# Utilizing Fuzzy Weights to Model Logical Reasoning in Digital Escape Rooms: Dynamic Difficulty Adjustment for Enhanced Digital Skill Development

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***Abstract*—This paper presents a novel digital escape room developed to increase users' digital skills by dynamically adapting puzzles using fuzzy weights. Players find themselves in a virtual room buried with ancient manuscripts and modern digital interfaces and take on a row of puzzles stretching their pattern recognition, logic and sequencing, cryptography, and data sorting capacities. These tasks range from very simple tasks for novice users to more complicated tasks for advanced users, all in the name of the development of skills important to problem-solving, critical thinking, and cyber security. This is novel in including an adaptive difficulty mechanism for regulating fuzzy weights in controlling puzzle complexity in real time. In this manner, it will adapt the challenges in the best manner possible over a continuum from novice to expert levels, ensuring that they will have optimal engagement and continue to develop their skills. Since it interacts with individual performance, the system allows for personalized learning, being linked to an increase in learners' engagement and the development of digital skills at a pace personalized to the learners.**

***Keywords—digital escape rooms; eLearning; digital skills; fuzzy logic; fuzzy weights; personalization; dynamic difficulty adjustment; puzzle; logical reasoning.***

## I. INTRODUCTION

Digital escape rooms are the latest in the entertainment block, having incorporated the kind of interactivity and engagement experienced in physical escape rooms but now virtually located [1]. In these spaces, more than just having fun, the digital literacy and problem-solving skills of a person might be enhanced. Therefore, leading oneself through elaborate enigmas and tasks, they will automatically have developed and mastered a series of digital competencies from basic computer operations to problem-solving techniques and logical thinking, which makes them a powerful educational enrichment tool.

Among the several elements in the world of digital escape rooms, personalization has one of the biggest roles: that of balancing the difficulty level and fun for an optimized experience. Dynamic difficulty adjustment (DDA) means that the challenge level of the puzzle can be personalized to that of an individual or group of individuals [2-4]. If the level of challenge is balanced, then all participants will feel adequately challenged but not overwhelmed, which should therefore lead to greater user engagement and better experiences.

Various techniques in digital environment personalization would be made possible using artificial intelligence (AI) with the help of machine learning algorithms, data mining, and pattern recognition. For example, content in an adaptive learning system can be modified on-the-go according to the change in the competencies of a user. Based on this information from AI-driven analytics, the challenge can be changed so that player behavior is predicted. Of these techniques, those in which human-like reasoning and uncertainty must be handled are particularly well-suited to using fuzzy logic [5, 6], and fuzzy weights hold promise for difficulty personalization in the context of digital escape rooms.

Fuzzy weights apply the principles of fuzzy logic to weigh various factors influencing a decision, accommodating the inherent vagueness and subjectivity in how different users perceive and solve problems [7-9]. In the context of digital escape rooms, fuzzy weights can dynamically adjust the difficulty of puzzles based on real-time data on user performance and preferences. This allows more flexible and fine-tuned adaptation compared to binary traditional systems, hence ensuring a smoother and more personalized user experience.

For example, literature has focused on the design of digital escape rooms, their user experience, and educational relevance in the past [10-25]. In the issue, the conducted studies involve issues of the impact of the narrative and thematic level on user engagement and educational effectiveness of such platforms. However, the application of fuzzy logic has proven that the research gap can be clearly recognized as to the issue of the application of advanced AI techniques for real-time difficulty adjustment in these games.

