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Hybrid evolutionary algorithm for effective adaptive teaching of medical students

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ABSTRACT

The article investigates three evolutionary algorithms are analyzed: genetic algorithm (GA), particle swarm algorithm (PSO) and ant colony algorithm (ACO) to assess their ability to adapt curriculum to different characteristics of students, including their level of knowledge, learning style, practical skills and pace of study. The study compares effectiveness for each evolutionary algorithm creating flexible curricula that meet the individual needs of each student. Based on the analysis, the author proposes a hybrid algorithm that combines the advantages of each of the approaches considered. The article discusses the features of the hybrid algorithm, its ability to quickly adapt the learning process, improve individual learning efficiency and improve the quality of medical training. The proposed hybrid approach was tested in simulation conditions, which demonstrated its advantages in ensuring effective personalization of learning, avoiding local minima, and responding flexibly to changes in students' performance.

Keywords: Swarm algorithms; learning optimization; medical education; genetic algorithm; particle swarm algorithm; ant algorithm; hybrid algorithm; personalized learning; adaptive learning; individual approach

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INTRODUCTION

Medical education is one of the most complex and demanding fields of study, requiring a high level of theoretical knowledge, practical skills and psychological readiness to work under high stress. Since each student has unique perception, basic level of knowledge and pace of learning, there is a need to develop individualized approaches to the learning process. This individualization of learning requires increasing the effectiveness of education and the adaptation of students to real clinical conditions. However, traditional approaches to planning and implementing educational programs often do not take into account the requirements for individualization of learning, which can lead to insufficient levels of training for graduates.

Nowadays, artificial intelligence methods, in particular evolutionary algorithms, are increasingly used to solve optimization problems in complex systems that require adaptability and flexibility.

Such algorithms include the genetic algorithm (GA), particle swarm algorithm (PSO), and ant colony algorithm (ACO). Each of them has its own advantages and disadvantages [1, 2], [3] for different types of tasks, and all of them are able to adapt to changing conditions, making them promising tools for individualizing the learning process.

The purpose of this study is to investigate the possibility of using evolutionary algorithms to optimize the curricula of medical students. The article analyzes how a genetic algorithm can be used to identify and adapt educational methods to meet the individual needs of students. The particle swarm algorithm is proposed for rapid adaptation of learning objectives and learning pace, while the ant algorithm can be useful in planning the sequence of practical classes to develop professional skills and critical thinking.

Also, the theoretical aspects of the application of each algorithm, the methodology for developing a hybrid approach and the results of simulation testing are considered, which confirm the advantages of the hybrid algorithm for personalized learning of medical students.

PROBLEM STATEMENT

Medical education is critical for training professionals who will work under high stress and make decisions that have a direct impact on the lives and health of patients. The lack of personalization leads to a decrease in learning effectiveness, as well as to different levels of graduates' training. Therefore, there is a need to create adaptive educational methods [7, 8] that provide an individualized approach to each student. Such an approach should take into account not only theoretical knowledge but also the development of practical skills, critical thinking and psychological training. Creating such adaptive programs is a difficult task, as it requires taking into account a large number of factors and parameters that affect learning outcomes.

In addition, the current structure of curricula does not always allow for timely adjustments for each student depending on their progress and individual needs. Outdated assessment methods, inability to adapt to new requirements in a timely manner, lack of automated solutions for personalizing the educational process – all this hinders the achievement of high standards of education [9, 10], [11].

Given these problems, the question arises: how can the educational process for medical students be optimized to ensure personalization, adaptation to individual needs, and improvement of the quality of training? This article offers an answer to this question. It is proposed to use evolutionary algorithms (genetic algorithm, particle swarm algorithm and ant algorithm) to create an adaptive individualized curriculum for medical students.

ANALYSIS OF LITERATURE DATA

The use of adaptive algorithms in education, in particular evolutionary algorithms, is actively discussed in the scientific literature as an effective approach to personalizing learning in various fields, including medical education. This section provides an overview of research on the use of swarm algorithms, such as GA, PSO, ACO, as well as their modifications and hybrid variants in educational processes.

1. Genetic algorithm (GA)

A genetic algorithm based on the principles of natural selection and evolution is often used to personalize learning. Literature shows that GA can effectively customize individualized learning paths, especially when it comes to adapting materials to a student's level of knowledge. For example, studies show that a genetic algorithm can optimize the sequence of tasks, learning materials, and exercises, selecting them depending on the individual student's performance [12, 13], [14, 15]. This is especially important in medical education, where students need to learn a large amount of complex information and practical skills.

2. Particle swarm algorithm (PSO)

The particle swarm algorithm is used to quickly adapt to changing learning conditions, as well as to efficiently allocate learning resources. Literature reviews show that PSO allows you to adjust the pace of learning according to the speed of learning. Research in this area shows that PSO can be useful for creating adaptive learning programs that meet the individual characteristics of each student, especially when it comes to the rapid acquisition of theoretical knowledge. In addition, PSO is able to effectively respond to changes in the student's level of training, allowing you to adjust the intensity of training.

