction of um, V_{i*}: The value function of V_i, V_i^k*: Value of the level of satisfaction V_i*, b_i: The weight of the criterion i, n_i: Number of sub-criteria for the i-criterion, V_{iq}: The satisfaction of the customer for the qq sub-criterion of the criterion i (q = 1, 2, ..., n, i = 1, 2 , ..., n), A_{iq}: Number of satisfaction levels for the q-sub-criterion of criterion i, $V^k{}_{iq}$: The satisfaction rates k for the qq sub-criterion of criterion i, V_{iq}*: Value of the function of Viq, V_{iq}^k*: Value of the level of satisfaction V_{iq}*, b_{iq}: Weight for the q-sub-criterion of criterion i, The partial and global utility function (z_m, w_{ik}, w_{iqk}) is achieved by solving the following LP problem shown in relation 1. In order to solve the linear programming, the MUSA method applies heuristic algorithms which have several problems such as large computer memory requirement, long computation time , lack of robustness and difficult implementation. In order to avoid these obstacles, we propose to use the genetic algorithm.

Since the parameters of GAs are correlated with each other, the continuous genetic algorithm (CGA) is preferable in this case (Arqub , O. A. , & Abo - Hammour , Z. 2014). Below is the qualitative regression analysis equation.

$$\text{Min } F = \sum_{j=1}^{M} \sigma_j^+ + \sigma_j^- \sum_{j=1}^{M} \sum_{i=1}^{n} \sigma_{ji}^+ + \sigma_{ji}^-$$

$$\sum_{i=1}^{n} \sum_{k=1}^{t_j - 1} w_{ik} - \sum_{m=1}^{t_j - 1} z_m - \sigma_j^+ + \sigma_j^- = 0$$

$$\sum_{q=1}^{n_j} \sum_{k=1}^{t_{j_{ij}} - 1} w_{iqk^k} - \sum_{k=1}^{t_{jj} - 1} w_{ik} - \sigma_{ji}^+ + \sigma_{ji}^- = 0$$

$$\sum_{i=1}^{n} \sum_{q=1}^{n_i} \sum_{k=1}^{a_k - 1} w_{iqk} = 100$$

$$\sum_{m=1}^{a-1} z_m = 100$$

$$\sum_{i=1}^{n} \sum_{k=1}^{a_j - 1} w_{ik} = 100$$

$$z_m, w_{ik}, w_{iqk}, \sigma_j^+, \sigma_j^- \geq 0 \forall m, i, j, k$$

MUSA mathematical model used

The MUSA method follows the general principles of qualitative regression analysis (ordinal regression techniques) under constraints, using linear programming techniques for its solution (Grigoroudis, Siskos, 2000). It contains an additive collective value function Y* and a set of partial satisfaction functions X $_i$ *, which are estimated based on the opinions of all respondents. The basic equation of linear regression analysis is as follows:

$Y^{*} = \sum_{i=1}^{n} b_i X_i^*, \sum_{i=1}^{n} b_i = 1$ (1)

where b $_i$ is the weight of criterion i and the functions Y* and X $_i$ * are normalized to the interval [0,100], so that at the lowest level of satisfaction the value of the function is 0 and at the highest it is 100.

By introducing a dichotomous error variable, the qualitative regression analysis equation (1) takes the following form:

$\widetilde{Y}^* = \sum_{i=1}^{n} b_i X_i^* - \sigma^+ + \sigma^-$(2)

where $\widetilde{Y^*}$ is the estimate of the collective value function Y* and σ $^+$ and σ $^-$ are respectively the overestimation and underestimation error respectively. The main objective of the method is to achieve the smallest possible deviation between the value function Y* and the opinions of the respondents Y, composing a set of different satisfaction opinions into unique functions Y* and X_i^*. Table 1 lists the variables of the method.

Table 1: Variables of the MUSA method (Grigoroudis & Siskos , 2009)

Variable	**Description**
Y	Total user satisfaction
a	Multiple levels of total satisfaction
y^m	Tom -th level of total satisfaction (m =1, 2, ..., a)
n	Lots of criteria
X_i	User satisfaction for the i -th criterion (i =1, 2, ..., n)
a_i	Number of satisfaction levels for the i - th criterion
x_i^k	The k -th level of satisfaction for the i -th criterion (k =1, 2, ..., a_i)
Y^*	Value function of Y
y^{*m}	Value of satisfaction level y^m
X_i^*	Value function of X_i
x_i^{*k}	Value of x_i^{*k} satisfaction level

MUSA assessment

The most important stages of evaluation with the MUSA method are the following and are illustrated in Figure 3 (Grigoroudis & Siskos, 2000):

1. Preliminary analysis: In this stage the problem to be analyzed is defined and it will include the analytical evaluation of the objectives of the satisfaction survey and an analysis of user behavior and market environment will be carried out (Questionnaire and survey).
2. Using a survey questionnaire, defining the parameters of the survey and conducting it. Specific important characteristics of the research such as the type of research, the sample, and the procedure will be defined before it is conducted.
3. Analyses: The information obtained from the sampling will be analyzed and quantitatively approached by statistical methods and the multi-criteria MUSA method . There will also be a segmentation analysis where a separate analysis will be carried out for the user groups, based on their characteristics.
4. Conclusions and Proposals: At this stage we have the presentation of the results and the proposals for specific improvements in the system.

