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Fuzzy Logic Approach for Measuring Graduate Attributes in Outcome-Based Education for Electronics

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ABSTRACT

Outcome-Based Education (OBE) has been adopted by universities in various countries, posing challenges in measuring the achievement of Graduate Attributes (GA) within individual courses and integrating them across study programs. This research employs Fuzzy Logic to assess GA achievement in the Computer Application in Electronics course. The study utilizes the Fuzzy Mamdani method to evaluate several GAs, considering cognitive, psychomotor, and affective domains. The system's input consists of assessments based on Course Learning Outcomes (CLOs), while the output reflects student performance. Experimental results indicate that parameter selection significantly impacts outcomes, though the differences between centroid and bisector fuzzification methods are relatively small, making both viable options. Specifically, the range of GA 7's final value difference using the centroid method falls between -1.9 and 0. In contrast, the bisector method ranges from -1 to 1.9, with a maximum point difference of 1.5 when comparing manual and centroid methods for GA 8. The average value differences are 0.598 for the centroid method and 0.580 for the bisector method.

1. INTRODUCTION

Outcome Based Education (OBE) based learning has currently been implemented in several countries [1][2] and is an effort to improve education in their countries [3]. Of course, implementing OBE has several challenges and opportunities [4][5]. Some challenges are difficulty developing learning outcomes, determining teaching strategies and learning materials, and implementing appropriate assessment methods. Another challenge is the time lecturers need to prepare to implement OBE. This infrastructure must support the achievement of the set graduate attributes (GA) and the high workload of lecturers [6]. However, research results show that OBE can improve student performance in attitude, knowledge, and student skills, including critical student skills that will be useful for students when they graduate later [7][8]. Compiling the OBE curriculum begins with determining the Program's Educational Objective (PEO) and Graduate Attributes (GA), compiling a curriculum map, selecting courses that support GA, and identifying materials where the Study Program must compile this process. Course Learning Outcome (CLO) of each course must, of course, be in line with the established GA [9][10].

The measurement of student outcomes in OBE has its method, which must align with the Program Educational Objective (PEO) and the study program's Graduate Attributes (GA). The measurements that are usually used use manual methods [11]. However, along with the growth of technology, assessments are carried out using technology. One of the measurements is carried out using integrating Generative Artificial Intelligence (AI) and blockchain technologies [12]. Other studies have been carried out using fuzzy in several courses [13][14][15][16].

In addition, the measurement of fuzzy GA achievement has also been widely applied in various fields of education. It has been used to support virtual learning [17], evaluate the learning process [18], and other contributions. In the health sector, it can be a decision support system for patient conditions [19][20], and in agriculture, for example, for irrigation systems [21] and fertilizer use productivity [22]. Energy management and other implementations are also used [23][24].

The above research has discussed various methods of assessing student learning outcomes. However, measuring student learning outcomes depends on each GA chosen in the study program. Indeed, currently, the most popular is the manual method. However, some institutions have implemented technology to facilitate its calculations [25]. In addition, it has proven that fuzzy implementations have been successfully applied in various fields, so this study uses the fuzzy method in conducting learning outcomes on computer applications in electronics.

This study aims to apply Fuzzy Logic to analyze the achievement of GA in the Computer Application in Electronics course. The selection of CLOs charged to the course is adjusted to the GA the study program has set. Based on the CLO, the course lecturer determines the sub-CLO. The measurement of student learning outcomes is adjusted to the set sub-CLO. Of course, the assessment method must also be adjusted so that the measurement of learning outcomes is appropriate.

2. METHODS

This research stage begins by determining the Course Learning Outcome (CLO) derived from the study program's GA. Then, the CLO analyzes the elements of the assessment. The next stage is a fuzzy design to analyze GA achievement.

Electronics are under the Electrical Engineering Education study program, where the GA set by the study program is as follows:

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1. Able to align the curriculum of the science subject-training group in vocational education relevant to the demands of global industrial development. (Education)
2. Able to plan, implement, and evaluate innovative learning programs that are effective and efficient in electrical engineering vocational education relevant to global industrial development. (Education)
3. Able to apply applied research for innovation in vocational learning methods, optimization of production process technology, and electrical engineering services relevant to industry. (Education)
4. Extensive knowledge in the fields of general knowledge, social knowledge, and humanities. (General Skills)
5. Able to communicate in Indonesian and English orally and in writing. (General Skills)
6. Have a responsible character and are committed to Professional Ethics. (Attitude/SSC4.6)
7. They have extensive mathematics, science, and electrical engineering knowledge to solve complex problems typical of the Electrical Power Engineering and Communication Electronics expertise program. (Special Skills/SSC1.1)
8. Able to analyze research and development in the fields of Education, Electrical Power Engineering, and Communication Electronics by following the rules of scientific writing. (Special Skills/SSC2.2)
9. Able to design circuits, devices, and products in the Electrical Power Engineering and Communication Electronics expertise program. (Special Skills/SSC3.1)
10. Able to become a practitioner who can comprehensively apply their knowledge and skills to develop products in the Electrical Power Engineering and Communication Electronics expertise program. (Special Skills/SSC4.1)
11. Have project management skills and business practices in entrepreneurship as a form of lifelong learning through formal and non-formal education/training. (Special Skills/SSC5.3)

This course contributes to GA 7, GA 8, and GA 9. Meanwhile, the measurement of GA 7 achievement is carried out by assessing the results of the reference review and previous research on the project to be carried out (in the form of a report) and the presentation of project planning according to the review results. GA 8 assessment is a written test (knowledge), the process of analyzing the project they have worked on and presenting the results of the project analysis that has been carried out. A written test assesses the achievement of GA 9, the results of the project design they will implement, and student performance when presenting their designs and products (before and after implementation). The assessment of this GA is explained in **Table 1**.