This paper discusses a novel way of implementing an advanced digital escape room with the purpose of increasing digital skills through dynamically modified puzzles employing fuzzy weights. The players are placed in a virtual room with old manuscripts and modern digital interfaces where they have to decode messages and sort data to unlock a safe in order to advance in a series of puzzles that grow in complexity. The puzzles range from pattern matching, where participants decode patterns linking ancient symbols to digital keys, which are very visible and straightforward for novices but advance to complex data and require decryption through multi-step processes by advanced users. Central to this challenge is critical thinking and the interpretation of data patterns. Logic and sequence puzzles require the participant to follow or deduce sequences that unlock digital files. This ranges from relatively simple direct instructions to unlock files up to requiring the participant to formulate algorithms without direct instructions, hence increasing logical and algorithmic problem-solving capabilities. Cryptography and encryption puzzles start with basic ciphers and go up to complex encryption that is used in real-world data security, making such puzzles vital to understanding cybersecurity principles. Information sorting and retrieval puzzles challenge the user to organize and extract data from complex databases using search algorithms, building on big data and research roles. The system will adapt the difficulty level of the puzzles on the fly based on fuzzy weight knowledge about that user to optimize the level of challenge and continue engagement. A user who rapidly demonstrates a high level of skill, for instance, will face increasing puzzle complexity, with the system adjusting in real time to their ever-increasing level of skill. Fuzzy weights are used to offer a user-centric experience that allows the user to engage with the system and develop digital skills at individualized paces.

## II. FUZZY WEIGHTS FOR DDA

Personalization of puzzles in the digital escape room involves detailed inquiry and understanding of the logic and reasoning ability of the user. The main way to personalize the puzzle difficulty is having a systematic investigation. For this purpose, a carefully designed questionnaire is developed through active participation of the 15 members of the consortium and informatics faculty from various public universities. The expertise was contributed to take care that the questionnaire measures the logical reasoning in the context of the digital escape room.

The questionnaire consists of five very carefully crafted questions. Each question is framed in a manner in which it would present a challenge to the respondents, but, at the same time, it would be a peek into a different aspect of their ability to reason logically. The respondents were compelled to make a choice out of several for each question, which enabled us to assess the acumen of recognizing and applying logical patterns and rules.

Table I provides a list of the questionnaire items and a comprehensive validation of each question for relevance and effectiveness in the measurement of logical reasoning.

TABLE I. QUESTIONNAIRE ON LOGICAL REASONING

| Questions | Option | Correct Answer | Validation |
|---|---|---|---|
| Look at this sequence of numbers: 2, 4, 8, 16. What is the next number? | A) 18, B) 20, C) 24, D) 32 | D) 32 | Tests ability to recognize and extend numerical patterns, specifically doubling, which is common in logical puzzles. |
| If all Zorgs are Vlads and no Vlad is a Klim, which of the following must be true? | A) Some Klims are not Zorgs, B) No Zorg is a Klim, C) All Vlads are Klims, D) Some Zorgs are not Vlads | B) No Zorg is a Klim | Evaluates deductive reasoning and understanding of set relationships, crucial for problem-solving in escape games. |
| Which geometric shape comes next in this series? Square, Circle, Triangle, Square, Circle... | A) Triangle, B) Square, C) Circle, D) Rectangle | A) Triangle | Assesses pattern recognition and prediction, important for anticipating puzzle mechanics and sequences. |
| You have a 3-gallon jug and a 5-gallon jug, and you need to measure exactly 4 gallons of water. How do you do it? | A) Fill the 3-gallon jug three times, B) Correct complex procedure, C) Another incorrect method, D) Guesswork | B) Correct complex procedure | Challenges participants with a practical problem-solving scenario, testing their ability to apply logical steps. |
| Imagine you fold a paper in half three times and then make a single cut. When you unfold the paper, how many holes will there be? | A) 2, B) 4, C) 8, D) Cannot be determined | C) 8 | Measures abstract reasoning and visualization skills, key for solving spatial and visual puzzles in escape rooms. |

For instance, accurately categorizing a user with a logical reasoning test score of 7.5 out of 10 presents a challenge due to the inherent ambiguity in classifying such scores as either “good” or “very good”—both labels could reasonably apply. To address this complexity, fuzzy logic provides a nuanced and effective solution. In this paradigm, we delineate learners' logical reasoning capabilities using four fuzzy categories: Beginner (B), Intermediate (I), Advanced (A), and Expert (E). Each category is characterized by trapezoidal membership functions, detailed in Table 2 and illustrated in Figure 1. These functions are defined by four boundary values (a1, a2, a3, a4), where the degree of membership transitions smoothly from 0 to 1 between a1 and a2, remains fixed at 1 between a2 and a3, and then gradually declines back to 0 between a3 and a4. The choice of trapezoidal membership functions allows for precise demarcation of the intervals within which a user’s score unambiguously identifies them within a specific category of logical reasoning.