The algorithm of the MUSA methodology is completed with the post-optimization analysis phase, which is carried out to analyze the stability of the method, since it is based on the general principles of linear programming. This analysis allows the stability analysis of the optimal solution, given that the range of values that the variables take in the various semi-optimal solutions are stable, while otherwise the solution is unstable. (Grigoroudis & Siskos, 2000; Grigoroudis & Siskos, 2010).

Educational Software

The main purpose of the research is the evaluation of the educational software GeoGebra , its extracted main advantages and disadvantages, which were used for training in various educational levels from different levels and roles of users.

Research Tool

A questionnaire was drawn up and sent to 50 respondents (educators, students and civil servants) who had experience with educational software. The questionnaire was chosen as a research tool in this research.

The questionnaire is a key tool for collecting quantitative data. It allows data to be collected in a standardized way, which makes it easier to analyze (Roopa & Rani, 2012).

As far as the questionnaire that was formed for this particular research is concerned, it consists of 6 questions in total and is of a closed type, i.e. specific options are given to the participants, from which they are asked to choose the one or the ones they wish (Zafeiropoulos , K. 2015) .

The advantages of this type of software such as GeoGebra can be summarized as follows:

▶ Students are able to see the **result of their actions immediately** and quickly so that they can justify with persuasive arguments the strength of the resulting results (Dugdale, 1999). Therefore, the "Possibility of Self-Assessment" is set as the first criterion for user satisfaction.

▶ A laboratory environment is provided so that students are able to **explore mathematical problems and approach mathematical concepts** by **experimenting** with problem data and evaluating the results provided by the software (Drier, 2001). So "Interactivity" is set as the second user satisfaction criterion.

- These programs support cognitive efficiency by letting the **computer do the difficult calculations or repetitive measurements** (Hooper & Hokanson, 2000). So it can facilitate exam and academic paper writing processes. Based on this comment, the 3rd user satisfaction criterion is "Facilitation of Student Progress Monitoring".

- GeoGebra is easy to use and has the ability to import data (input) and export results (output) in a multitude of other software and programming languages (word , excel , powerpoint , prezi , spss , minitab , matlab). So the 4th user satisfaction criterion for GeoGebra is the ease of use.

Questionnaire

1. Possibility of Self-Assessment

- Does the environment support continuous formative assessments as an essential feature to continuously capture student thinking, providing feedback where needed, ie on each student's learning?
- Community-centred approach: does the environment provide ways in which people can both learn, such as through questioning of the negotiation of meaning and each student's progress in relation to shared student understanding?

2. Interactivity

Does the software take advantage of psychometric models to create interactive learning?

3. Student progress monitoring facility

- Does the software organize student learning elements into a developmental framework, such as a learning progression, to better interpret assessment results?

- Is the learner-centered (learner model) environment incorporating various testing methods desired by the learner according to knowledge, skills, attitudes and beliefs?

4. Ease of Use

Is it easy to use and does it require special IT knowledge?

Administration of the questionnaire

The administration of the questionnaire to the respondents was carried out electronically. Specifically, the questionnaire was completed electronically through Google Forms. In the first phase, there was a pilot administration of the questionnaire to five people. From the resulting data, some necessary modifications were made. The modified questionnaire was then administered to the total survey sample.

- Scale

The scale used is the Likert scale (with the options 'very dissatisfied', 'dissatisfied', 'neutral', 'satisfied', 'very satisfied'

- How to analyze the data

Finally, regarding the analysis of the data, which resulted from the conduct of the specific survey to which all 50 respondents responded, for the evaluation of the GeoGebra educational software, this was carried out through the MUSA Mathematical Model .

Presentation of results

The participants (as seen in Figures 4, 5 and 6) are predominantly female (54% versus 46% male). Most participants are teachers (46% of the sample), 40% are students and 14% have another capacity (most of them professionals who have recently completed their studies). Most participants (42%) are in the age range between 26-50 years, followed by people between 18-25 years (34%) and finally come people older than 51-65 years (24%).