Table 1. Input and Output Variables

No	Measurement	Assessment	Aspects assessed
1.	GA 7	Literature review (report).	Cognitive
		Project planning capability according to review results.	Psychomotor
		Presentation of review paper results (designing experiments to solve problems)	Psychomotor, Affective
2.	GA 8	Paper-based examination	Cognitive

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No	Measurement	Assessment	Aspects assessed
		The process of analyzing the projects they have worked on.	Psychomotor, Affective
		Presentation of the results of the analysis of the projects that have been carried out	Cognitive, Affective
3.	GA 9	Report of the results of the analysis of the projects that have been carried out (in the form of a report)	Cognitive
		The final design results of the project that they have implemented.	Psychomotor, Affective
		Student performance when presenting their designs and products (before and after implementation).	Cognitive, Affective

Based on the identification results in **Table 1**, the next step is to design the input-output for the fuzzy system we built. **Table 2** provides a more detailed explanation. The results in **Table 2** then become the basis for the fuzzy design.

Table 1. Illustration of System Input/ Output

Input	Aspect	Output (GA)	Final output
Literature review (report).	Cognitive (to measure extensive knowledge in mathematics, science, and electrical engineering so that they can solve complex problems)	They have extensive mathematics, science, and electrical engineering knowledge to solve complex problems typical of the Electrical Power Engineering and Communication Electronics expertise program. (Special Skills/SSC1.1)	Overall Performance
Project planning capability according to review results.	Psychomotor (to measure the extent to which electrical engineering skills can solve complex problems)		
Presentation of review paper results (designing experiments to solve problems)	Psychomotor		
Communication, Group work	Affective		
Paper-based examination	Cognitive (to measure analytical skills in development in the fields of Education, Electrical Power Engineering and Electronics)	Able to design circuits, devices, and products in the Electrical Power Engineering and Communication Electronics expertise program. (Special Skills/SSC3.1).	
The process of analyzing the projects they have worked on.	Psychomotor (to measure analytical skills in development in the fields of Education, Electrical Power Engineering and Electronics)		
Presentation of the results of the project analysis that has been carried out	Cognitive (to measure communication by following scientific writing rules)		

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Input	Aspect	Output (GA)	Final output
Communication, Group work.	Affective		
Report on the results of the analysis of the project that has been carried out (in the form of a report)	Cognitive (to measure designing circuits, devices, and products in the Electrical Power Engineering and Communication Electronics expertise program).	Able to analyze research and development in the fields of Education, Electrical Power Engineering, and Communication Electronics by following the rules of scientific writing. (Special Skills/SSC2.2).	
The final design results and the projects they implemented.	Psychomotor, Affective (to measure designing circuits, devices, and products in the Electrical Power Engineering and Communication Electronics expertise program).		
Students' performance when presenting their designs and products (before and after implementation).	Affective		

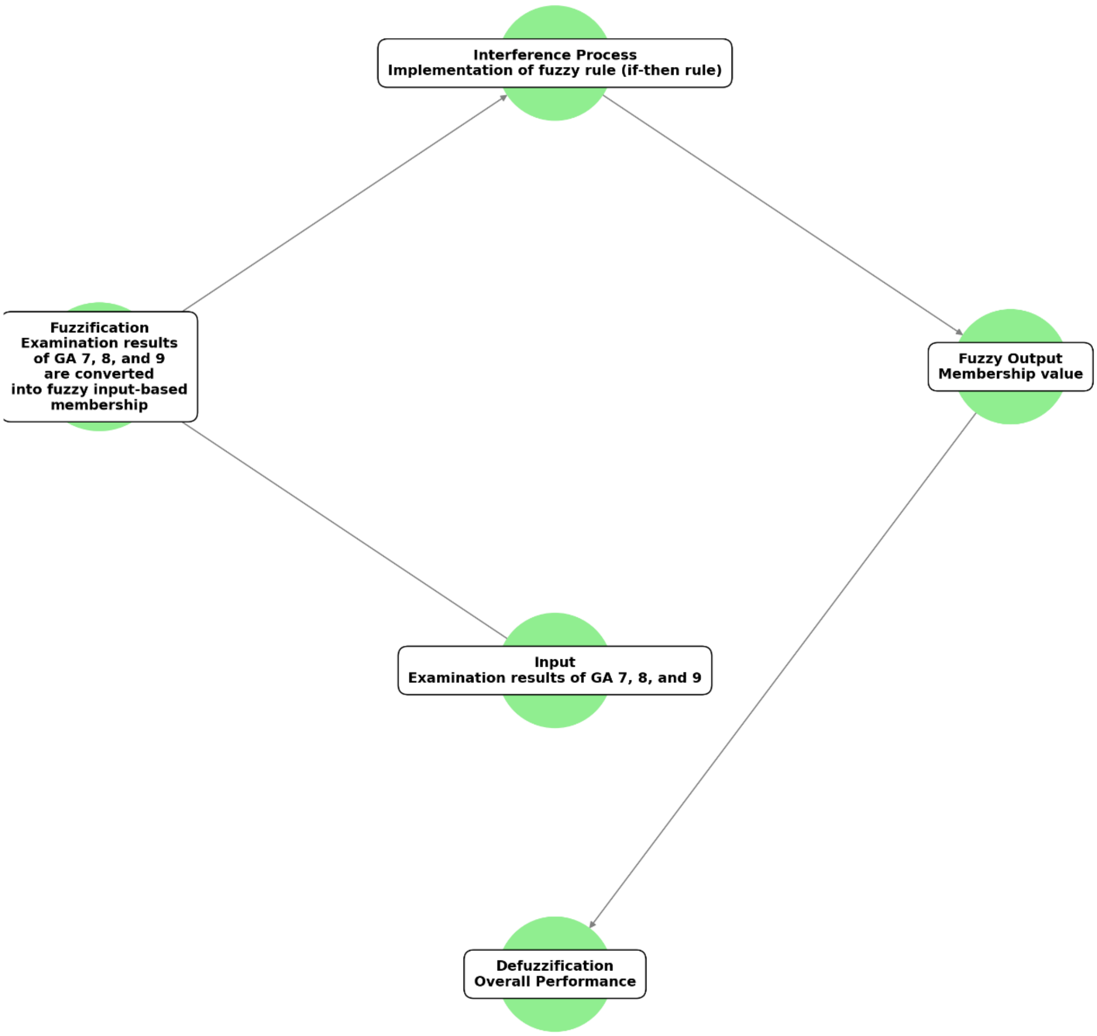

Figure 1. Design of fuzzy logic system

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Fuzzy design is depicted in **Figure 1**, where this design has 3 inputs, namely GA 7, GA 8, and GA 9. Each input and output has a membership function. The fuzzy algorithm applied is as follows:

- Formation of fuzzy sets for each variable, both input and output.
- Determination of implication functions.
- Preparation of rules-based systems.
- Defuzzification process: the results of defuzzification are the results of measuring student learning outcomes.