3. Ant colony optimization (ACO)

The ant algorithm is a common method for solving routing problems and finding optimal paths, which makes it promising for planning the sequence of practical classes in medical education. Studies show that ACO can optimize students' routes through different stages of learning, ensuring smooth learning of practical skills and development of clinical thinking. The ant algorithm is especially useful in simulation training and practical exercises where the sequence of tasks and time constraints need to be taken into account.

4. Hybrid algorithms in learning personalization

There is a lot of research on developing hybrid approaches that combine the strengths of different algorithms to achieve better results. Hybrid algorithms that combine GA, PSO, and ACO show high potential for creating personalized learning paths, as they are able to combine global search for optimal solutions, adaptive learning rate, and efficient routing [17, 18], [19]. Studies confirm that such hybrid algorithms improve the flexibility and adaptability of learning processes, which is especially important for medical education.

5. Challenges and prospects of using swarm algorithms in medical education

Despite significant progress, there are certain challenges in the application of evolutionary algorithms in education. These include the complexity of configuring algorithm parameters, the need for significant computing resources, and ensuring the accuracy of results for various educational scenarios. However, current research indicates that the use of powerful hybrid algorithms integrated into learning platforms can significantly improve the quality of medical training.

PURPOSE AND OBJECTIVES OF THE STUDY

The purpose of this study to evaluate the effectiveness of the genetic algorithm, particle swarm algorithm, and ant algorithm for building individualized teaching methods, as well as to create a hybrid algorithm that combines the advantages of each of these approaches. Such a hybrid approach is designed to increase learning efficiency [16] and provide flexibility and adaptation of the curriculum to the individual needs of students.

This purpose can be achieved by completing the following steps.

1. Analysis of the advantages and limitations of each of the evolutionary algorithms – GA, PSO ACO in the context of adaptive learning and personalization of the educational process.

2. Identification of criteria for an individual approach that should be taken into account when building curricula for medical students, such as basic level of knowledge, specialization, learning style, practical skills and pace of learning.

3. Development of a hybrid algorithm that combines the advantages of GA, PSO, and ACO, providing resistance to local minima, adaptability to changing conditions, and quick adjustment to individual student needs.

4. Conducting a simulation of testing a hybrid algorithm to evaluate its effectiveness compared to individual algorithms in creating an adaptive learning process.

5. Analysis of the benefits and challenges of the hybrid approach in the context of medical education, in particular, assessment of its ability to improve the quality of training of future medical professionals through individualized learning and flexible scheduling**.**

MATERIALS AND RESEARCH METHODS

To implement this study, we used data on the educational process of medical students collected from various educational platforms and simulation programs. These data included.

1. **Academic profiles of students** – information about the level of knowledge, learning style, speed of learning, specialization and personal interests.

2. **Results of tests and practical tasks** – data on students' progress, their achievements in theoretical and practical stages of training, including the results of simulations.

3. **Training materials** – distribution of learning tasks by complexity, taking into account both theoretical and practical aspects, such as clinical cases, simulations and critical thinking modules.

Genetic algorithm. It was used to determine the optimal curriculum by “evolving” it to best suit the individual characteristics of students. Selection, crossover, and mutation were used to adapt training modules to each student [20, 21], [22, 23].

Particle swarm algorithm. PSO was used to adapt the pace of learning and select learning materials based on students' current achievements. Each “lobe” in PSO represented a separate learning strategy, and the algorithm optimized the process by finding the most effective approaches.

Ant algorithm. ACO was used to optimize the routing of the learning process, as a Fig. 1, in particular when planning the sequence of practical tasks and cases. The algorithm built optimal paths that ensured the best development of practical skills and clinical thinking.

Description of the scheme

1. Student – a student who requests an individualized study plan.

2. GA – a genetic algorithm that generates optimal learning directions, transmits the best plan options to PSO.

3. PSO is a particle swarm algorithm that adapts the learning rate and transmits progress data to the ACO for scheduling practice tasks.

4. ACO is an ant algorithm that optimizes the learning path by creating a sequence of tasks based on ratings and feedback.

Development of a hybrid algorithm

Based on the analysis of the results of individual algorithms, a hybrid algorithm was developed that combines the strengths of GA, PSO, and ACO. To implement the hybrid approach, a model was created where the genetic algorithm provides a global search for optimal curricula, PSO allows for quick adaptation of the plan to changing learning conditions, and ACO optimizes the sequence of practical classes.

The hybrid algorithm combines the best solutions of each method to increase flexibility and adaptation of the training plan visualized on the Fig. 2.