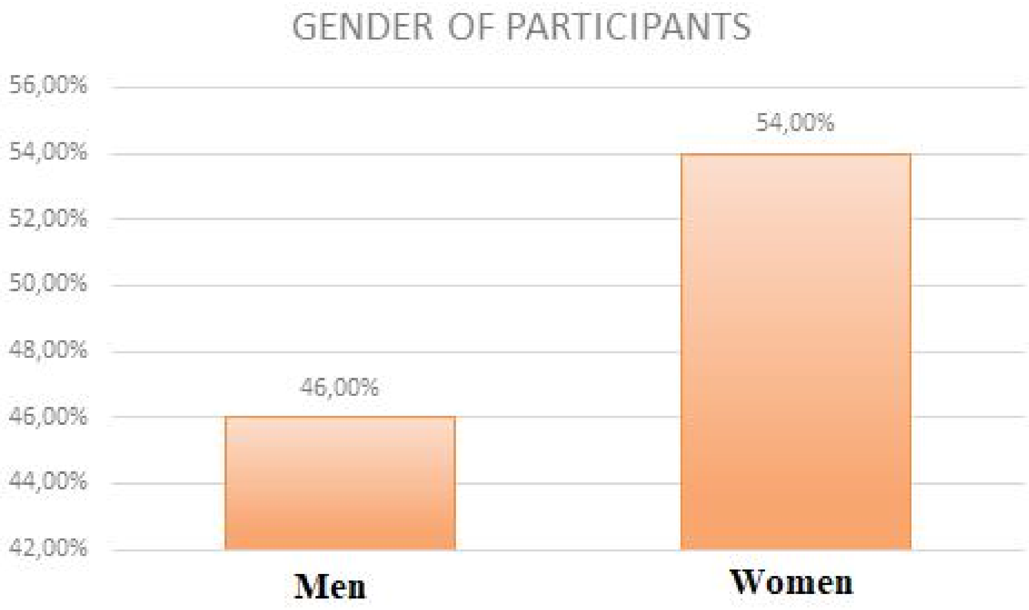

Figure 2 Gender of Participants

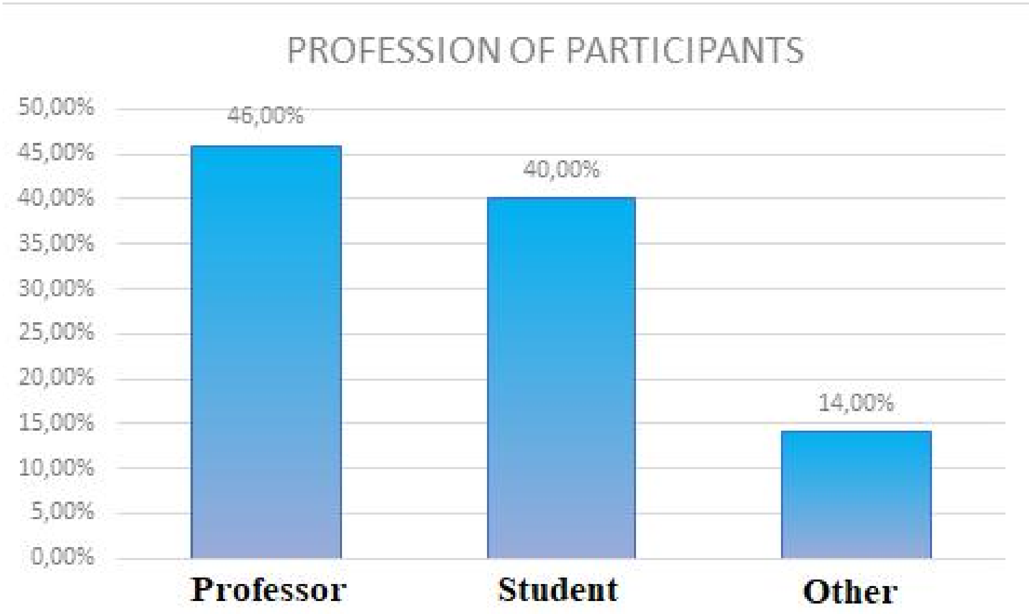

Figure 3. Participant profession

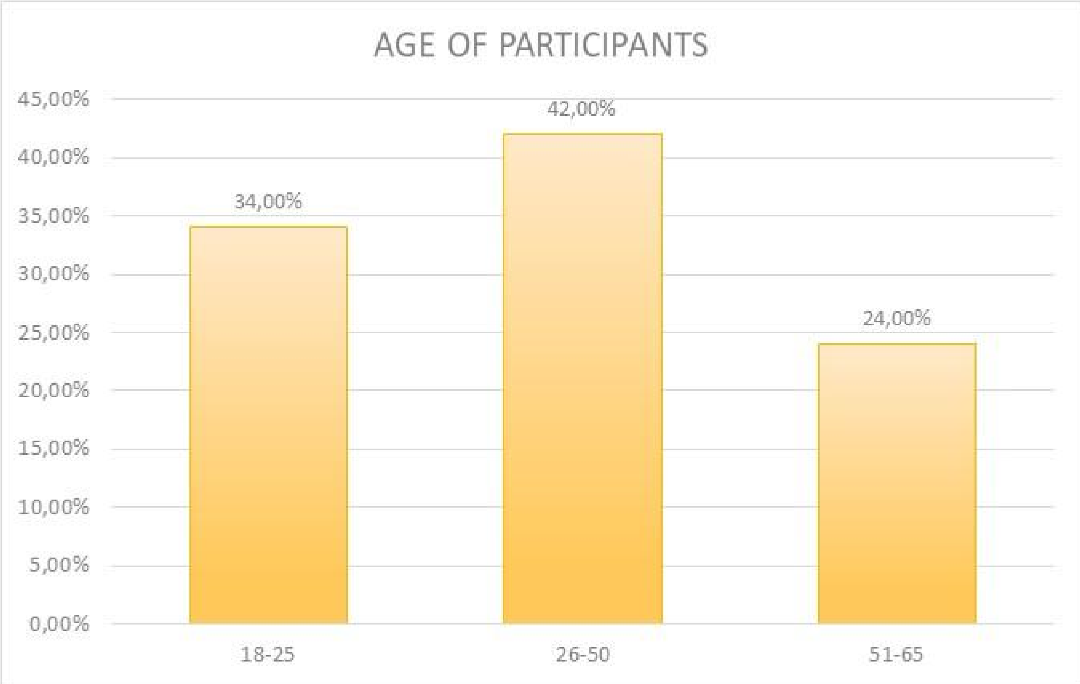

Figure 4. Ages of Participants

EVALUATION OF CRITERIA

The Evaluation of the criteria - variables used in the research is given as follows in images 5,6,7 and 8.

In the 1st criterion "Possibility of Self-Assessment" 36% of the participants declared very satisfied, 34% satisfied, 20% declared neutral in their disposition, 6% were very dissatisfied and 4% were dissatisfied.

In the 2nd criterion "Interactivity" 32% of the participants declared very satisfied, 26% declared neutral in their disposition, 24% declared satisfied, 10% declared very dissatisfied and 8% declared dissatisfied.