3. RESULTS

Some tasks that must be completed are divided into 3 parts, namely embedded system programming with various sensors, IoT-based monitoring programming, and the third is programming for IoT-based controlling processes. This project involves several sensors, including PIR, DHT, raindrop, LDR, MQ2 sensor, flame detector, ultrasonic, and LM35. This project is depicted in **Figure 2**.

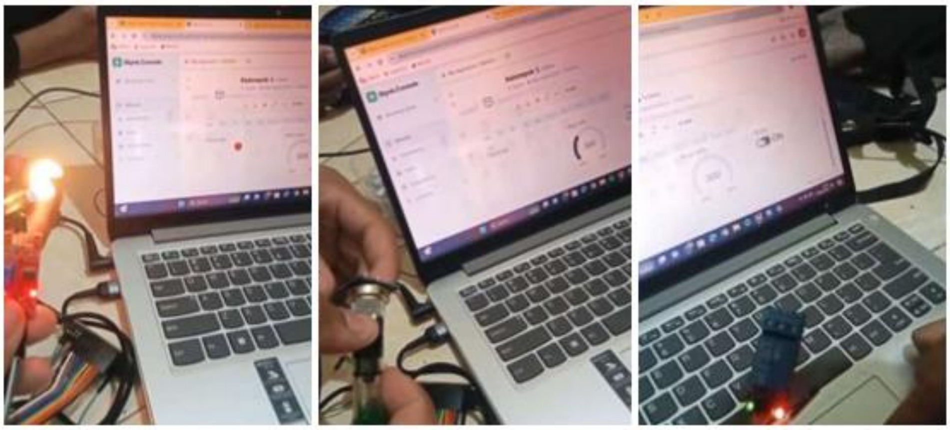

Figure 2. Project of Computer Applications in Electronics

3.1. Measuring the achievement of GA7

Figure 3 depicts the fuzzy logic design for measuring GA 7 achievement. There are 3 inputs: cognitive, psychomotor, and effective results. The membership function is Gaussian, and the fuzzification process uses the centroid and bisector methods.

The rule-based system in GA 7 is depicted in **Figure 4**. The rule-based system is entered using the or operator; there are 28 applicable rules. Input assessments from the results of literature reviews (reports), project planning capabilities according to the review results, presentation of review paper results (designing experiments to solve problems), communication skills, and group work processes are input to the system. These assessments were previously grouped into cognitive, psychomotor, and affective assessments and then used as input for the GA 7 fuzzy measurement system.

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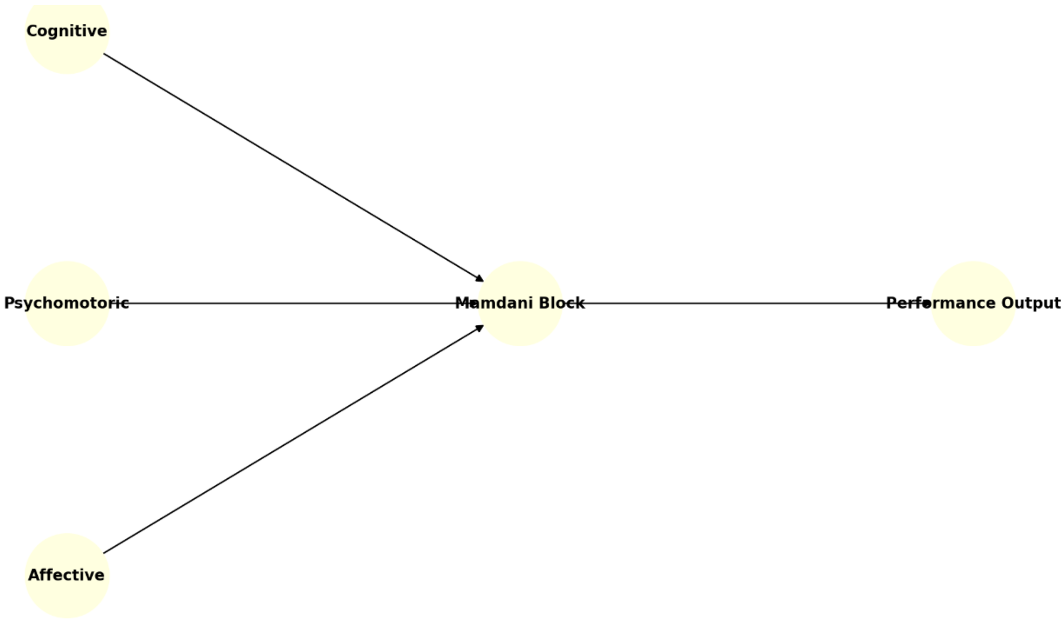