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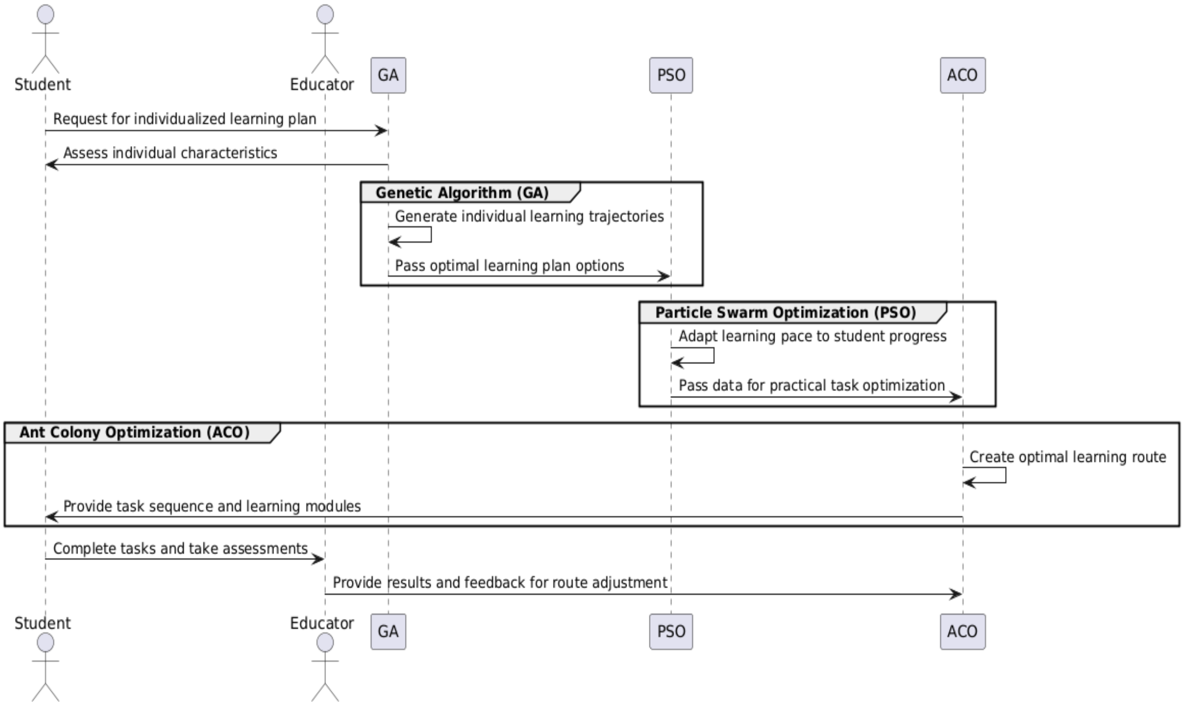

Fig. 1. **Interaction of genetic algorithm, particle swarm algorithm and ant algorithm in adaptation of individualized curriculum**

