Optimizing Player Engagement in an Educational Virtual Game through Fuzzy Logic-based Challenge Adaptation

Akrivi Krouska, Christos Troussas, Yorghos Voutos, Phivos Mylonas, Cleo Sgouropoulou
Department of Informatics and Computer Engineering
University of West Attica
Egaleo, Greece
{akrouska, ctrouss, gvoutos, mylonasf, csgouro}@uniwa.gr

***Abstract*—Adaptive virtual learning environments provide an ideal foundation for enhancing personalized learning experience. Moreover, the incorporation of game elements enhances motivation levels, further enhancing the potential for improving learning outcomes. This paper explores the integration of fuzzy logic as a dynamic adaptivity tool in virtual educational games. By employing user-specific characteristics as input, including student progress, gaming time, and knowledge, the output of the fuzzy logic system represents the challenging level presented to the player in the educational game. Then, a set of rules is applied to tailor the complexity and pacing of challenges presented to learners. This adaptation extends to virtual character behavior, the learning path, and task complexity, aligning with learning objectives and proficiency levels. The study presents a practical implementation of this fuzzy logic-driven adaptivity mechanism in a virtual game environment designed for C++ programming education. The virtual game has been evaluated and the results of the evaluation showcase the potential of this approach in enhancing the learning process by tailoring the environment to learners' specific needs and preferences.**

Keywords—virtual games, puzzle-based learning, intelligent tutoring system, adaptivity, personalization, fuzzy logic, game difficulty, virtual environment, game-based learning, programming education, adaptive virtual learning environments

I. INTRODUCTION

Virtual games have primarily focused on entertainment purposes, but during the last decades they have been powerful tools for educational reasons as well [1]. Due to their inherent nature holding immersive and interactive characteristics, they provide an engaging environment for the learners and can support knowledge acquisition [2]. Indeed, the merging of education and entertainment has provoked the interest of many researchers as a means to revolutionize traditional teaching approaches. Needless to say, virtual games align with other technological approaches, such as social media, to provide innovative avenues for enhancing and modernizing education.

The blending of entertainment and education in virtual games environments is a task that hinders compelling opportunities or even obstacles [3]. Education does not simply involve the delivery of information to learners; its main objective is to create a fertile ground for learners to comprehend this information and at the same time to be motivated to learn. On the other hand, entertainment has the ability to engage users and as such it can help towards the creation of captivating learning environments. By combining elements of entertainment, virtual games can be used for education as platforms where learning is an enjoyable and immersive experience.

Due to the different background of users of virtual games, it is of great importance to adapt these environments to their learning needs and interests [4]. Adaptivity techniques stem from the field of artificial intelligence (AI) and are used to provide a personalized environment for the learners to support their evolving preferences. Adaptability is crucial to enhancing engagement and offer a challenging environment to learners that is tailored to their abilities.

There are several AI techniques that can offer adaptation to learning environments. Machine learning techniques, such as artificial neural networks or decision trees, are considered valuable tools for promoting adaptation in learning technology systems. These techniques have the ability to analyze a large pool of data towards identifying patterns among them and subsequently tailor their environment to the learners. Furthermore, reinforcement learning has also been utilized in ameliorating the learning experience in a personalized way. One other technique is fuzzy logic [5]. Despite the numerous adaptation techniques at our disposal, fuzzy logic remains unquestionably a standout choice. Fuzzy logic is a branch of artificial intelligence which is responsible for handling uncertain situations. Indeed, it can model the complexity of several characteristics, including the ones of users, and offer a sophisticated tool for decision making. Fuzzy logic is based on the concept of fuzzy sets, which allows for the representation of linguistic variables as well as gradual transitions between different states rather than strict binary distinctions.

Analyzing the related literature, it can be inferred that adaptivity plays a crucial role in building personalized learning environments. The same also applies in virtual educational environments, where researchers have explored various ways to tailor the learning experience to learners based on their requirements and preferences [6-15]. In more detail, in these works, the researchers have focused on enhancing the engagement, motivation and the learning outcomes through adaptivity. Moreover, within the concept of adaptivity, fuzzy logic has been utilized as a powerful tool for its advancement. Indeed, the researchers have employed fuzzy logic for representing and managing variables like student preferences, cognitive load and emotional states, allowing for a nuanced adaptation of content and challenges to optimize the learning process [16-25].