Figure 3. Fuzzy used for GA 7 measurement

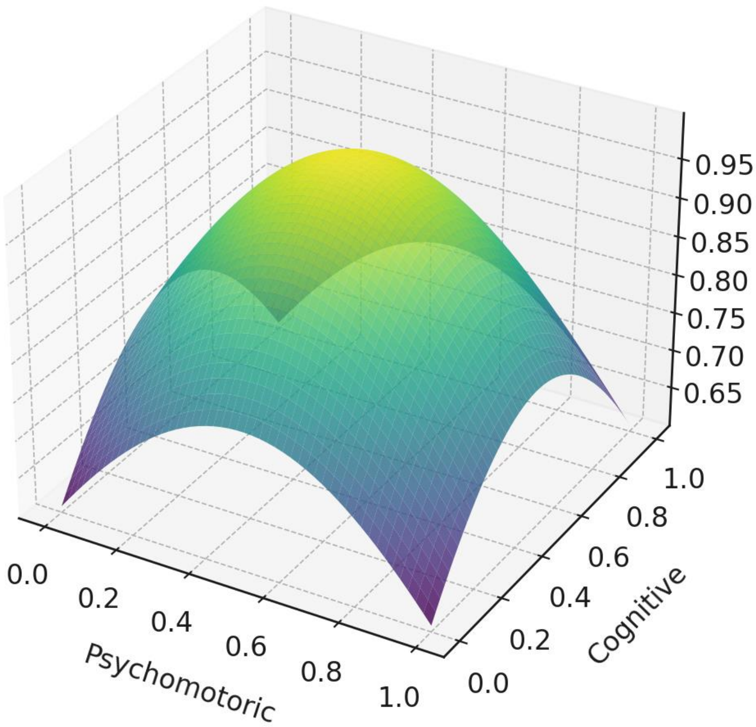

Figure 4. Rule-based system in GA 7

Figure 5 depicts the results of manual GA 7 measurements using fuzzy with centroid defuzzification and bisector. This output is a total assessment that considers several aspects explained above. Based on **Figure 5**, there are differences between using the manual method, centroid defuzzification, and bisector.

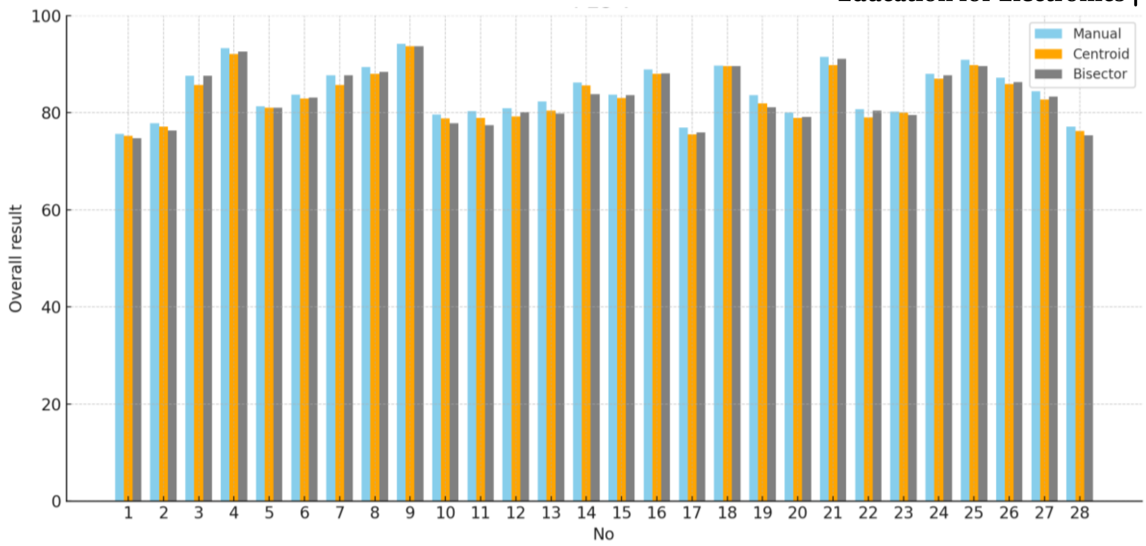

Figure 5. Results of GA 7 measurements using manual, fuzzy with centroid defuzzification and bisector.

Figure 5 shows that the final results using manual, fuzzy, centroid defuzzification, and bisector are almost identical. However, if we observe more deeply, there are differences in the final results at values 6, 7, and 14 in the results using manual and centroid. This difference is even greater when using bisector defuzzification; the final value ranges from 0 to 1.9 points.

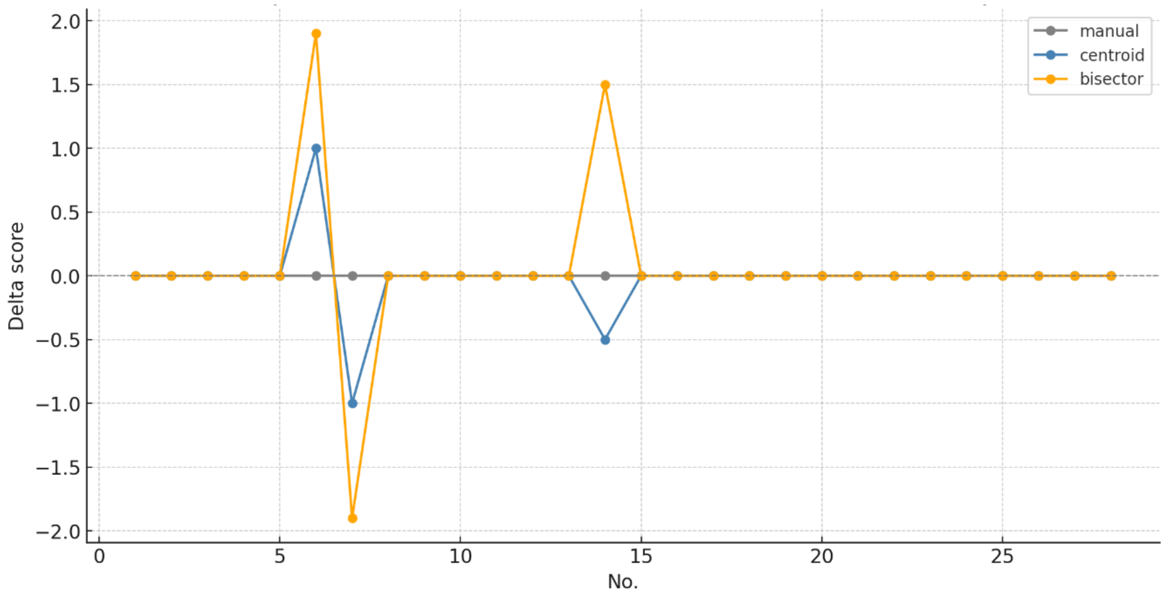

Figure 6. Differences in GA 7 measurement results using manual, fuzzy using centroid, and bisector defuzzification.