***Source:* compiled by the authors**

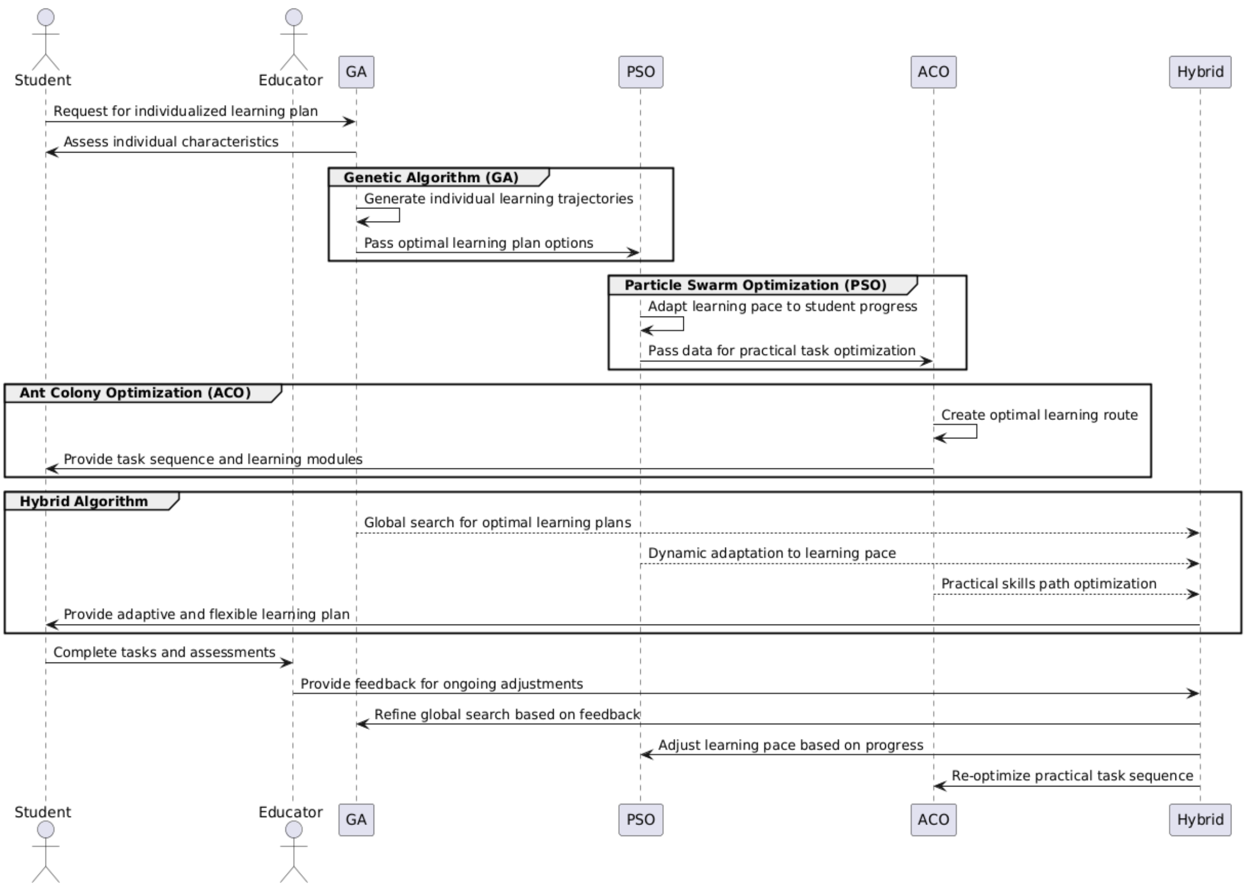

Fig. 2. **Integration of genetic algorithm, particle swarm algorithm, and ant algorithm into a hybrid approach to adapt individualized curriculum**

***Source:* compiled by the authors**

This diagram shows the process of transferring data from separate algorithms to a hybrid algorithm that combines the results to provide an adaptive curriculum, as well as adjusting this plan based on feedback from students and teachers.

RESEARCH RESULTS

The graph illustrates the impact of the hybrid algorithm on the level of students' knowledge in different areas of medical specialties. Initial knowledge scores varied depending on the specialty, indicating different levels of student preparation at the start. The use of a hybrid algorithm that adapts the pace of learning and selects optimal educational materials [24, 25] allowed us to improve the level of knowledge in each group.

This adaptive approach contributed to accelerated learning for students with an initially higher level of knowledge and gradual development for students with a lower level of knowledge as shown in Fig. 3, which led to an increase in the average score for all areas.

The initial level of knowledge ranged from 3.5 to 8.0 points (out of 10 possible). After applying the algorithm, a significant increase was achieved in all groups: the greatest improvements were seen in Dentistry and Physical Therapy, where the level of knowledge increased to 6.5 and 6.5 points, respectively. For General Medicine and Pharmacy, the level of knowledge also improved to 8.0 points, which indicates the effective adaptation of educational materials to the individual needs of each group of students.

This graph shows how the hybrid algorithm affected the development of students' practical skills in different medical specialties. The initial level of practical skills varied significantly between groups, with particularly low scores in Dentistry and Pharmacy. The application of the hybrid algorithm allowed us to adapt the intensity and complexity of tasks to the individual needs of each student, gradually increasing the load and complexity on the Fig. 4.

The initial level of practical skills ranged from 2.5 to 8.5 points, indicating significant differences between the groups. After applying the hybrid algorithm, the practical skills score increased in all groups, in particular for Dentistry and Pharmacy students, who showed an increase to 5.0 and 5.5 points, respectively. This demonstrates the effective integration of gradual and more complex practical tasks that helped students to adapt more quickly to the practical aspects of their specialty. Practical Skills Before and After Hybrid Algorithm describes the impact of the hybrid algorithm on the development of students' practical skills, which is key for medical specialties where practical skills are of great importance. The importance of using this algorithm in the hybrid approach is due to the need to increase the efficiency of learning practical skills and their gradual development in conditions adapted to the needs of students [26, 27], [28].