Building on this foundational framework, the incorporation of fuzzy logic not only tackles the challenge of assigning categorical levels to nuanced measures of logical reasoning but also provides a more detailed and granular representation of learners' proficiencies. By utilizing trapezoidal membership functions (Table II), our fuzzy logic model adeptly handles the inherent uncertainties and imprecisions associated with human cognitive assessments (Fig. 1). This adaptability facilitates a more flexible approach to assessing and refining users' logical reasoning skills within the context of digital escape rooms. The sophisticated integration of fuzzy logic into this setting lays the groundwork for personalized and targeted interventions designed to boost user engagement and enhance the effectiveness of interactions within digital escape rooms, ultimately enriching the user experience and educational outcomes.

TABLE II. MEMBERSHIP FUNCTIONS

| **Logical Reasoning Level** |
|---|
| **Membership Function** |
| Novice (N) |
| $\mu_B(x) = \begin{cases} 1 & x \le 30 \\ 1 - \frac{x-30}{20} & 30 < x < 50 \\ 0 & x \ge 50 \end{cases}$ |
| Basic (B) |
| $\mu_I(x) = \begin{cases} \frac{x-30}{20} & 30 < x < 50 \\ 1 & 50 \le x \le 70 \\ 1 - \frac{x-70}{10} & 70 < x < 80 \\ 0 & x \le 30 \text{ or } x \ge 80 \end{cases}$ |
| Advanced (A) |
| $\mu_A(x) = \begin{cases} \frac{x-70}{10} & 70 < x < 80 \\ 1 & 80 \le x \le 90 \\ 1 - \frac{x-90}{5} & 90 < x < 95 \\ 0 & x \le 70 \text{ or } x \ge 95 \end{cases}$ |
| Proficient (P) |
| $\mu_E(x) = \begin{cases} \frac{x-90}{5} & 90 < x < 95 \\ 1 & 95 \le x \le 100 \\ 0 & x > 100 \end{cases}$ |

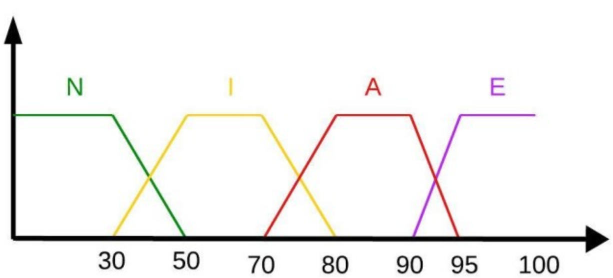


Fig. 1. Fuzzy Weights schemes.

As highlighted earlier, our current methodology utilizes membership functions to accurately represent a user's level of logical reasoning within the context of digital escape rooms. These membership functions form the foundational basis for assigning values to the fuzzy weights, which range from 0 to 1. A value of 1 for a logical reasoning level indicates a user's high proficiency and potential to excel in logical reasoning tasks encountered in digital escape rooms and associated puzzles. Accordingly, the aggregate of each segmented fuzzy set defines the overall logical reasoning level, adhering to the normalization condition: $\mu_B(x)+\mu_I(x)+\mu_A(x)+\mu_E(x)=1$.

The fuzzy weights were derived from the responses of a panel of 15 faculty members working in Greek public universities who were consulted, and each member was specializing in informatics. They were all requested to describe, in some detail, learners' logical reasoning levels for several puzzling scenarios, and for each of the three levels of logical reasoning, they defined the ranges of achievement. Taken together, these faculty members have specialized in academic environments for more than a dozen years, offering, therefore, an unmatched knowledge depth that allows close approximation of the users' logical reasoning abilities.

Further, through the inclusion of these domain experts, it will not only ensure the robustness and validity of the fuzzy weighting framework but also allow them to have confidence in the reliability and precision of the fuzzy logic model in the assessment and improvement of the logical reasoning of the users in digital escape rooms. Their contributions significantly enrich the methodology, boosting the credibility and practical applicability of the research findings. This collaborative approach not only elevates the academic rigor of our study but also ensures that the fuzzy logic-based adjustments are grounded in real-world educational principles, enhancing the educational value and engagement of digital escape rooms.