In view of the above, this paper presents a novel adaptivity mechanism for tailoring the challenges presented to users in a virtual educational game. To achieve this, the proposed system uses a fuzzy control system to personalize an educational virtual game by adjusting content, challenges, and virtual character behavior. This system considers inputs like student progress, gaming time, and knowledge to maintain an engaging and adaptive learning experience. The fuzzy control system predicts the game's challenge level, ensuring tasks align with the player's abilities to maintain motivation. Then, several fuzzy rules are applied to provide the key concepts for challenges that will be delivered to users. This adaptation extends to the behavior of virtual characters, the learning path, and the complexity of puzzles and tasks, all designed to align with learning objectives and the students' proficiency level. As a testbed for our research, the virtual game is designed with a focus on facilitating the learning of C++ programming concepts, covering a spectrum from novice to more advanced topics.

II. Fuzzy-based Detection of Challenging Level

The proposed system provides an innovative way of adapting to student profile using a fuzzy control system. In particular, the developed educational virtual game adjusts its content and challenges to match the individual needs and progress of each student. This feature is a crucial for enhancing the effectiveness of the game by making learning more engaging, personalized, and efficient.

The fuzzy control system is applied to predict the level of challenge in the game. This parameter represents how demanding the game's tasks, puzzles, problems, or challenges are for the player to complete or solve. It encourages the player to stay engaged and motivated to overcome obstacles and learn new concepts. As such, game difficulty matches the player's abilities, resulting in an enjoyable and productive learning experience. Based on the challenging level, the developed game adjusts the following:

- The behavior of the virtual characters, included in the game environment. The virtual characters either facilitates or complicates the navigation of students, by helping guide students or generating obstacles, respectively.
- The learning path, by providing personalized content and advancing the plot according to player profile.
- The puzzles and tasks needed to be solved, ensuring that they are aligned with the learning objectives and match student current level of proficiency.

The fuzzy control system is composed of three primary components: the fuzzification module, the inference engine, and the defuzzification module. In the fuzzification phase, it takes the input crisp set and transforms it into a fuzzy set using triangular membership functions. Afterwards, the inference mechanism computes fuzzy outputs by applying the Mamdani method to combine the active rules of the IF-THEN rule base, consisted of 81 statements. Finally, the defuzzification module applies the Center of Gravity (COG) technique to translate the resultant fuzzy output into a crisp value based on triangular membership functions. Fig. 1 illustrates the architecture of the fuzzy control system employed.

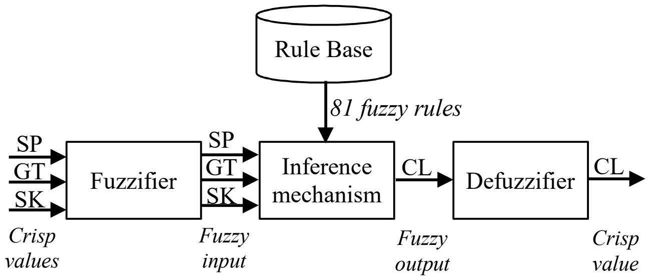

Fig. 1. Architecture of the fuzzy control system

The input set of the fuzzy model includes the following:

- Student progress (SP): It refers to the ratio of the completed puzzles, tasks and missions to the total ones required from the game.
- Gaming time (GT): It is about the ratio of time the student has spent playing to the set timeframe.
- Student knowledge (SK): It concerns the knowledge acquisition measured by the scores achieved in the quizzes and assessments within the game.

The output of the fuzzy model is the following:

- Challenging level (CL): It refers to the degree of difficulty or complexity presented to the player while engaging with the game's educational content.

All the variables are arithmetical values converting into fuzzy ones based on triangular membership functions. Table 1 shows the fuzzy input and output set. For instance, the equations of the membership functions of student progress are the following:

$$\mu_{LSP}(x) = \begin{cases} 0, & x \leq 0 \\ \frac{x}{0.2}, & 0 \leq x \leq 0.2 \\ \frac{0.4-x}{0.2}, & 0.2 \leq x \leq 0.4 \\ 0, & x \geq 0.4 \end{cases}$$

$$\mu_{ISP}(x) = \begin{cases} 0, & x \leq 0.3 \\ \frac{x-0.3}{0.2}, & 0.3 \leq x \leq 0.5 \\ \frac{0.7-x}{0.2}, & 0.5 \leq x \leq 0.7 \\ 0, & x \geq 0.7 \end{cases}$$

$$\mu_{ASP}(\mathrm{x}) = \begin{cases} 0, & \mathrm{x} \leq 0.6 \\ \frac{\mathrm{x}-0.6}{0.2}, & 0.6 \leq \mathrm{x} \leq 0.8 \\ \frac{1-\mathrm{x}}{0.2}, & 0.8 \leq \mathrm{x} \leq 1 \\ 0, & \mathrm{x} \geq 1 \end{cases}$$

Fig. 2 illustrates the scheme of above membership functions. All the other variables are represented correspondingly.