Figure 6 depicts the difference between the two methods when compared manually. The average value produced using the manual is 79.843 when using centroid 80, while using a bisector is 79.485. This shows that with the same input, the highest average value uses fuzzy with centroid defuzzification. For the range of the final value difference of GA 7 using a centroid between -1.9 and 0 and using a bisector, the difference is -1 to 1.9.

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3.2. Measuring the achievement of GA 8

Figure 7 shows a fuzzy design applied to measure the achievement of GA 8. Like GA 7, GA 8 also considers cognitive, psychomotor, and affective aspects. The membership function is Gaussian, and the fuzzification process uses the centroid and bisector methods.

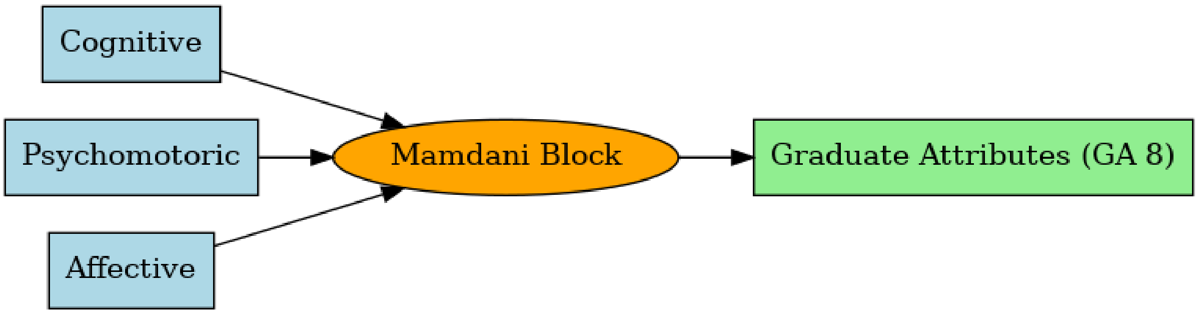

Figure 7. Fuzzy used for GA 8 measurement

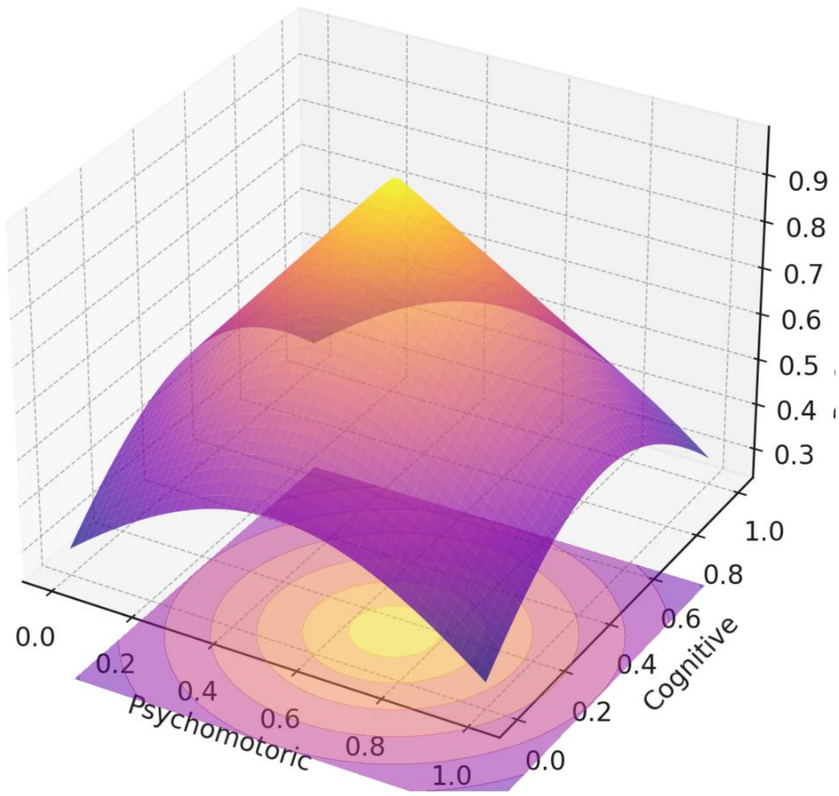

Figure 8. Rule-based system of GA 8

Figure 8 shows the rule-based system used in measuring GA 8. Written tests measure students' cognitive abilities (measuring analytical skills in development in Electrical Engineering), the results of analyzing projects they have worked on through presentations and reports, and communication skills.

Figure 9 depicts the results of manual GA 8 measurements using fuzzy with centroid defuzzification and bisector defuzzification. This output is a total assessment that considers

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several aspects explained above. Based on **Figure 9**, there are differences between using the manual method, centroid, and bisector defuzzification.

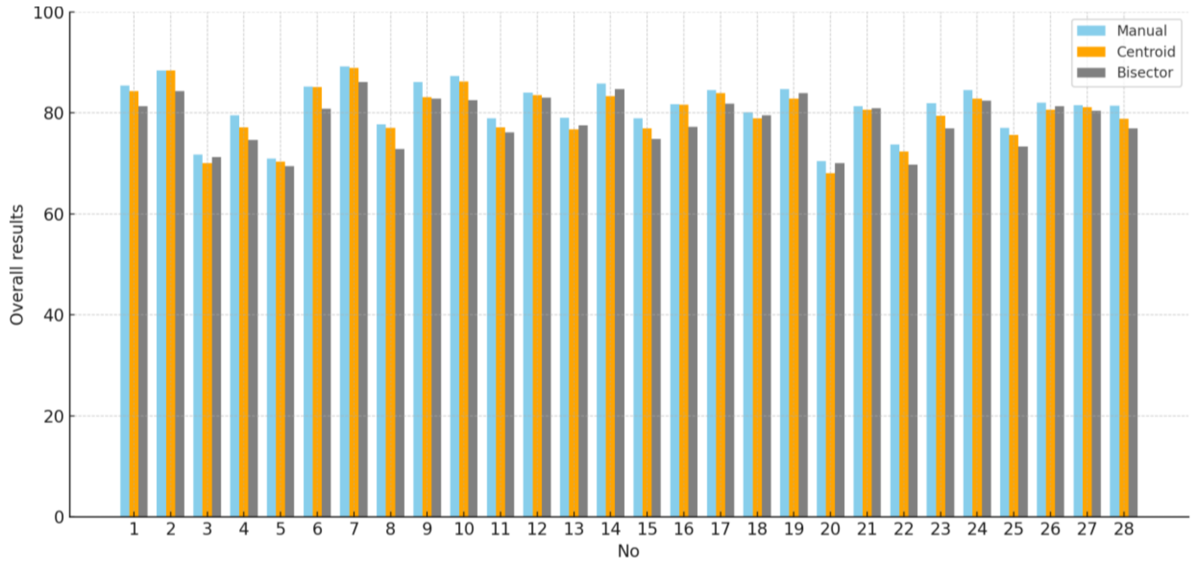

Figure 9. Results of GA 8 measurements using manual, fuzzy with centroid defuzzification and bisector.