## III. DYNAMIC DIFFICULTY ADJUSTMENT

Every one of the enigmas in this developed digital escape room is designed to be part of the steps that the user will take and elaborately enhance some special digital skills that will lead him on to the ultimate goal: the acquisition of a key to unlock the door to his next challenge. The scenario is that the players begin their adventure in a virtual room filled with ancient manuscripts and modern digital interfaces scattered around. Their task is to decode hidden messages, sort through data, and unlock a digitally enhanced safe that contains the key to the next puzzle room.

One is pattern identification, whereby one is exposed to a series of ancient manuscripts and current graphical data and must find the underlying patterns that relate ancient symbols to digital encryption keys. This particular puzzle would, for the beginner, start with some very clear and distinctive patterns or anomalies, such as matching a key to the first batch of like-looking symbols right away. As the complexity of the levels increases to higher levels, the patterns turn out to be subtle and possibly multi-step in its decryption, thus the candidate is supposed to differentiate subtle differences and likenesses across datasets. It is just at this level that an individual develops these important skills in the nature of critical thinking, attention to detail, recognizing and deciphering patterns in the data, which are applicable in the disciplines of data analysis and user interface design.

Another important type of puzzle focuses on logic and sequencing. Players are given a series of locked files in the digital document drive, each one with a certain set of steps to unlock it. In the beginning levels, very clear instructions can be located within the files on how to complete the steps in a very linear sequence; for example, how to reset a password using security questions for which the answers can be readily obtained from text information displayed on the walls in the room. But then, in the more difficult of the skill levels, the sequence is cryptic and requires complex problem-solving to resolve; it might involve creating an algorithm or scripting some basic code with no guidance. This really builds logical thought, algorithmic problem-solving, and understanding procedural steps; these are important in programming and technical troubleshooting.

Cryptography and encryption puzzles are one more layer in the challenge of the room. In this category, participants will first get to solve basic substitution ciphers, which can be easily solved with the aid of a decryption tool that is available in the room. As participants progress or exhibit a level of competence, they level up and solve tougher encryption, such as transposition ciphers, or they build their key from fragmented data, which is spread across various digital platforms within the room, just as the securing of data in the real world would be. These sorts of puzzles help a lot in understanding encryption methodologies, data security principles, and cryptographic techniques that form the backbone of cybersecurity and information technology.

There are also information-sorting and retrieval-type puzzles. Participants may be given an unsorted database and then be required to filter and sort according to clearly defined, simple criteria. In harder levels, the databases become large and the information complex. The user will have to run search algorithms and perform Boolean logic to extract the information needed to access the next clue or task. They learn to develop skills needed for data management, information sorting, and data retrieval from complex databases, a core need for big-data jobs, research jobs, and administrative tech-based jobs.

The dynamic difficulty adjustment of puzzles is masterfully handled through a fuzzy-weights-based system. It classifies user skill level, ranging from novice to expert through a spectrum of ability, and matches each with certain puzzle complexities by using fuzzy weights.

For example, a user with a fuzzy weight near "Novice" would receive more direct clues to puzzles, which would have fewer complexities. More context would be given, or the techniques by which the keys are encrypted would be made simpler, until the level of maximum solvability, but without going above the frustration threshold. A user who will have his or her performance sway the fuzzy weight to "Expert" will be sent harder puzzles where minimal direction is given—more abstract thinking and less direct instructions. This user may have to crack the series by collecting them from random content over platforms or decrypt them through lesser-used techniques without any hints.

Fuzzy weights track and adapt to the difficulty level of a puzzle as the user interacts with it, based on responses to previous puzzles. For instance, if a user was classified as an Intermediate and solved an advanced logic sequence very quickly, the system would recalibrate the following puzzles to be of higher complexity just like that—the system adapts to the user's developing skills.

By adopting fuzzy weights, it is possible to develop a digital escape room that gives personalized challenges to optimally challenge the capabilities of each individual participant. This keeps interests up, challenges of the right magnitude, and enriches the educational contribution of the escape room by pushing the digital skill boundaries of each of the participants at a pace they can cope with.