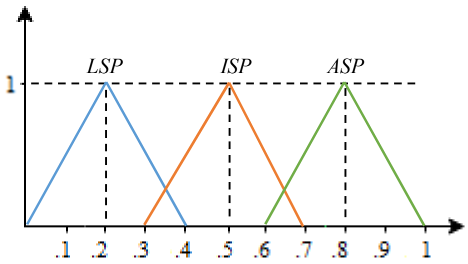

Fig. 2. Scheme of triangular membership functions of Student Progress variable (LSP: Low Student Progress; ISP: Intermediate Student Progress; ASP: Advanced Student Progress)

TABLE I. FUZZY INPUT AND OUTPUT SET OF DETECTING CHALLEGING LEVEL

Variable	Linguistic Term	Symbol	Interval
Input Set			
Student Progress (SP)	Low	LSP	(0, 0.2, 0.4)
	Intermediate	ISP	(0.3, 0.5, 0.7)
	Advanced	ASP	(0.6, 0.8, 1)
Gaming Time (GT)	Start	SGT	(0, 0.2, 0.4)
	Middle	MGT	(0.3, 0.5, 0.7)
	End	EGT	(0.6, 0.8, 1)
Student Knowledge (SK)	Novice	NSK	(0, 0.2, 0.4)
	Intermediate	ISK	(0.3, 0.5, 0.7)
	Advanced	ASK	(0.6, 0.8, 1)
Output Set			
Challenging Level (CL)	Easy	ECL	(0, 0.2, 0.4)
	Intermediate	ICL	(0.3, 0.5, 0.7)
	Difficult	DCL	(0.6, 0.8, 1)

Regarding the rule base, the formulation of the 81 IF-THEN statements was based on the authors' experience in implementing fuzzy control systems [5, 16, 20], as well as educational games [4, 26]. The rationale behind the construction of these statements is that the more easily and fast a good student solves the game's puzzles/tasks/missions, the more complex the challenges provided to them are. On the other hand, the more a student with low cognitive level finds it difficult and delay to solve the puzzles/tasks/missions, the easier and more supportive the environment becomes. A sample of the defined fuzzy rules is the following:

- **IF** SP = LSP *and* GT = SGT *and* SK = NSK **THEN** CL = ECL
- **IF** SP = LSP *and* GT = SGT *and* SK = ASK **THEN** CL = ICL
- **IF** SP = ISP *and* GT = MGT *and* SK = LSK **THEN** CL = ICL
- **IF** SP = ISP *and* GT = SGT *and* SK = ASK **THEN** CL = DCL
- **IF** SP = ASP *and* GT = EGT *and* SK = ISK **THEN** CL = ICL
- **IF** SP = ASP *and* GT = MGT *and* SK = ISK **THEN** CL = DCL

The scope of the fuzzy rules is to predict the challenging lever properly for adjusting game difficulty dynamically. Therefore, if a student is finding the game too easy, the system can introduce more challenging obstacles and puzzles to keep student experience engaging. Conversely, if the student is struggling, the game simplify tasks and provide additional guidance. To better clarify the functionality of this inference, an example of operation is given. In this case, a student, named Mary, is a very good student (SK = ASK). While she is playing, she solves very fast the puzzles of the game (SP = ISP, GT = SGT). As such, the system provides her more complex challenges to match her needs and abilities (CL = DCL), maintaining her motivation and engagement.

III. SYSTEM EVALUATION AND DISCUSSION

Evaluating educational virtual games is crucial to assess their effectiveness in promoting learning outcomes and engaging students. As such, an evaluation model for assessing the presented system was developed based on the pertinent literature [16]. The model considers four aspects of the game's effectiveness:

- Game engagement and experience, to analyze the game's ability to engage and motivate students.
- Educational effectiveness, to ensure the game meets learning objectives and enhances students' understanding of the subject matter.
- Usability, to ensure the game is user-friendly and effective learning tools.
- User satisfaction, to understand how well the game meets the needs and expectations of learners.