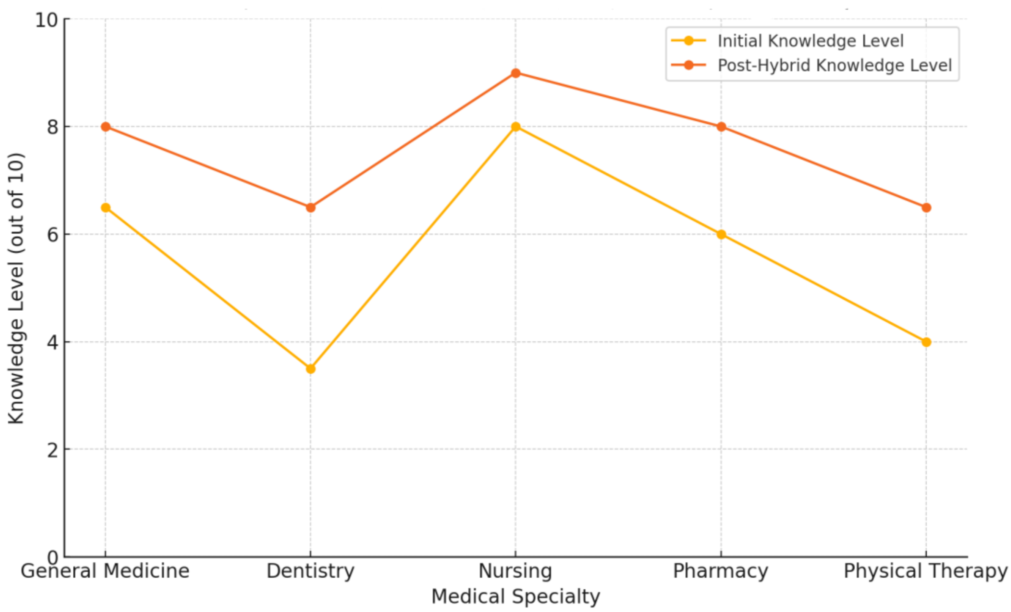

Fig. 3. **Knowledge level before and after hybrid algorithm**
Source: **compiled by the authors**

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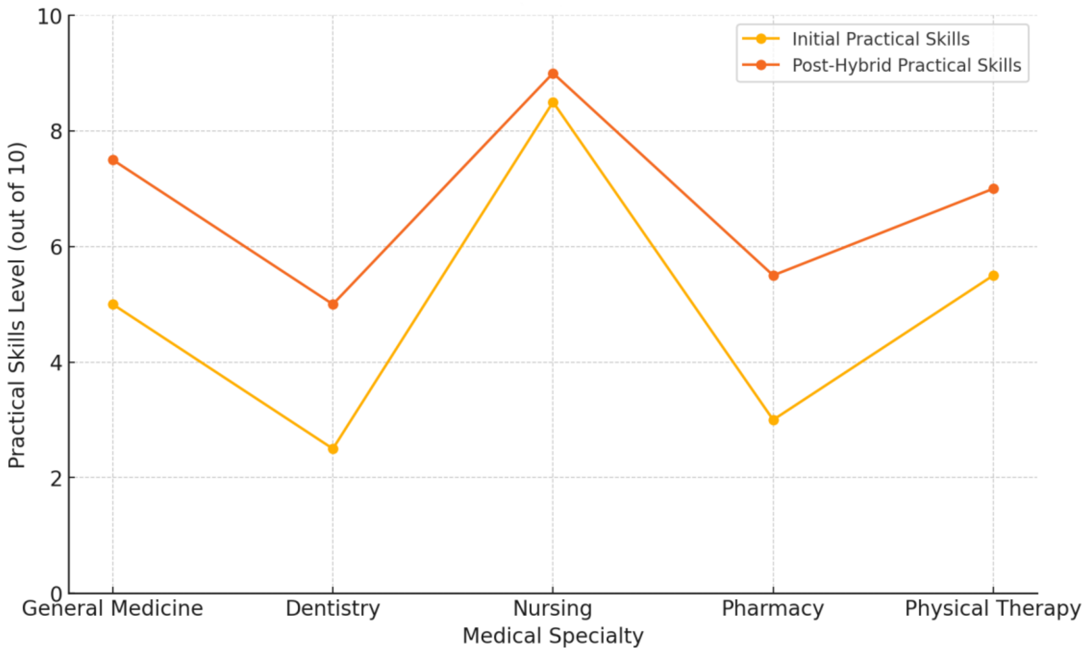

Fig. 4. **Practical skills before and after hybrid algorithm**
Source: **compiled by the authors**

Beginner level of practical skills. At the beginning of the study, the practical skills of students in different specialties differed significantly: from the lowest level among Dentistry students (2.5 points out of 10) to the highest among Nursing students (8.5 points out of 10). Such discrepancies indicate different levels of training in certain areas, which may depend on both previous experience and individual characteristics of each group. For specialties with low scores, such as Dentistry and Pharmacy, the use of an adaptive algorithm is particularly important as it helps to eliminate gaps in practical skills, giving students the opportunity to develop more intensively in this area.

The hybrid algorithm uses three main approaches to develop practical skills

Genetic algorithm. This approach uses a global search to determine the optimal practical tasks and simulations that best suit the student's level of training. This algorithm selects tasks with progressive difficulty, as well as those aimed at strengthening basic skills. This choice helps to gradually improve students' skills, especially in areas with a low initial level.

