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Smart Differentiation System using Self-Adaptive Ensemble-based Differential Evolution (SAEDE) as a Learning Aid for Learning Differentiation

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Abstract

Future workforce skills are dominated by a good understanding of technology and engineering, and problem-solving skills. Therefore, the importance of science, technology, engineering, mathematics (STEM) education is globally recognized. Among the STEM-related subjects, mathematics is known as a challenging subject. Mathematics learning during pandemic Covid 19 becomes more challenging when students are encouraged to self-learn at home. An appropriate combination of pedagogy and technology such as artificial intelligence (AI) will benefit mathematical learning. Therefore, this study is to investigate the effectiveness of an AI-based learning aid for a mathematics topic, which is differentiation. An artificial intelligence-based learning aid known as the “Smart Differentiation System” or known as SDS in short, is developed to allow students to cross-check differentiation solutions in solving differential equations. An AI technique called Self-Adaptive Ensemble Based Differential Evolution (SAEDE) is integrated into the development of the Smart Differentiation System. Smart Differentiation System is developed based on the Agile model. A multiple-choice questionnaire is used to collect data from the target group of respondents regarding their problems in learning mathematics and feedback about the Smart Differentiation System. Based on the results, 86.7% of the respondents agreed that the use of Smart Differentiation System as a learning aid in the classroom is more fun and exciting and 80% agreed that Smart Differentiation System is acceptable and can be used by secondary school students in learning mathematics. In conclusion, the learning aid has determined the effectiveness of the AI-based learning aid especially in helping students to perform self-learning in mathematics.

Keywords: Artificial intelligence-based learning aid, differential evolution, self-adaptive ensemble-based differential evolution

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INTRODUCTION

Over the last twenty-five years, the field of Artificial Intelligence in Education (AIED) is experiencing significant development. Research has shown that AI and adaptive learning technologies are prominently featured in the development of educational tools and systems. (Educause, 2018). However, the use of AI-based tools and systems in education is still a young field. To actively engage students in mathematical practice especially during self-learning sessions, a learning aid that allows students to cross-check the mathematical solutions on their own is needed. An AI-based learning aid known as Smart Differentiation System based on Differential Evolution (SDSDE) is developed to cross-check solutions of differential equations. An AI technique known as Self-Adaptive Ensemble Based Differential Evolution (SAEDE) is integrated into the development of SDSDE. In this way, SDSDE will support students to self-learn differentiation. The use of SDSDE requires students to write source codes of differential equations in the system. Since students need to understand the given differential equation and produce the source codes for the equation in SDS, students have the opportunity to practice mathematical and computational thinking at the same time in solving the problem.

LITERATURE REVIEW

Artificial Intelligence-based Learning Aid

According to Educause (2019), AI applications related to teaching and learning are projected to increase even more significantly. Montebello (2017) has stated that AI can help improve learning opportunities for students and management systems. Contact North, a major Canadian non-profit online learning society, concludes that "there is little doubt that the [AI] technology is inexorably linked to the future of higher education" (Contact North, 2018). Besides, AI in education provides adaptive support (Gilbert et al., 2015), address student learning styles (Dorca, 2015), or provides culturally appropriate communication (Blanchard, 2015). The Department of Education's STEM 2026 vision states that intelligent tutoring systems, the primary AI-based educational tools currently, "may play a key role in the future of education" (Tanenbaum 2016). Using AI in education (AIED) has created new opportunities for designing productive learning activities and developing better technology-enhanced learning applications or environments (Gwojen, H et al., 2020). According to Schiff, D (2021), AI is important to educational fields such as educational data mining (Romero and Ventura 2010) and computer-supported collaborative learning (Dillenbourg et al. 2009). AI can drive efficiency, personalization and streamline admin tasks to allow teachers the time and freedom to provide understanding and adaptability (Kengam, J, 2020).

In Malaysia, the use of AI is no exception especially for the benefit of children in ensuring their future careers and avoiding mismatching of skills and talents. Muhamad Fazil Ahmad and Wan Rohila Ganti Wan Abdul Ghapar (2019) stated that AI in the education sector can interact, assist, and guide students through Self-Exploration Education (SEE) in Self Determined Learning (SDL). According to former Minister of Education, Dr. Mazlee (Malay Mail, 2019), "AI needs to be implemented in schools to facilitate students and teachers in digital-making activities, to provide training for teachers and bring awareness to the children on the importance of mastering digital tools". At school, Design and Technology subjects related to AI or known as Reka Bentuk Teknologi (RBT) in Malay, computer programming and robotics have been introduced to create a critical, creative and innovative human capital. For this reason, teachers must be able to acquire some kind of knowledge from the area of AI behavioral science to become competent observers and evaluators of such intelligent learning environments (Flogie, A & Abersek, B, 2021).