## IV. Evaluation

For the purposes of our digital escape room, we developed a focused questionnaire in order to probe three important dimensions of the user experience in detail: personalization, puzzles, and user interface. Each of these dimensions focuses on particular features of the digital escape room, ensuring that we cover the entire appraisal. "Personalization": The dimension tries to evaluate how effective the escape room can adapt to different skill levels and learning paces among users. It attempts to understand how the levels of difficulty are dynamically adjusted in response to the users' interactions and if these meet the needs of each individual participant, thus assuring a constantly engaging and appropriately challenging experience. The "puzzles" dimension focuses on the design, complexity, and educational value of the presented challenges. The appraisal looks at the fit challenge of the puzzles, the ability to drive critical thinking, and usefulness for skill development. Actually, this part of user feedback identifies what puzzles are the most beneficial to the users or are not and, therefore, need to be redesigned in order to best fulfill the educational goals set before the escape room. The dimension "user interface" evaluates how intuitive, accessible, and friendly the interface of the escape room is for the user. The interest lies in the ease of navigation, clarity of the instructions, responsiveness of the interactive elements, and visual design. Therefore, this feedback is highly important as it will ensure that the users are able to interact with the escape room easily and not get frustrated.

The participant group in this evaluation consisted of 60 postgraduate students who are studying at the Department of Informatics and Computer Engineering of a public university in a postgraduate course specializing in Information Technology and Applications. This evaluation took place over a 3-month period, during which participants had a chance to visit the escape room and try it out for themselves. All subjects were asked to complete comprehensive questionnaires 3 months after their visit to the room. These focus questions per assessment dimension use a 1-10 rating scale for the quantification of feedback. The general feedback along with the detailed results is depicted in a structured way in Table III.

TABLE III. Evaluation questions.

| Dimension | Question |
| --- | --- |

| | |
|---|---|
| Personalization | Q1. How well did the escape room adapt to your skill level throughout the experience? |
| Puzzles | Q2. Were the puzzles in the escape room appropriately challenging and engaging? |
| User experience | Q3. How intuitive and user-friendly did you find the user interface of the digital escape room? |

The responses to the questions detailed in Table 1 are illustrated in Fig. 2.

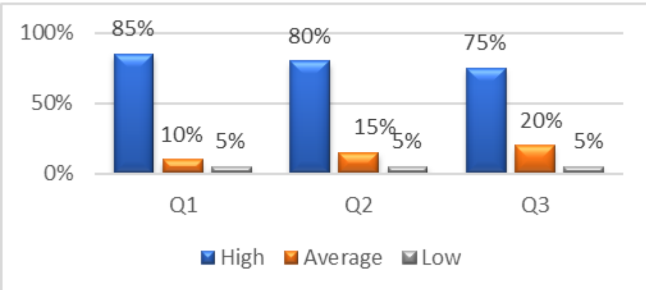


Fig. 2. Questionnaire results.

After analyzing the results of this assessment, it can be judged that the digital escape room was quite successful in enhancing the digital skills of its users. This is majorly done by enabling the way in which the difficulty level of a puzzle can be adjusted on a dynamic basis that is based on the power of logical reasoning of the users, mediated by the fuzzy weights applied. An integrated approach like this, in the context of the digital escape room, fully conforms to and serves the key dimensions taken from the questionnaire:

- Personalization: The system can use fuzzy weights to fine-tune puzzle challenge on the fly to make sure the level of the challenge faced by a user is well-optimized in regard to his or her logical reasoning potential.
- Puzzle Design: By dynamically adapting to the puzzles, the system sustains user engagement but at the same time maximizes educational outcomes because users are constantly pushed to apply and expand their digital problem-solving skills within an appropriate context.
- User Interface: Fuzzy weights adaptiveness enhances the user experience with the interface. This makes users feel that their system is responsive to their interactions and progressing, thus reducing their frustration and significantly improving the overall usability and satisfaction.