Particle swarm algorithm. Allows you to adapt the intensity and pace of practice sessions based on individual student progress. PSO helps to quickly adjust the intensity of practical exercises, lowering it if necessary to avoid overload, or increasing it for students with a high learning rate. This allows students to develop practical skills gradually, at their own pace, which increases their effectiveness.

Ant algorithm. It is used to build an optimal sequence of practical tasks. ACO allows you to build a learning path where each subsequent task is gradually more complex, based on the skills you have already mastered. This contributes to the consistent development of practical skills and allows students to confidently approach more complex tasks, which significantly increases their readiness for real clinical situations in optimized process, the result of such a process is shown in Fig. 5.

The graph “Adaptation to technology before and after hybrid algorithm” demonstrates how the hybrid algorithm helped students adapt to the use of new technologies in their studies. The initial level of adaptation to technology ranged from 4.5 to 8.5 points. After applying the algorithm, the adaptation improved significantly, especially for Dentistry and Physical Therapy groups, where the level increased to 8.0 and 6.5 points, respectively. This growth is attributed to the adjustment of the learning pace and the introduction of appropriate technological tools, which contributed to the increase in digital literacy and comfort in using technology, the results of which are shown in Fig. 6.

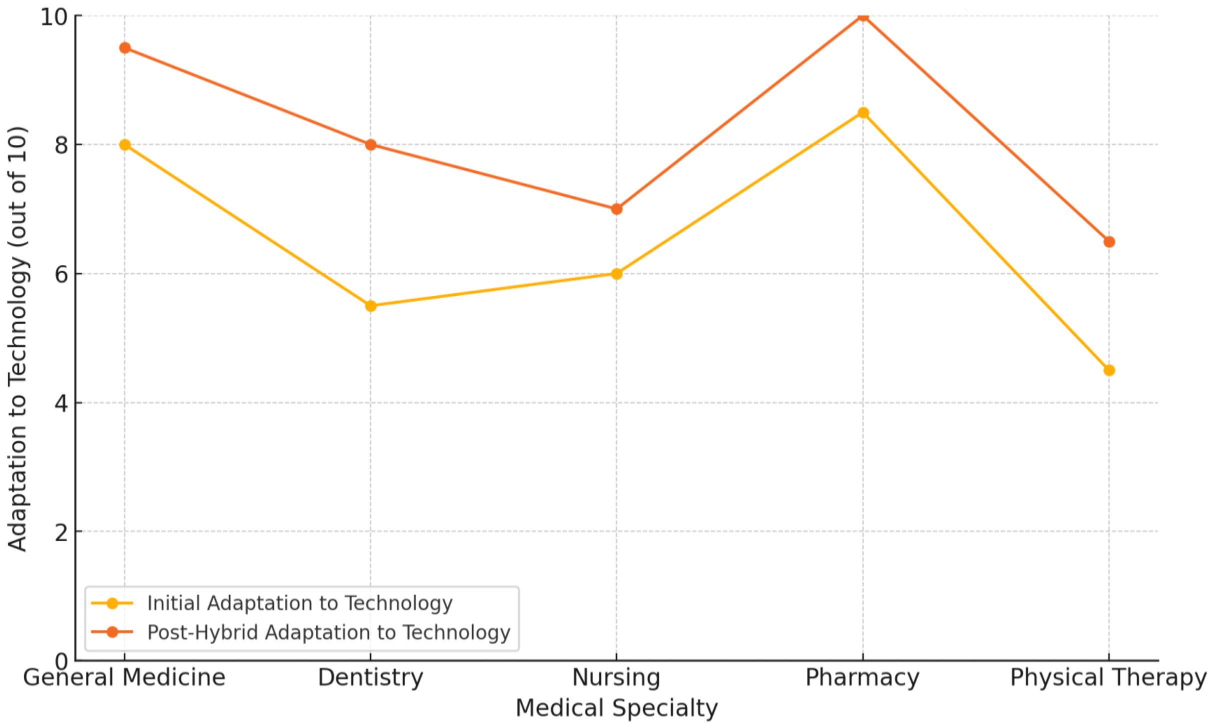

Fig. 5. **Adaptation to technology before and after hybrid algorithm**
Source: **compiled by the authors**