In the 3rd criterion "Facilitation of student progress monitoring" 32% of the participants declared neutral in their disposition, 30% declared satisfied, 26% declared very satisfied, 10% declared dissatisfied and 2% declared very dissatisfied.

In the 4th criterion "Ease of Use" 36% of the participants declared neutral to their use, 32% declared satisfied, 16% declared very satisfied, 12% declared very dissatisfied and 4% were dissatisfied.

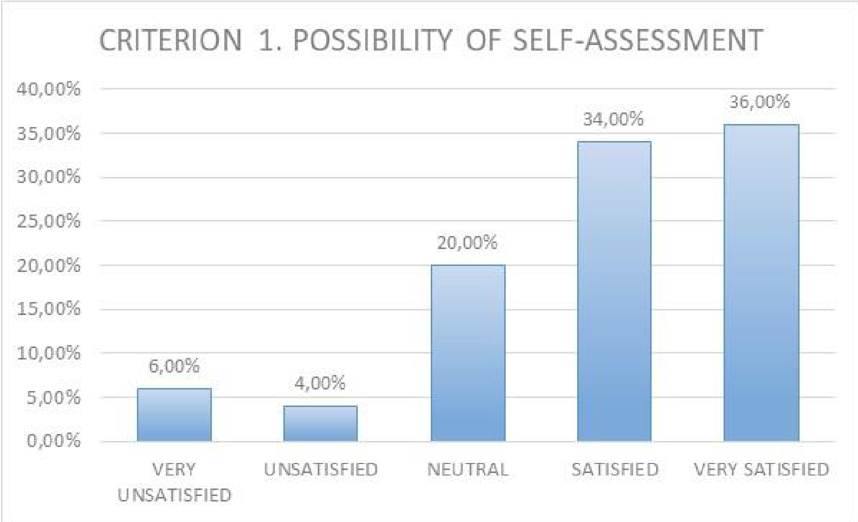

Figure 5. Satisfaction with the 1st Geogebra software evaluation criterion "Self-Assessment Capability"