In order to evaluate model's aspects, a questionnaire consists of 12 questions was conducted, namely three question items per aspect. The survey uses a 5-point Likert scale, ranging from "Very Dissatisfying" to "Very Satisfying", to measure respondents' opinion and attitude. Table II shows the questionnaire used for assessing the developed system.

The survey was conducted among 40 university students, namely 22 males and 18 females, having similar characteristics. In particular, all students study at the same class in the same University, being in average 18-22 years old. Prior to using the educational virtual game, students received instructions on its usage and information regarding its features and functionalities. It was noted that students quickly acclimated to the system's usage. Throughout their interaction with the system, they displayed a strong affinity for it and devoted a significant amount of time to using it daily.

TABLE II. EDUCATIONAL VIRTUAL GAME EVALUATION QUESTIONNAIRE

Aspects	#	Question Item
Game Engagement and Experience	1	How would you rate the overall enjoyment and engagement level of the game?
	2	Did the game motivate you to continue playing and learning?
	3	To which degree the challenging level of the game met your expectations?
Educational Effectiveness	4	Do you believe that this game has helped you improve your knowledge and skills in the subject it covers?
	5	Do you think the game aligns with the educational objectives or learning goals it aims to address?

	6	Have you noticed any improvements in your problem-solving or critical thinking abilities as a result of playing this game?
Usability	7	How would you rate the ease of use and navigation of the game's interface?
	8	Were the game instructions clear and understandable?
	9	Were the game controls intuitive and responsive?
User Satisfaction	10	How satisfied were you with the game's overall experience?
	11	Were the educational content and challenges in the game relevant to your needs and skill level?
	12	Based on your experience, would you recommend this game to other learners?

The evaluation results are illustrated in Fig. 3 and Fig. 4. The results in Fig. 4 are aggregated into three categories, namely high acceptance emerged from the average percentage of "Satisfying" and "Very Satisfying" answers of the questions belonging to each aspect, average acceptance calculating correspondingly from "Neutral" answers, and low acceptance resulted respectively from "Dissatisfying" and "Very Dissatisfying" answers.

As it is observed, the students expressed their strong acceptance of the system in all evaluation aspects. Regarding the game engagement and experience aspect, the vast majority of the students found the game experience very enjoyable and engaging, with the satisfaction level exceeding 80%. Moreover, it seems that the game motivated them to continue playing and being involved in the learning process (up to 80% the "Satisfying" and "Very Satisfying" answers). More than 80% of the students stated that the challenging level of the game met their expectations.

Concerning the educational effectiveness of the game, the 77.5% of the participants believe that the game helped them improve their knowledge and skills in programming subject. Also, the same percentage found the game consistent with the learning objectives. The 72.5% of the students was satisfied with the extent to which playing the game has helped them improve their problem-solving and critical thinking abilities.

The usability of the system was rated highly, with satisfying level around 80%. The students found the game's interface ease of use, as well as its instructions clear and understandable. Moreover, it seems they did not face technical problems while playing the game, since they found its controls intuitive and responsive.

Regarding user satisfaction, the vast majority of the participants (more than 80%) were immensely satisfied with the overall game experience, having the intention to recommend it to other students. Furthermore, the survey shows that the educational content and the challenging level provided by the game were relevant to players' needs and abilities.