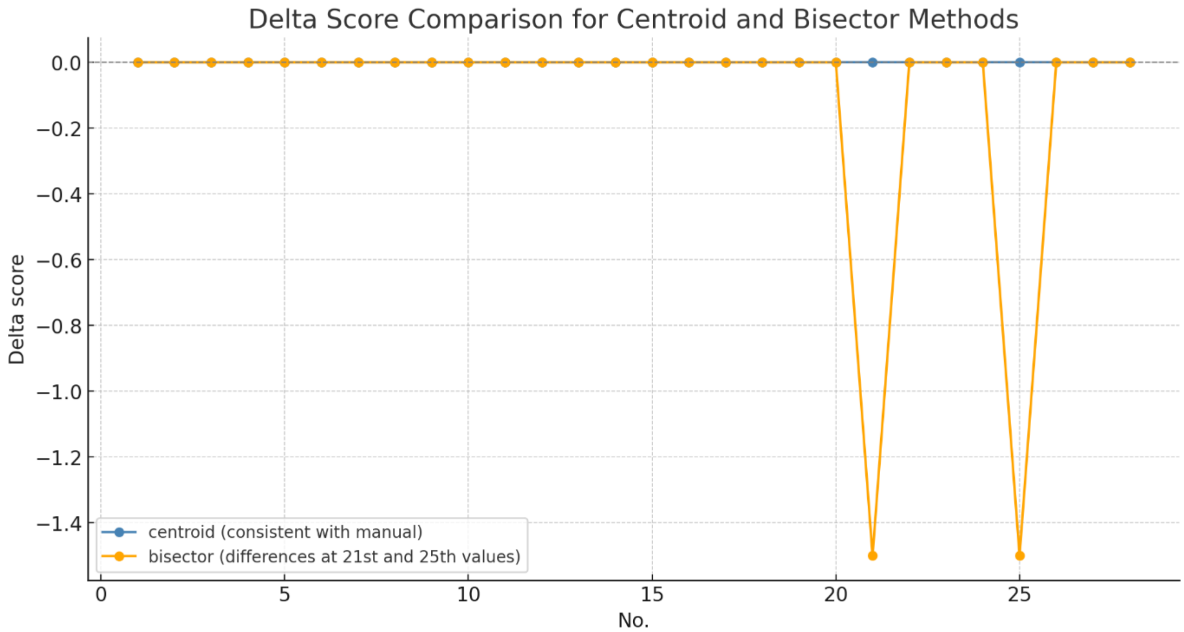

Figure 10. Differences in GA 8 measurement results using manual, fuzzy using centroid defuzzification and bisector.

Figure 10 shows that the final results using the three methods in the centroid method are the same as those of manual calculations. In contrast, there is a difference in the 21st and 25th values for using fuzzy with bisector defuzzification. This difference is a maximum of 1.5 points compared to manual and centroid.

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The average value generated using manual and centroid is 71.939 while using bisector is 71.846. There is no difference between calculations using manual and centroid, while the range of the final value difference using bisector is -1.5 to 0.

3.3. Measuring the achievement of GA 9

Figure 11 depicts the measurement of GA 9 achievement. The system input is the value of the project analysis report (in the form of a report), the final design results and the projects they implement, and the students' performance when presenting their designs and products (before and after implementation).