Differential Evolution

Differential Evolution (DE) was introduced as a vector population-based stochastic optimization method (Storn, R, & Price, K, 1995). DE equation is chosen as the mathematical topic for the development of AI-based learning aid owing to its relevance to optimizing decision-making and problem-solving in real-world situations. DE is used to find approximate solutions in solving problems. Greco, R and Vanzi, I, (2019) stated that DE is used because of a "parameters-less" algorithm especially in solving optimization problems. Despite its simplicity, it proved a great performance in solving non-differentiable, non-continuous and multi-modal optimization problems (Storn, R, & Price, K, 1997). A maintained vector population needs to be initialized which contains the dimensional vectors of real-valued parameters before going through the evolutionary algorithm procedure. After initialization, the vector population will go through mutation, crossover and selection processes iteratively until optimal solutions are found. Table 1 shows explained the details of the processes.

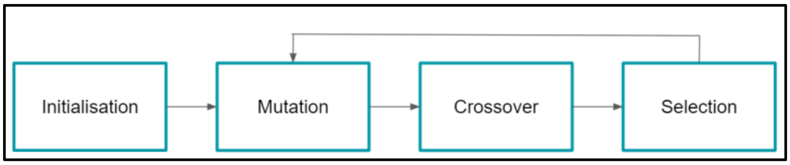

Figure 1: General Evolutionary Algorithm Procedure

a) *Initialisation*
   Before the population can be initialized, both upper and lower bounds for each parameter must be specified. Once initialization bounds have been specified, a random number generator assigns each parameter of every vector a value from within the prescribed range

b) *Mutation*
   After initialization, the search space will be expanded. Mutation operators are used in an attempt to avoid local minima by preventing the population of chromosomes from becoming too similar to each other, thus slowing or even stopping convergence to the global optimum.

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c) *Crossover*

In this phase, a successful solution is incorporated from the previous generation. Recombination is applied to each pair of the target vector and its corresponding mutant vector to generate a trial vector. The crossover operator avoids the generation of invalid solutions.

d) *Selection*

The last stage is described in which individual genomes are chosen from a population for later breeding by using the recombination procedure. The pre-specified range is randomly initialized if the values of some parameters of a newly generated trial vector exceed the corresponding upper and lower bounds. Then, the objective function values of all trial vectors are evaluated. After that, a selection operation is performed.

Self-Adaptive Ensemble-based Differential Evolution (SAEDE)

Differential Evolution (DE) is an optimization algorithm but its performance is parameter dependent and user-dependent. To minimize the influences of parameters and users on the performance, a DE algorithm that can self-adapt its parameters while solving optimization problems is required. Thus, an algorithm known as Self-Adaptive Ensemble-based Differential Evolution (SAEDE) is being used. SAEDE algorithm is convenient to use in which it can self-adapt its parameters to solve differential equations with minimum reliance on user-specified parameters.

The performances of SAEDE have been compared with another two adaptive DE variants over 34 benchmark functions of high complexity. From 28 out of 34 benchmark functions, SAEDE achieves the highest frequency of maximum success rate based on experimental results. According to Wang et al. (2018), the experimental results have shown the competitiveness and efficiency of SAEDE in locating optimal solutions while avoiding exhaustive searches of suitable parameters by users in terms of achieving optimization whilst minimizing the dependency on user-setting. Therefore, SAEDE is used as the AI technique in the development of SDSDE. The details of SAEDE can be found in Wang et al. (2018).

RESEARCH METHODOLOGY

This methodology used for this project is adapted from the Agile methodology as it is mainly used for software development, where demands and solutions evolve through the collaborative effort of self-organizing and cross-functional teams with customers. Figure 2 illustrates the five phases which are meet and plan, design, code and test, release and feedback.

Figure 2 : Phases in Agile Model (Fraguela, 2017)

In the meet and plan phase, discussion and review of an existing document are done to understand the problems of the project as well as to identify techniques used to develop the Smart Differentiation System. Next is the design phase where the system is designed to identify whether it meets project requirements or not. Next, the code and test phase which the fully functional system is developed that helps as a learning aid for students. Testing is conducted to make sure the system has a high percentage of accuracy without errors. Next, the project is released to end-users and a survey is conducted to collect information about student perception towards AI-based learning aid for Mathematics. All phase needs to be successful to achieve the aim and objective of the project.