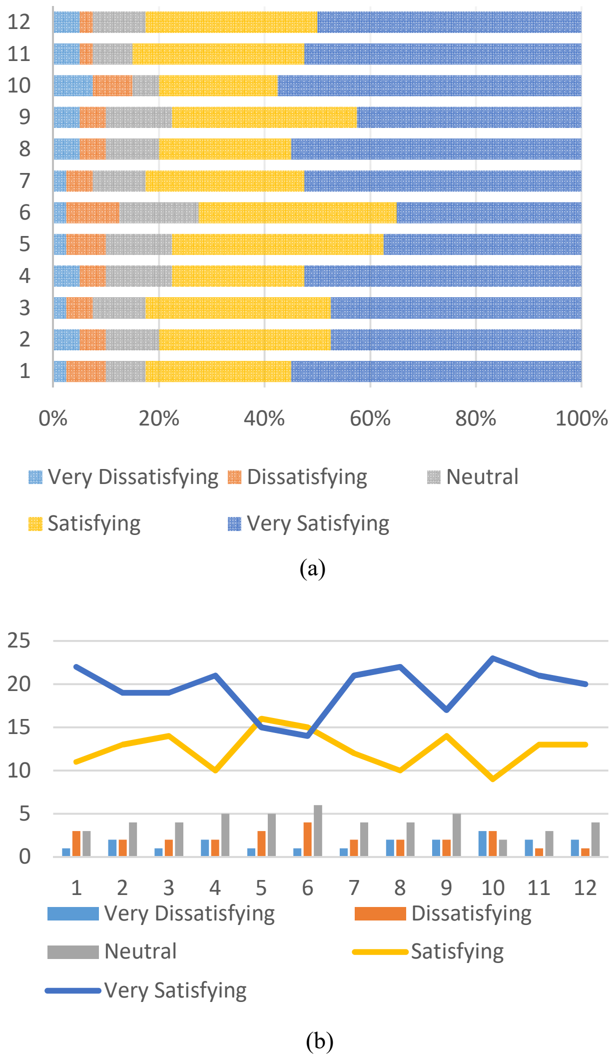

Fig. 3. Evaluation results.

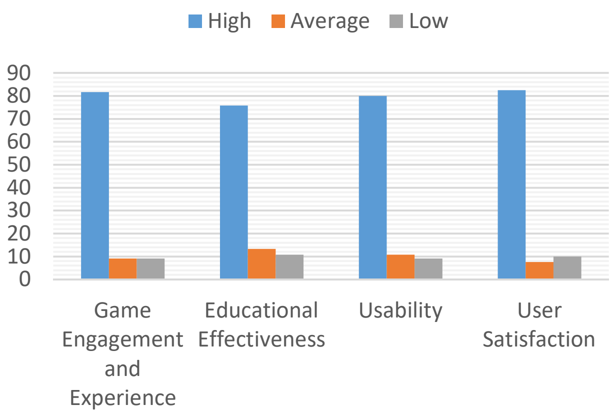

Fig. 4. Aggregated evaluation results.

In order to further assess the educational affordance of the virtual game, a pre-test/post-test evaluation design without a control group was conducted. Students completed a knowledge assessment before the learning process using the game and after the end of the intervention. The test scores ranged from 1 to 100. On average, there was a statistically significant increase in students' performance on the assessment after completing the intervention, having Mean

Difference = 19.28, Standard Deviation = 11.45, t = 7.965, p < 0.01, 95% Confidence Interval [15.31, 23.25]. This improvement can be described as substantial (Cohen's d = 1.58).

To sum up, the positive evaluation results of the educational virtual game are indeed encouraging for adopting this technology in learning process. As it shown, the game has effectively met its educational objectives. Students, after engaging with the game, demonstrated significant improvements in their knowledge and skills. The game's content was not only engaging but also aligned with the curriculum, ensuring its relevance to the educational goals. Furthermore, the interactive elements and clear instructions within the game contributed to a positive learning experience. These positive evaluation results affirm the game's value as an effective educational tool, demonstrating its potential to enhance the learning experience of students.

IV. Conclusions

In conclusion, this paper has explored the integration of fuzzy logic in order to enhance the learning experience and outcomes of users, learning C++ programming concepts. The system takes as input several characteristics (SP, GT, SK) and applies a set of rules to adjust the complexity and pacing of challenges. The system has been evaluated and the results are very promising in terms of game engagement and experience, educational effectiveness, usability and user satisfaction.

It is in our future plans to further refine the fuzzy logic-based adaptivity mechanism in order to explore whether it enhances its precision and effectiveness. Moreover, we plan to extend the evaluation by incorporating statistical analysis methods such as the student's t-test. This will allow us to gain a more comprehensive understanding of the impact and effectiveness of the presented mechanism in our educational game environment.

Acknowledgment

This research was funded by the European Union and Greece (Partnership Agreement for the Development Framework 2014-2020) under the Regional Operational Programme Ionian Islands 2014-2020, project title: "Indirect costs for project "TRaditional corfU Music PresErvation through digiTal innovation" ", project number: 5030952.

References

[1] G. Chen, X. Xie, Z. Yang, R. Deng, K. Huang and C. Wang, "Development of a Virtual Reality Game for Cultural Heritage Education: The Voyage of "Gotheborg"," 2023 9th International Conference on Virtual Reality (ICVR), Xianyang, China, 2023, pp. 531-535, doi: 10.1109/ICVR57957.2023.10169671.