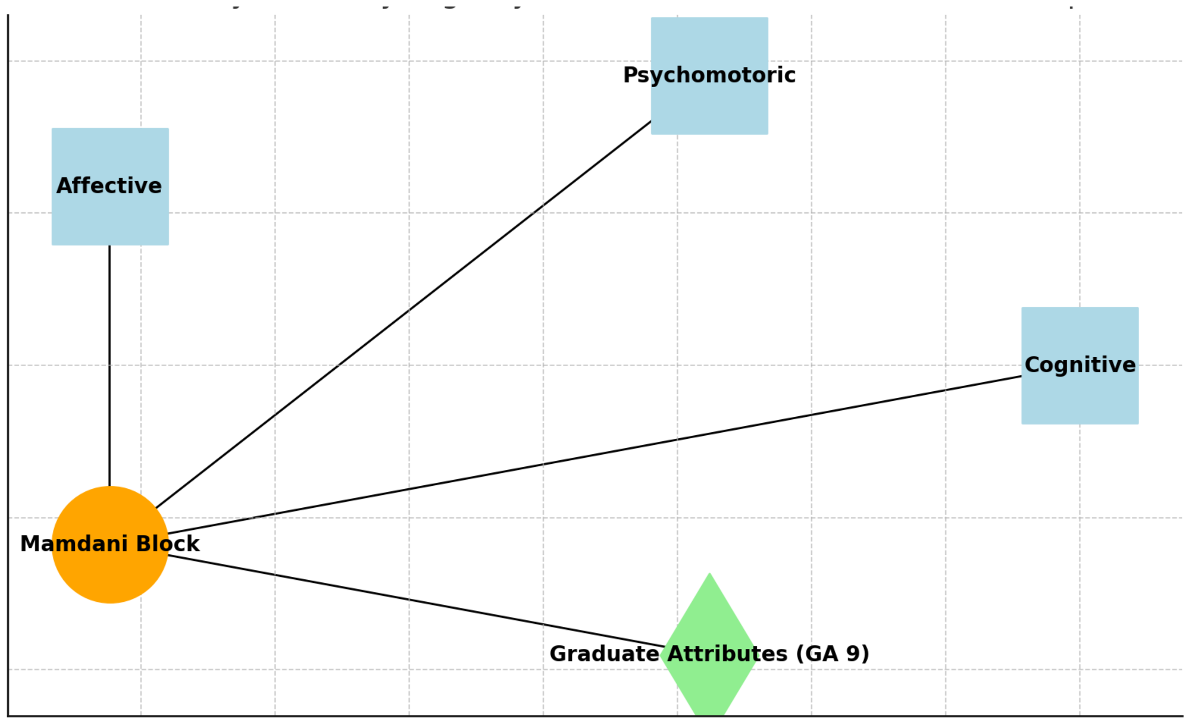

Figure 11. Fuzzy used for GA 9 measurement

Figure 12 depicts the rule-based system in GA 9. The rule-based system is entered using the or operator; there are 28 applicable rules. This assessment is grouped into cognitive, psychomotor, and affective aspects, and then this score becomes input for the GA 9 fuzzy measurement system.

Figure 13 explains the measurement results of GA 9 using a fuzzy design. Similar to the previous measurement, this output uses a Gaussian membership function. Based on **Figure 13**, there is a slight difference when using the third method. The average manual value is 74.428, and using fuzzy with centroid defuzzification is 74.629 and 73.847.

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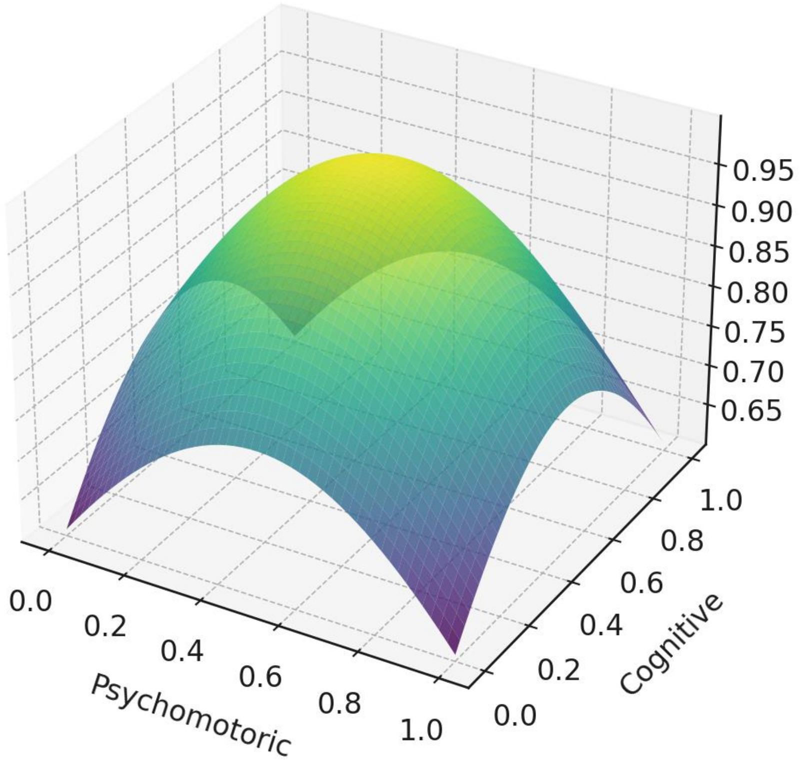

Figure 12. Rule-based system of GA 9

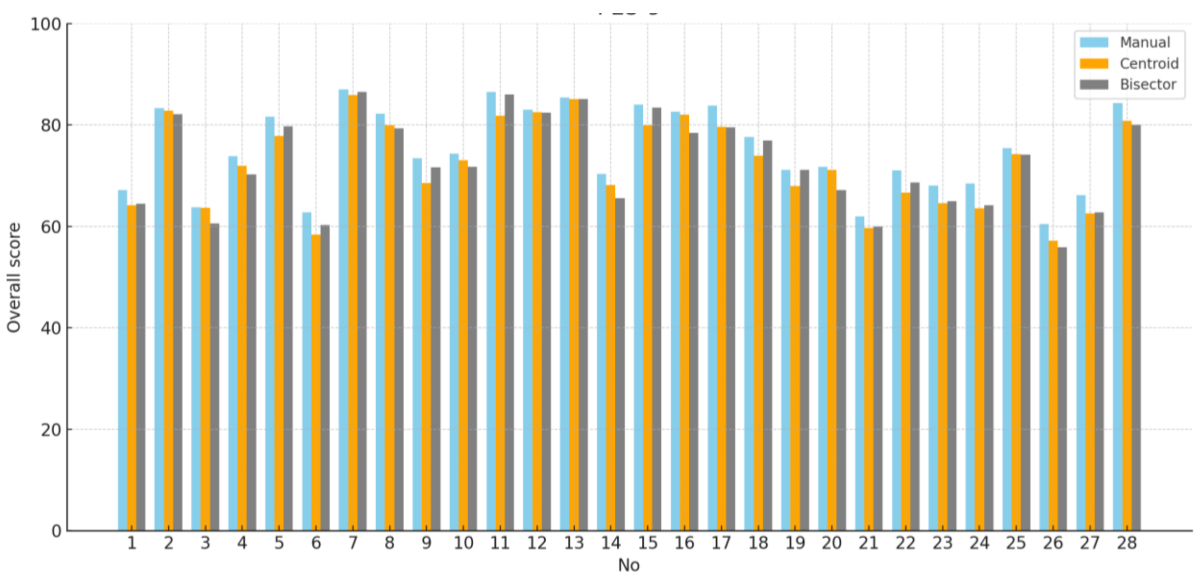

Figure 13. Results of GA 9 measurements using manual, fuzzy with centroid and bisector defuzzification.

When analyzed more deeply, the difference in using these two defuzzifications for GA 9 measurements is depicted in **Figure 13**. The average difference in value is 0.598 for using centroids and 0.580 when using bisectors. This value is somewhat different from the measurements of GA 7 and GA 8, where both measurements have a trend of differences that occur using centroids lower than bisectors. Further analysis shows that centroids tend to have higher values than manual calculations for using this rule-based system for values 80 and above, this condition also occurred in previous research [13], where the results using centroid and bisector fuzzification produced different final results. The difference was not too high or occurred at certain value points [14].