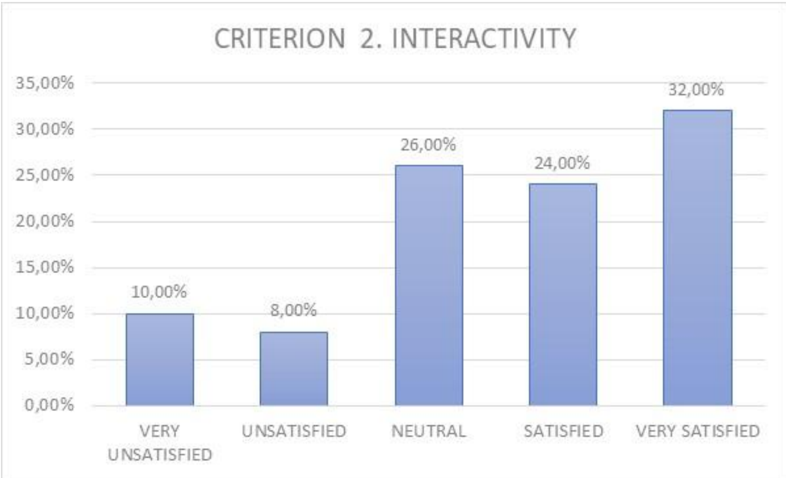

Figure 6. Satisfaction with the 2nd Geogebra software evaluation criterion "Interactivity"

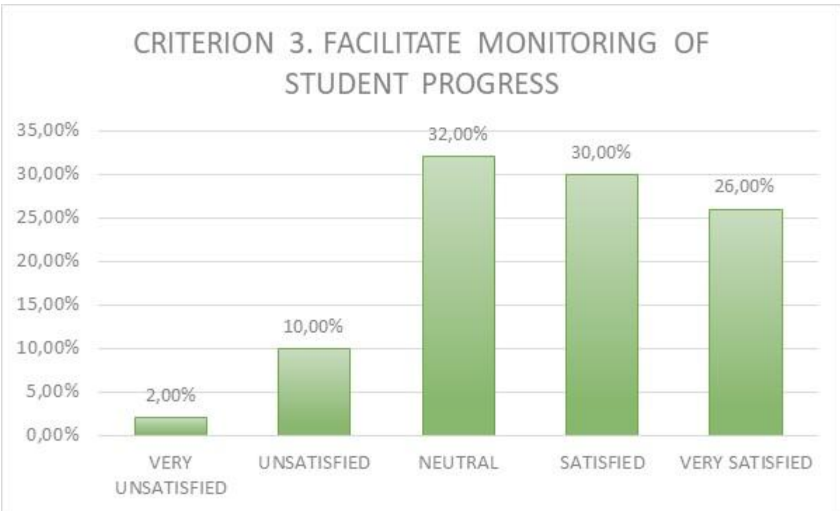

Figure 7. Satisfaction with GeoGebra Software Evaluation Criterion 3 " Facilitating Student Progress Monitoring"

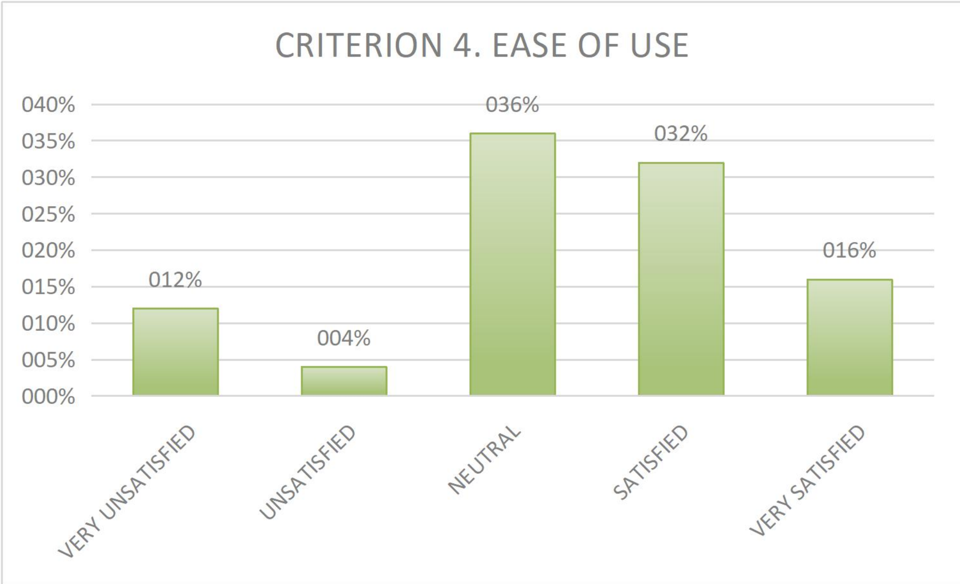

Figure 8. Satisfaction with the 4th Geogebra software evaluation criterion "Ease of Use"

CHART OF WEIGHTS

The weight chart in the current phase was selected based on the MUSA algorithm and the following results were obtained: a) Ease of Monitoring Student Progress, 29.43%, b) Self-Assessment Ability, 24.65%, c) Ease of Use, 24.47% and d) Interactivity 21.45%.