[2] A. Marougkas, C. Troussas, A. Krouska, C. Sgouropoulou, "A Framework for Personalized Fully Immersive Virtual Reality Learning Environments with Gamified Design in Education", Novelties in Intelligent Digital Systems: Proceedings of the 1st International Conference (NIDS 2021), Athens, Greece, IOS Press, vol. 338, pp. 95-104, 2021, doi:10.3233/FAIA210080.

[3] R. Karunakaran and S. S, "Quantifying the New Media Literacy of Rural People: An Online Video Entertainment Perspective," 2022 Interdisciplinary Research in Technology and Management (IRTM), Kolkata, India, 2022, pp. 1-5, doi: 10.1109/IRTM54583.2022.9791650.

[4] A. Marougkas, C. Troussas, A. Krouska, C. Sgouropoulou, "How personalized and effective is immersive virtual reality in education? A systematic literature review for the last decade", Multimedia Tools and Applications, 2023, https://doi.org/10.1007/s11042-023-15986-7

[5] A. Krouska, C. Troussas, C. Sgouropoulou, "Fuzzy Logic for Refining the Evaluation of Learners' Performance in Online Engineering Education", European Journal of Engineering and Technology Research, vol. 4, no. 6, 2019, pp. 50–56, doi: https://doi.org/10.24018/ejeng.2019.4.6.1369.

[6] A. Alam, S. Ullah and N. Ali, "The Effect of Learning-Based Adaptivity on Students' Performance in 3D-Virtual Learning Environments," in IEEE Access, vol. 6, pp. 3400-3407, 2018, doi: 10.1109/ACCESS.2017.2783951.

[7] S. Meacham, V. Pech and D. Nauck, "AdaptiveVLE: An Integrated Framework for Personalized Online Education Using MPS JetBrains Domain-Specific Modeling Environment," in IEEE Access, vol. 8, pp. 184621-184632, 2020, doi: 10.1109/ACCESS.2020.3029888.

[8] M. A. Akour and A. Das, "Developing a Virtual Smart Total Learning Environment for Future Teaching-Learning System," 2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE), Takamatsu, Japan, 2020, pp. 576-579, doi: 10.1109/TALE48869.2020.9368373.

[9] H. Singh, K. V. S. Praveena, M. Raja, Nikhilesh, T. Kumar and K. Tongkachok, "Adaptive 3D and VFX Films Virtual Learning Environments," 2022 5th International Conference on Contemporary Computing and Informatics (IC3I), Uttar Pradesh, India, 2022, pp. 1129-1134, doi: 10.1109/IC3I56241.2022.10073177.

[10] A. Prakash, "[DC] Investigating student's learning processes in a Virtual Reality learning environment by analyzing their interaction behavior," 2023 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), Shanghai, China, 2023, pp. 995-996, doi: 10.1109/VRW58643.2023.00340.

[11] M. Momenzad, B. Majidi and M. Eshghi, "Deep Summarization of Academic Textbooks for Adaptive Gamified Virtual Learning Environments," 2018 2nd National and 1st International Digital Games Research Conference: Trends, Technologies, and Applications (DGRC), Tehran, Iran, 2018, pp. 88-94, doi: 10.1109/DGRC.2018.8712065.

[12] B. N. Ncube, P. A. Owolawi and T. Mapayi, "Adaptive Virtual Learning System Using Raspberry-Pi," 2020 International Conference on Artificial Intelligence, Big Data, Computing and Data Communication Systems (icABCD), Durban, South Africa, 2020, pp. 1-5, doi: 10.1109/icABCD49160.2020.9183844.

[13] E. Cibuļska and K. Boločko, "Virtual Reality In Education: Structural Design Of An Adaptable Virtual Reality System," 2022 6th International Conference on Computer, Software and Modeling (ICCSM), Rome, Italy, 2022, pp. 76-79, doi: 10.1109/ICCSM57214.2022.00020.

[14] Z. Liu, M. Fan and B. Wang, "Discussion on the Basic Model of Intelligent Technology to Enable the Transformation of Learning Methods," 2022 International Symposium on Educational Technology (ISET), Hong Kong, Hong Kong, 2022, pp. 123-125, doi: 10.1109/ISET55194.2022.00033.

[15] A. Prakash, D. S. Shaikh and R. Rajendran, "Investigating Interaction Behaviors of Learners in VR Learning Environment," 2023 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), Shanghai, China, 2023, pp. 931-932, doi: 10.1109/VRW58643.2023.00308.