These dimensions work together to make the efficacy of the digital escape room very strong from the educational and engagement perspective, thereby only serving to showcase its utility as a powerful tool for the purpose of skill development.

In order to gain a better understanding and assess the efficacy of using fuzzy weights inside the digital escape room, a t-test was conducted. The performance results of the digitally enriched escape room were compared against a conventional escape room in this analytical test. The conventional escape room was designed to simulate the user interface and puzzle environment of the digital room without its adaptive difficulty function. It offered the users a set of puzzle problems that were incrementally increasing in difficulty.

Group A represents the experimental group; it is made up of 60 students who interact with the electronic escape room with adaptive and adjustable difficulty, developed with the use of fuzzy weights. Then there is the other group called Group B, also having 60 students, that is the control group interacting with the traditional version of the escape room. The two groups could then be matched, compared and contrasted in terms of demographic and academic characteristics in a controlled fashion.

The main objective of this testing was to probe the effectiveness of the higher-level technological integration of the system, in this case fuzzy weights. The responses to Question 1 were formulated for the very purpose of specifically measuring the effectiveness of dynamic difficulty adjustments in improving digital skills. For this, a t-test was run. The findings of this comparative analysis are elaborated in detail in Table IV, targeting to statistically establish the effect of personalizing puzzle difficulty on learning outcomes.

TABLE IV. T-TEST RESULTS.

| Metric | Question 3 | |
|---|---|---|
| | Group A | Group B |
| Mean | 4,05 | 3 |
| Variance | 0,861864 | 0,576271 |
| Observations | 60 | 60 |
| Pooled Variance | 0,719068 | |
| Hypothesized Mean Difference | 0 | |
| df | 118 | |
| t Stat | 6,782113 | |
| P(T<=t) one-tail | 2,49E-10 | |
| t Critical one-tail | 1,65787 | |
| P(T<=t) two-tail | 4,99E-10 | |
| t Critical two-tail | 1,980272 | |

As shown in the data in Table 2, there is a statistically significant difference in the average score for the first question for both groups. This difference highly indicates that the digital escape room, including the dynamic difficulty adaptation with fuzzy weights, is much better than the traditional one. In general, the whole credit for the system's sophistication goes to the fact that it has developed a dynamic procedure in puzzle difficulty adaptation that efficiently applies the level of challenge to fit a user's various skills.

So, the expected results from the study were due to the fact that this digital escape room entailed an intelligent adaptive mechanism. So finely does the puzzle tune the difficulty with the fuzzy weights in the way that it does, meaning the system becomes in tune with the different abilities each user has. Being personalized is so important because it allows users to constantly operate at the edge of their competency, which maximizes skill acquisition and engagement.

The introduction of fuzzy weights in the construction of the escape room shall augment the degree of customer experience in terms of a personalized challenge and greatly improve the exercise of digital skills. This is configured in a manner such that users are not overwhelmed by too much difficulty but are stimulated by not being adequately impressed by too-easy tasks, so that an optimal learning environment is created within which digital skills can be learnt and then trained with respect to the logical reasoning capabilities of every individual.

## V. Conclusions

In fact, there has been increasing attention in digital escape rooms as a potent mechanism for building digital skills in users. This paper outlines the concept design of an advanced mechanism for dynamically matching puzzle difficulty using fuzzy weights to categorize puzzles into five groups to be used in this innovative integration of adaptive technology in educational gaming.

Such an evaluation of this adaptive learning environment is quite promising for its effectiveness in personalization, puzzle complexity, and user interface design. It is really useful to implement fuzzy weights to try to fine-tune the challenges in real time according to logical reasoning skills for each participant, thus making learning optimized and engagement levels optimal at all times.

The positive findings from the study make personalization invaluable within this digital educational tool, and similar adaptive strategies of this nature could work well for different educational situations. This approach not only supports users in developing a given digital skill but also enhances their overall problem-solving ability in a digital environment.

We plan on extending the use of the technology to different educational content in the future and going deeper into the integration with AI to provide better adaptability and intelligence in the system. Further, we aim at fine-tuning the fuzzy weighting system for the incorporation of more granular adjustments based on a wider array of cognitive and learning styles, making the system even more responsive and effective.

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