Software Requirements

The software used in developing the project is Umlet, GanttProject, Eclipse IDE and Matlab. Umlet software version 14.3 is used to create all the diagrams for the project. Next is GanttProject version 2.8.11 that is used to create a gantt chart for the whole activities in this project within the due date that has been given. Lastly, Eclipse IDE is used for the whole development of the system with the use of Java Language and JDK Java. Matlab is used to generate the graphs for the equation enter in Eclipse.

RESULT AND ANALYSIS

Evaluation needs to be done as it is an important step in software development to improve certain aspects of the system and to achieve the aim of the project which is to determine the effectiveness of AI-based ABM in education. Quantitative research using a questionnaire which is Multiple Choice and Likert scale that follows System Usability Scale (SUS) is used. The evaluation is carried out to survey system usability and feedback on student perception using Smart Differentiation System as a learning-aid. Data is collected by distributing questionnaires to 30 students consisting of Form 4 and Form 5 from SMK Sungai Kertas and the collected data is analysed. Respondents were asked to rate their level of agreement on each statement using the 5-point Likert scale, which starts from 1 (Strongly Disagree) to 5 (Strongly Agree) and Multiple Choices which are “Yes” and “No”.

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Table 1: Evaluation of system usability for SDS

Scale Question	1: Very Disagree	2: Disagree	3: Neutral	4: Agree	5: Very Disagree	Mean
1. The lesson planning easy to access	0 (0%)	0 (0%)	5 (16.7%)	17 (56.7%)	8 (26.7%)	4.1
2. The system can be access without internet connection	0 (0%)	1 (3.3%)	7 (23.3%)	10 (33.3%)	12 (40%)	4.1
3. Text type, size and content are very consistent	0 (0%)	0 (0%)	5 (16.7%)	15 (50%)	10 (33.3%)	4.17
4. The images and icons are consistent	0 (0%)	0 (0%)	3 (10%)	19 (63.3%)	8 (26.7%)	4.17
5. The colour of the background is consistent	0 (0%)	0 (0%)	4 (13.3%)	17 (56.7%)	9 (30%)	4.17
6. Simple and brief design interface for beginner	0 (0%)	0 (0%)	7 (23.3%)	15 (50%)	8 (26.7%)	4.03
7. Size of button easy to click	0 (0%)	0 (0%)	4 (13.3%)	15 (50%)	11 (36.7%)	4.23
8. The answer are accurate and understandable	0 (0%)	0 (0%)	5 (16.7%)	14 (46.7%)	11 (36.7%)	4.2
9. Can view example/graph easily	0 (0%)	0 (0%)	7 (23.3%)	11 (36.7%)	12 (40%)	4.17
10. Overall performance	0 (0%)	0 (0%)	2 (6.7%)	15 (50%)	13 (43.4%)	4.37

Based on findings in Table 1, 93.4% of the respondents agreed with statement 10 which is “Overall performance” with the highest mean among all. This means that most of the respondents agreed with the features of this system that is accessibility, consistency, design and efficiency. This can be proven in statement 1 (26.7% strongly agreed and 56.7% agreed) where “The lesson planning is easy to access” and statement 2 (40% strongly agreed and 33.3% agreed) on “The system can be accessed without internet connection”. This shows that the system is accessible for users to use. Finding in Table 1 shows that the design of the system is acceptable by the respondents. This can be proven on statement 6 (26.7% strongly agreed and 50% agreed) on “Simple and brief design interface for beginner” and statement 7 (36.7% strongly agreed and 50% agreed) which is “Size of a button easy to click”. Based on the result in Table 1, respondents agreed with the efficiency of the system. 36.7% strongly agreed and 46.7% agreed with statement 8 on “The answers are accurate and understandable” and statement 9 (40% strongly agreed and 36.7% agreed) which is “Can view example/graph easily”. Thus, it shows that the system feature is efficient for users to use.