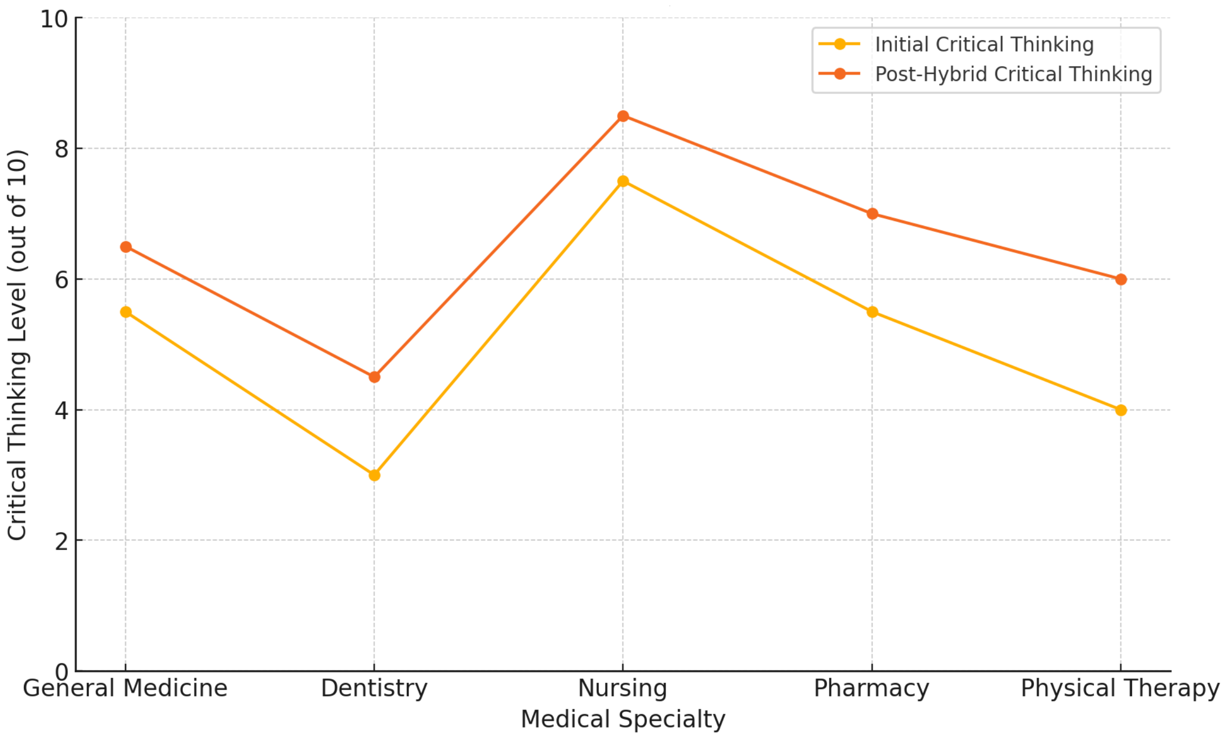

Fig. 6. **Critical Thinking Before and After Hybrid Algorithm**
Source: **compiled by the authors**

The graph "Critical Thinking Before and After Hybrid Algorithm" shows the changes in the level of critical thinking that were achieved with the help of the hybrid algorithm. The initial level of critical thinking ranged from 3.0 to 7.5 points, depending on the specialty. After applying the algorithm, a general improvement was recorded in all groups. For example, for Dentistry and Physical Therapy students, critical thinking increased to 4.5 and 6.0 points, respectively. This indicates the effectiveness of the selection and adaptation of tasks aimed at developing analytical thinking and the ability to make informed decisions.

DISCUSSION OF THE RESULTS

Each of the criteria showed a significant improvement after applying the adaptive learning approach, which emphasizes the importance of integrating individualized algorithms into medical education.

1. Increasing the level of knowledge

The hybrid algorithm showed a significant improvement in students' knowledge in all areas. This confirms the effectiveness of the global search for optimal educational materials using the genetic algorithm and the customization of the learning pace using the particle swarm algorithm. The results indicate that students learn the material faster when it is adapted to their initial level of knowledge, and the learning process ensures the gradual complication of topics. For medical education, this means that students gain a knowledge base that becomes the basis for further development and specialization.

2. Development of practical skills

The results showed a significant increase in practical skills, especially among students with an initially lower level of practical training. Thanks to the adaptive approach provided by the hybrid algorithm, students received tasks with a gradual increase in complexity, which contributed to sustainable progress. The genetic algorithm optimized the choice of tasks based on the students' skill level, while the particle swarm algorithm ensured individualized learning intensity. This allowed students to better master practical skills, which is critical for medical specialties that require a high level of competence in performing procedures and manipulations.

3. Adapting to technology

The hybrid algorithm also proved to be effective in improving students' technological training, especially for specialties where the initial level of adaptation to technology was relatively low. The use of ACO helped to optimize the sequence of technology integration into the learning process, allowing students to gradually get acquainted with new tools and digital resources. The particle swarm algorithm ensured a comfortable learning pace for each student, which contributed to faster adaptation. For modern medical education and practice, it is important that students are fluent in using technological tools, as medical technology and digital resources play a key role in modern healthcare.