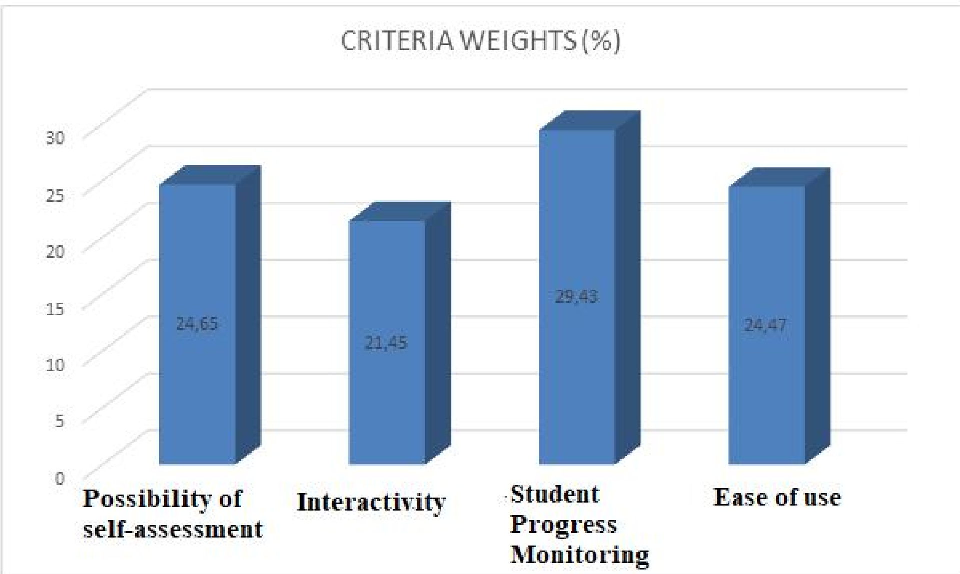

Figure 9. Weight Chart

OVERALL SATISFACTION

Entering the above data into the MUSA Mathematical Model we have from the individual results (Partial Satisfaction) the Total Satisfaction for the mathematical educational software GeoGebra .

With an excellent 100 in the individual criteria

a) Possibility of Self-Assessment 78%, b) Interactivity 72%, c) Ease of monitoring student progress, 73.60%, d) Ease of Use 67.20%.

The overall weighted satisfaction average is equal to 72.78%.

TOTAL REQUIREMENT

The overall demand as shown in Figure 13 for the GeoGebra software per criterion is equal to: Self-Assessment Ability, -28.91%, Interactivity, 3.87%, Ease of Monitoring Student Progress, -3.21% and Ease of Use, 43.86%. The weighted average claim is equal to : 3.49%.