Table 2: Students' feedback toward SDS as the AI-based learning aid (ABM) in learning differentiation topic

Question **Scale**	**1:** **Very Disagree**	**2:** **Disagree**	**3:** **Neutral**	**4:** **Agree**	**5:** **Very Disagree**	**Mean**
1. I found out SDS helped me learn something new.	0 (0%)	0 (0%)	8 (26.7%)	16 (53.3%)	6 (20%)	3.93
2. I can try different approaches to solve math problems.	0 (0%)	1 (3.3%)	9 (30%)	13 (43.3%)	7 (23.3%)	3.86
3. I can start looking for a solution with the graphical, numerical, or algebraic approach.	0 (0%)	4 (13.3%)	3 (10%)	18 (60%)	5 (16.7%)	3.80
4. I can save my time to learn basic skills by using SDS	0 (0%)	1 (3.3%)	11 (36.7%)	13 (43.3%)	5 (16.7%)	3.73
5. SDS helps me in recognizing concepts of integration of function in the algebraic and graphical representation.	0 (0%)	4 (13.3%)	5 (16.7%)	16 (53.3%)	5 (16.7%)	3.73
6. SDS helps me learn mathematics with the help of computer language (coding).	0 (0%)	4 (13.3%)	11 (36.7%)	9 (30%)	6 (20%)	3.57
7. SDS helps me to learn additional mathematics in an easy and simple way	0 (0%)	3 (10%)	7 (23.3%)	13 (43.3%)	7 (23.3%)	3.80
8. I can solve mathematics problems and learn coding at the same time.	0 (0%)	2 (6.7%)	10 (33.3%)	9 (30%)	9 (30%)	3.83

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Continue

9. I found out how AI is used in education especially in Mathematics	0 (0%)	1 (3.3%)	7 (23.3%)	12 (40%)	10 (33.3%)	4.03
10. I am ready to use SDS in my own classroom	0 (0%)	4 (13.3%)	8 (26.7%)	15 (50%)	3 (10%)	3.57
11. I believe by using learning aid (ABM) helps me in learning	0 (0%)	1(3.3%)	5 (16.7%)	20 (66.7%)	4 (13.3%)	3.9
12. I believe using ABM in the classroom will be more fun and exciting.	0 (0%)	0 (0%)	4 (13.3%)	17 (56.7%)	9 (30%)	4.17
13. SDS can act as tools for learning material in the classroom.	0 (0%)	0 (0%)	8 (26.7%)	14 (46.7%)	8 (26.7%)	4.0
14. The lesson planning, answer, example in SDS are easy to understand	0 (0%)	3 (10%)	9 (30%)	14 (46.7%)	4 (13.3%)	3.63
15. Do you find AI in learning aid meaningful and helpful for you?	0 (0%)	2 (6.7%)	7 (23.3%)	14 (46.7%)	6 (20%)	3.70
16. Would you suggest SDS to your friends?	0 (0%)	2 (6.7%)	5 (16.7%)	11 (36.7%)	13 (43.3%)	4.27

Based on the findings in Table 2, the respondents provided the most favourable opinion on statement 16 with the highest mean (43.3% strongly agreed and 36.7% agreed). Among the rest of the respondents, 16.7% remained neutral and 6.7% disagreed with the statement “Would you suggest SDS to your friends?”. From the result analysis, 80% agreed that this system is acceptable and can be used by secondary school students in learning mathematics. This can be proven in statement 13 (46.7% strongly agreed and 26.7% agreed) where “SDS can act as tools for learning material in the classroom”. Overall, this system is accepted by the respondent based on statements 1 to 5. More than 70% of the respondents agreed that the system will help them learn something new, trying different approaches to solve math problems and saving time to learn basic skills. Not only that, the respondents agreed that the system helps in recognizing concepts of integration of function in the algebraic and graphical representation which will be beneficial in learning mathematics.

This research aimed to study the student problems in learning Additional Mathematics and to carry out an evaluation about student receptions towards AI-based learning aid for Mathematics. In conclusion, the existence of this system may bring a new experience of learning Differential Equation topics in Additional Mathematics. The results revealed that the majority of the respondents were satisfied with the ease of accessing and using the Smart Differentiation System. However, there are still some improvements that need to be done to provide users with a better experience in using the system and will be improved in the future. Thus, the aim of this project to determine the effectiveness of AI-based ABM in DE that is related to STEM education is achieved.

CONCLUSION

In conclusion, the focus of the study is to develop an AI-based learning aid in learning the differentiation topic. Besides, the study investigates the usability of SDS and students' feedback toward SDS. The results revealed that the majority of the respondents were satisfied with the ease of accessing and using the SDS as a learning-aid for learning the differentiation topic. There are several suggestions for the enhancement of the system such as adding more interactive educational content and adding a tracking system for the user to be able to record and track their learning progress easily in the future.

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