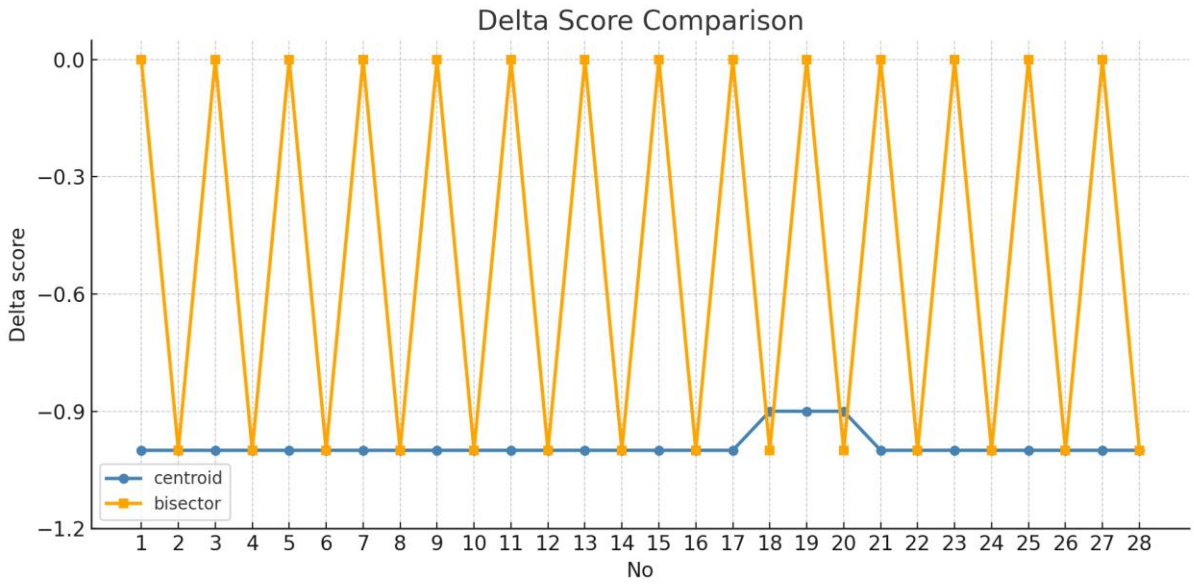

Figure 14. Differences in GA 9 measurement results using manual, fuzzy using centroid, and bisector defuzzification.

The measurement results also show similar results to GA 7 and GA 8. Based on this, using fuzzy can be an alternative solution to measure the achievement of GA. The selection of parameters used in the fuzzy system must be considered because it can produce different scores. The rules-based system must be considered and tested first. Because the applied rule-based system should benefit all parties, the solution must be tested until the difference is known. In addition, the type of membership function parameters, the number of members, and the use of the kind of fuzzification must also be considered.

4. DISCUSSION

The results obtained from implementing Fuzzy Logic to measure the achievement of Graduate Attributes (GA) in the Computer Application in Electronics course demonstrate the effectiveness of this approach within the Outcome-Based Education (OBE) framework.

4.1. Comparison with Traditional Methods

A comparative analysis between traditional manual methods and fuzzy logic-based assessments reveals that while both approaches produce comparable results, the fuzzy logic system offers more consistency and adaptability when dealing with complex and multidimensional assessment criteria. For example, the centroid and bisector methods produced only marginal output differences, illustrating robustness and flexibility in the fuzzy-based approach.

4.2. Implications of Findings

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The adoption of fuzzy logic in educational outcome measurement has significant implications. It provides educators with an automated, flexible, and scalable tool to evaluate student performance across cognitive, psychomotor, and affective domains, ensuring a holistic assessment of learning outcomes. This is particularly crucial in engineering education disciplines, where practical skills must be assessed alongside theoretical knowledge. Furthermore, this approach could reduce educators' workloads by automating parts of the assessment process while maintaining transparency and objectivity.

4.3. Limitations of the Study

Despite its benefits, the fuzzy logic approach has limitations. This system's accuracy and effectiveness heavily depend on the initial selection of membership functions, input variables, and rule-based systems. Fine-tuning these parameters requires expertise and careful consideration to avoid biases or inaccuracies. Moreover, this study focused exclusively on GAs related to the Computer Application in Electronics course, limiting generalizability across different disciplines or broader educational contexts.

4.4. Future Research Directions

Future research could explore further integration of other artificial intelligence methods, such as machine learning or deep learning algorithms, to enhance educational assessments' precision and adaptability. Additionally, applying the fuzzy logic framework across multiple courses within a study program would provide a more comprehensive evaluation of GA achievement and facilitate continuous program improvements. Longitudinal studies measuring the impact of fuzzy-based assessments on long-term student performance and career readiness are also warranted.

5. CONCLUSION

This study aimed to apply fuzzy logic to evaluate the achievement of learning outcomes in the Computer Application in Electronics course. The assessment covered multiple GAs, and findings indicate that fuzzy logic can be a viable alternative for measuring GAs within the OBE framework. Experimental data highlight that the choice of parameters within the fuzzy system significantly impacts the outcomes. However, the differences between the centroid and bisector fuzzification methods were relatively small, making both approaches useful. Specifically, for GA 7, the range of final value differences using centroids was between -1.9 and 0, while bisectors ranged from -1 to 1.9. In GA 8, the maximum observed difference when comparing manual and centroid results was 1.5 points, and the average value differences were 0.598 for centroids and 0.580 for bisectors.

Future studies could extend GA further by integrating other AI techniques, such as machine learning or deep learning, to enhance measurement precision. Expanding GA assessments to multiple courses within a single study program would also enable ongoing monitoring of GA achievements, fostering continuous improvement in educational outcomes.

6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article and confirm that the paper is free of plagiarism.

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7. AUTHORS' CONSTRIBUTOR ROLE

Yuli Sutoto Nugroho: Conceptualization, Methodology, Writing Original Draft, Investigation, Formal Analysis, Supervision, Data Curation, Software, Review & Editing.

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