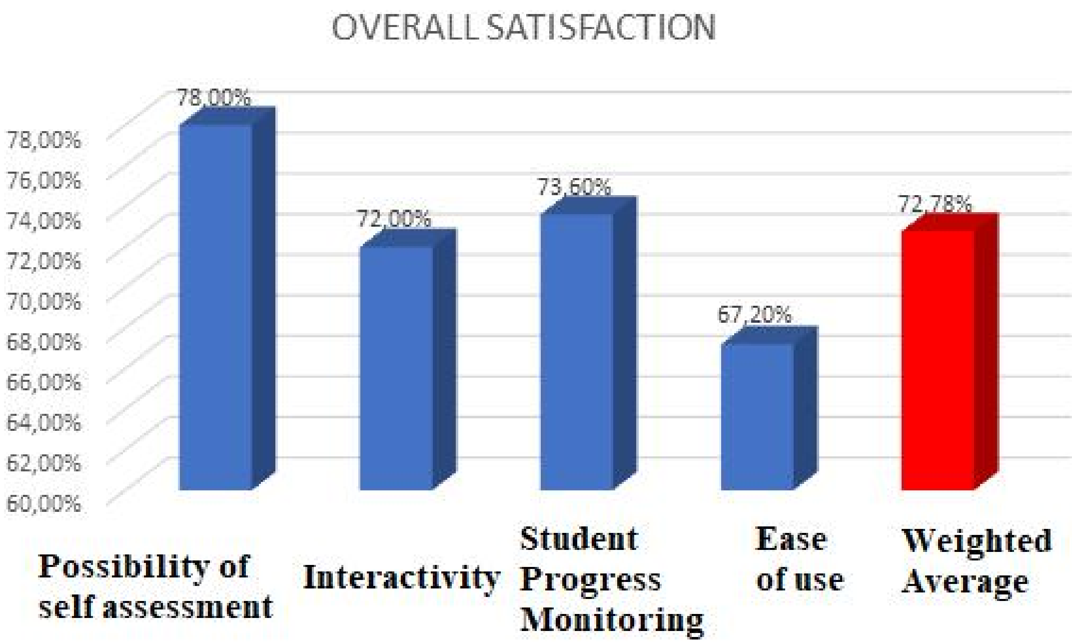

Figure 10. Overall Satisfaction Chart for GeoGebra software

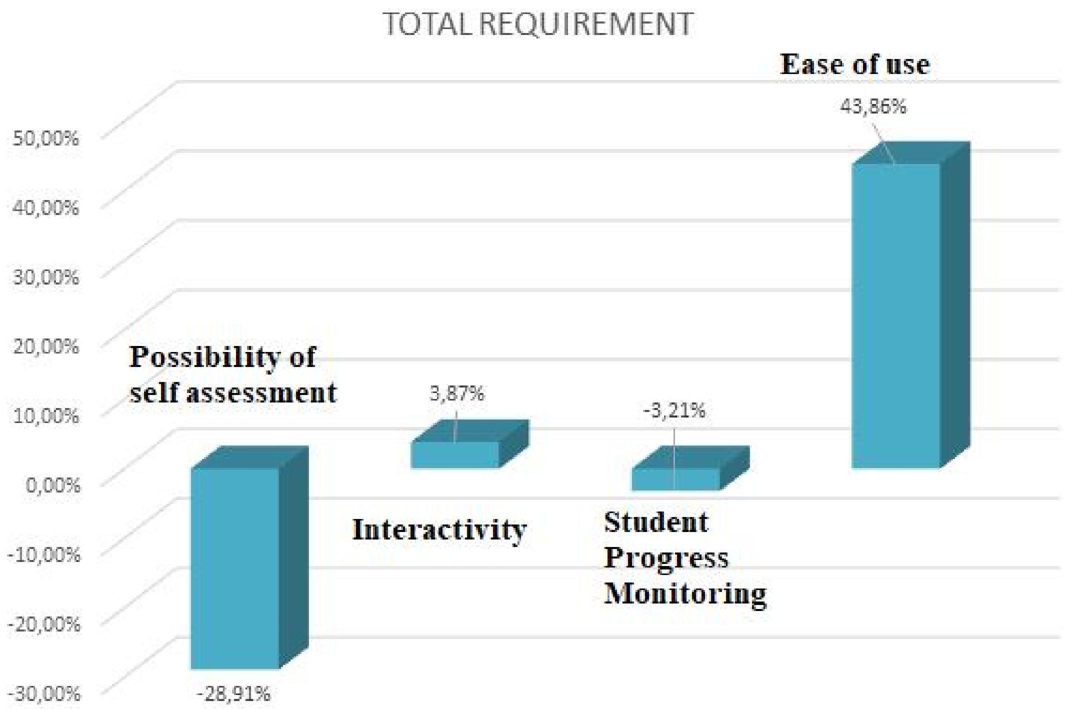

Figure 11. Total Requirement Diagram for GeoGebra software

ACTION CHART

The Action Diagram is presented as shown in Figure 14 in the following areas:

a) Action Area A with low Action and high importance

b) Power area B with high Performance and high importance

c) Status area C with low Performance and low importance

d) Resource Transfer Area D with low Performance and high importance

For GeoGebra the action diagram is as follows:

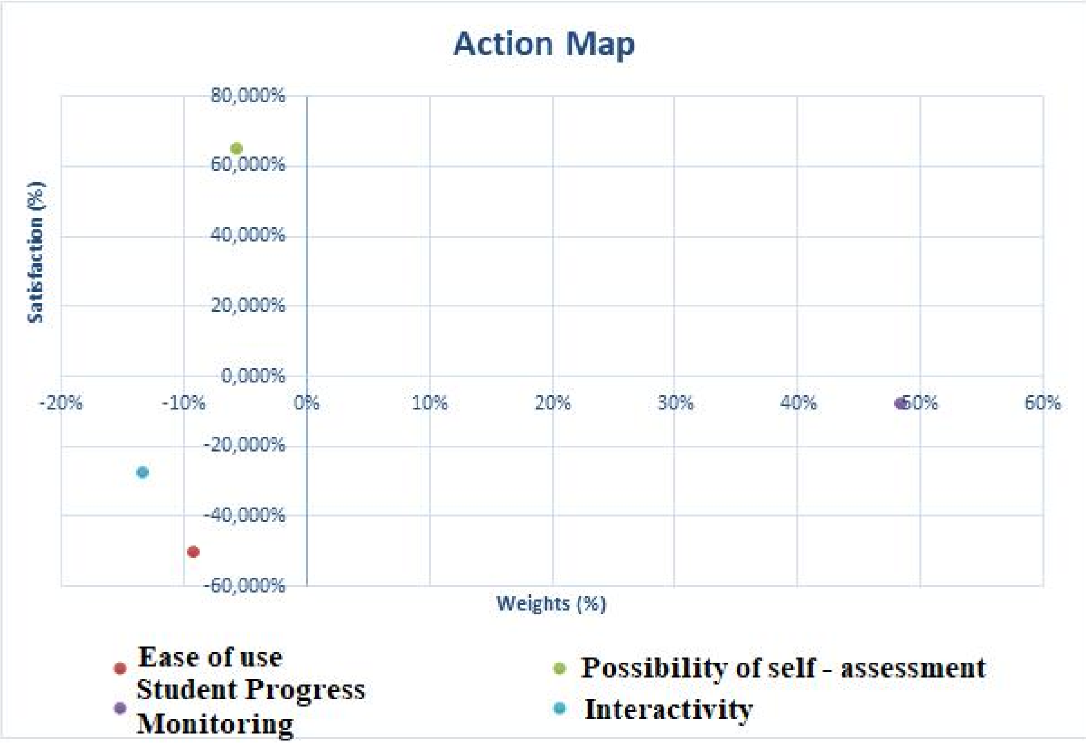

Figure 12. Action Diagram for GeoGebra software

It is observed from the action diagram for GeoGebra software that the evaluation criteria are ranked as follows:

1) The student progress monitoring facility has low performance and high importance

2) Interactivity has low performance and low importance. Even lower performance and slightly higher importance has the Ease of Use criterion of the software

3) The Self-Assessment capability criterion has high performance and low importance.

IMPROVEMENT CHART

The Improvement Chart is illustrated in figure 16 in the following areas:

a) Priority 1 Area A with High Efficiency and Low Effort

b) Priority 2 Area B with High Efficiency and High Effort

c) Priority 2 Area C with Low Efficiency and Little Effort

d) Priority 3 Area D with Low Efficiency and High Effort

GeoGebra educational software , the following improvement diagram was obtained based on the MUSA algorithm.

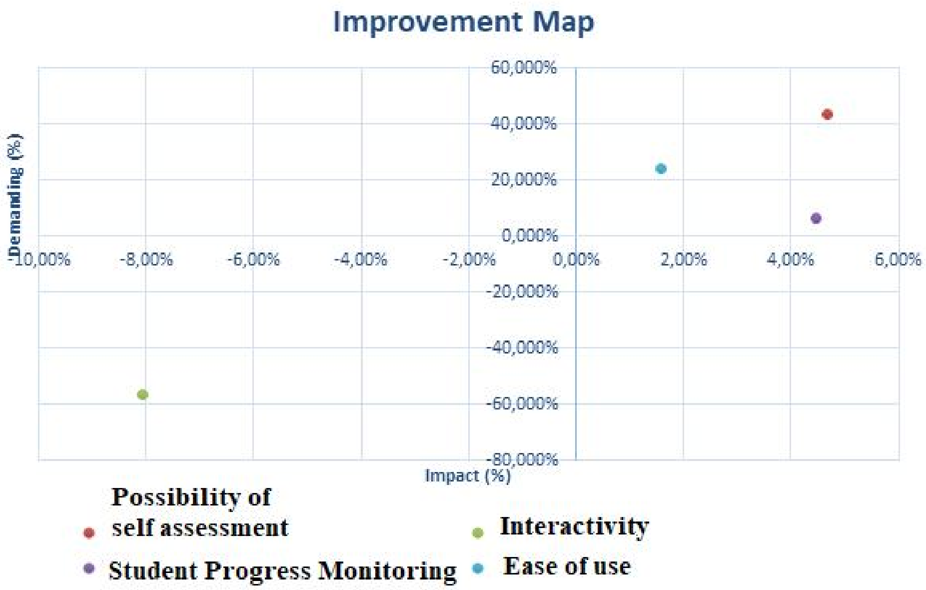

Figure 13. Improvement Diagram for GeoGebra software

It is observed from the improvement chart for GeoGebra software that the evaluation criteria are ranked as follows:

1) The criteria "Possibility of Self-Assessment", "Easier monitoring of student progress", "Ease of Use" are classified in the 2^{nd} priority category (high efficiency and great effort). The most important criterion (most critical) in terms of improvement is the possibility of self-evaluation.

2) The interactivity criterion also belongs to the 2nd priority(Low Efficiency and Little Effort).

CONCLUSIONS

MUSA reaches safe evaluative conclusions regarding the criteria that have been used to evaluate the GeoGebra educational software , which are as follows:

1. Possibility of Self-Assessment

2. Interactivity

3. Student progress monitoring facility

4. Ease of Use

Greater satisfaction with the Self-Assessment Capability, increased overall satisfaction with the software, and greater demand for the Ease of Use criterion were found. Finally, it was found in the action diagram that the most critical criterion is the student progress monitoring facility which has low performance and high importance, while in the improvement diagram for GeoGebra the most critical criterion was also the student progress monitoring facility as well as the possibility of self-evaluation (high efficiency and little effort).

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