[16] C. Troussas, A. Krouska, C. Sgouropoulou, "Dynamic Detection of Learning Modalities Using Fuzzy Logic in Students' Interaction Activities", V. Kumar, C. Troussas, Intelligent Tutoring Systems. ITS 2020. Lecture Notes in Computer Science, Springer, Cham, col. 12149, 2020. https://doi.org/10.1007/978-3-030-49663-0_24

[17] K. Kulagin, M. Salikhov and R. Burnashev, "Designing an Educational Intelligent System with Natural Language Processing Based on Fuzzy Logic," 2023 International Russian Smart Industry Conference (SmartIndustryCon), Sochi, Russian Federation, 2023, pp. 690-694, doi: 10.1109/SmartIndustryCon57312.2023.10110734.

[18] A. Bhardwaj, H. Tyagi and C. Dubey, "Evaluation of Student Performance Using Fuzzy Logic," 2021 3rd International Conference on Advances in Computing, Communication Control and Networking (ICAC3N), Greater Noida, India, 2021, pp. 895-897, doi: 10.1109/ICAC3N53548.2021.9725495.

[19] M. Dhokare, S. Teje, S. Jambukar and V. Wangikar, "Evaluation of Academic Performance of Students Using Fuzzy Logic," 2021 International Conference on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA), Coimbatore, India, 2021, pp. 1-5, doi: 10.1109/ICAECA52838.2021.9675557.

[20] C. Papakostas, C. Troussas, A. Krouska, C. Sgouropoulou, “Modeling the Knowledge of Users in an Augmented Reality-Based Learning Environment Using Fuzzy Logic”. A. Krouska, C. Troussas, J. Caro (eds), Novel & Intelligent Digital Systems: Proceedings of the 2nd International Conference (NiDS 2022). NiDS 2022. Lecture Notes in Networks and Systems, Springer, Cham, vol. 556, 2023. https://doi.org/10.1007/978-3-031-17601-2_12

[21] M. Gupta, R. Kumar, A. Arora and J. Kaur, "Fuzzy logic-based Student Placement Evaluation and Analysis," 2022 4th International Conference on Advances in Computing, Communication Control and Networking (ICAC3N), Greater Noida, India, 2022, pp. 1503-1507, doi: 10.1109/ICAC3N56670.2022.10074547.

[22] L. Anifah, E. Sulistiyo, M. S. Zuhrie, F. Achmad, Y. S. Nugroho and S. Schulte, "Decision Support System of Student Learning Outcomes Assessment on Digital Electronic Subject using Fuzzy Logic," 2021 Fourth International Conference on Vocational Education and Electrical Engineering (ICVEE), Surabaya, Indonesia, 2021, pp. 1-6, doi: 10.1109/ICVEE54186.2021.9649735.

[23] A. Rachmawati, S. M. Susiki and E. M. Yuniarno, "Implementation Of Fuzzy Logic For Determining The Level Score Historical Character Recognition Puzzle Educational Game," 2022 International Seminar on Intelligent Technology and Its Applications (ISITIA), Surabaya, Indonesia, 2022, pp. 232-237, doi: 10.1109/ISITIA56226.2022.9855377.

[24] C. Troussas, A. Krouska, P. Mylonas and C. Sgouropoulou, "Personalized Learner Assistance Through Dynamic Adaptation of Chatbot Using Fuzzy Logic Knowledge Modeling," 2023 18th International Workshop on Semantic and Social Media Adaptation & Personalization (SMAP)18th International Workshop on Semantic and Social Media Adaptation & Personalization (SMAP 2023), Limassol, Cyprus, 2023, pp. 1-5, doi: 10.1109/SMAP59435.2023.10255169.

[25] M. S. Ivanova, "Fuzzy Set Theory and Fuzzy Logic for Activities Automation in Engineering Education," 2019 IEEE XXVIII International Scientific Conference Electronics (ET), Sozopol, Bulgaria, 2019, pp. 1-4, doi: 10.1109/ET.2019.8878622.

[26] C. Papakostas, C. Troussas, A. Krouska, and C. Sgouropoulou, “Personalization of the Learning Path within an Augmented Reality Spatial Ability Training Application Based on Fuzzy Weights,” *Sensors*, vol. 22, no. 18, p. 7059, Sep. 2022, doi: 10.3390/s22187059.