4. Development of critical thinking

The development of critical thinking is one of the most challenging aspects of learning, but the results showed that the hybrid algorithm is also able to effectively promote its formation. The combination of GA and ACO provided an adaptive selection of tasks that gradually develop students' analytical skills, ability to make informed decisions and evaluate clinical situations. These skills are fundamental to the medical profession, as they require a deep understanding of theoretical knowledge and the ability to apply it correctly in practical settings.

5. Implications of the results for medical education

The results of this study emphasize the importance of individualized approaches to teaching in medical specialties, where different levels of student training require differentiated curricula. The hybrid algorithm allows us to take into account the unique needs of each group, which significantly increases the efficiency of learning. It is also important that such a learning system reduces the risk of stress and overload, as the pace and complexity of learning are adjusted to the individual student's capabilities. This allows students to remain motivated and confident in their abilities, which is important for achieving high results.

6. Challenges and future prospects

High computing resources. One of the key challenges in applying the hybrid algorithm is the need for significant computing resources. Since the algorithm combines three complex methods (genetic algorithm, particle swarm algorithm, and ant algorithm), powerful processors and a large amount of RAM are required for their synchronized operation. This limitation can make it difficult to implement the algorithm in educational institutions with limited technical resources. To overcome this obstacle, further research is needed to optimize the computational efficiency of the algorithm, as well as the possibility of implementing it on cloud platforms that can provide scalability.

7. The complexity of setting parameters

The hybrid algorithm requires fine-tuning of numerous parameters, such as mutation rates in the genetic algorithm, inertia coefficients in the PSO, and pheromone levels in the ant algorithm. Each parameter can have a significant impact on the result, and their adjustment requires considerable time and professional knowledge. One possible solution is to develop a system for automatically adjusting parameters based on machine learning[29]. This would increase the efficiency of the algorithm and simplify its adaptation to different educational programs.

8. Integration into existing learning platforms

Another challenge is integrating the hybrid algorithm into existing educational platforms and Learning Management Systems (LMS). Many of them are not designed to support adaptive algorithms, especially those as complex as the hybrid algorithm. This may require additional costs to modify or expand the functionality of the LMS. In the future, it is possible to develop application programming interfaces (APIs) that would allow for easy integration of the algorithm into various educational systems and platforms.

9. Ensuring the confidentiality of student data

The use of the algorithm involves the collection and analysis of a significant amount of data about students, including their level of knowledge, progress in learning, and individual characteristics. This raises questions about privacy and data protection. To ensure data security, it is necessary to implement reliable information storage and processing policies, as well as to comply with privacy laws such as the GDPR. Research in this area should consider the use of data anonymization or differential privacy techniques..

10. Psychological aspect of adaptive learning

Adaptive learning can have both positive and negative psychological effects on students. On the one hand, personalization promotes motivation and increases self-confidence, while on the other hand, over-adaptation can cause additional pressure and stress for students who may feel the expectation to achieve consistently high results. For further development of the algorithm, it is necessary to take into account the psychological aspects of adaptive learning and develop mechanisms to support students to prevent emotional burnout. The general aggregation of the study results is shown in Fig. 7.

Graphic **“Aggregated Criteria Before and After Hybrid Algorithm”** illustrates all criteria (Knowledge Level, Practical Skills, Adaptation to Technology, Critical Thinking) and highlites improvements in each specialty. This graph shows that the hybrid algorithm had a positive impact on all aspects of learning, including theoretical knowledge, practical skills, technology adaptation, and critical thinking[30]. For example, in Dentistry, the initial indicators were the lowest, but after applying the algorithm, each criterion increased significantly. This emphasizes the flexibility and adaptability of the hybrid algorithm, which customizes learning trajectories to the individual needs of each group, thus improving the quality of learning.

CONCLUSIONS

This study evaluated the effectiveness of a hybrid evolutionary algorithm that combines a genetic algorithm (GA), a particle swarm algorithm (PSO), and an ant colony algorithm (ACO) for adaptive learning for medical students. The findings show that the hybrid approach significantly improves students' knowledge, practical skills, adaptation to technology, and critical thinking. The main findings of the study include:

1. Increase in the level of knowledge by 1.5-3 points in all groups. The hybrid evolutionary algorithm allowed students to learn theoretical material more effectively by adapting the pace of learning and individualizing the selection of materials. The use of GA ensured the selection of optimal learning materials, which contributed to an increase in the average level of knowledge in all areas. This shows that personalization of learning is critical for the quality of knowledge acquisition in medical education.

2. Increase in practical skills by 1.5-4 points, especially in groups with initially low scores. Thanks to PSO and ACO, the algorithm ensured optimal adjustment of the pace of practical classes and gradual complication of tasks, which allowed students to significantly improve their practical skills. Students of Dentistry and Pharmacy achieved an increase of 5.0 and 5.5 points, respectively, which indicates the high efficiency of the hybrid approach for developing practical skills even for students with an initially low level of training.

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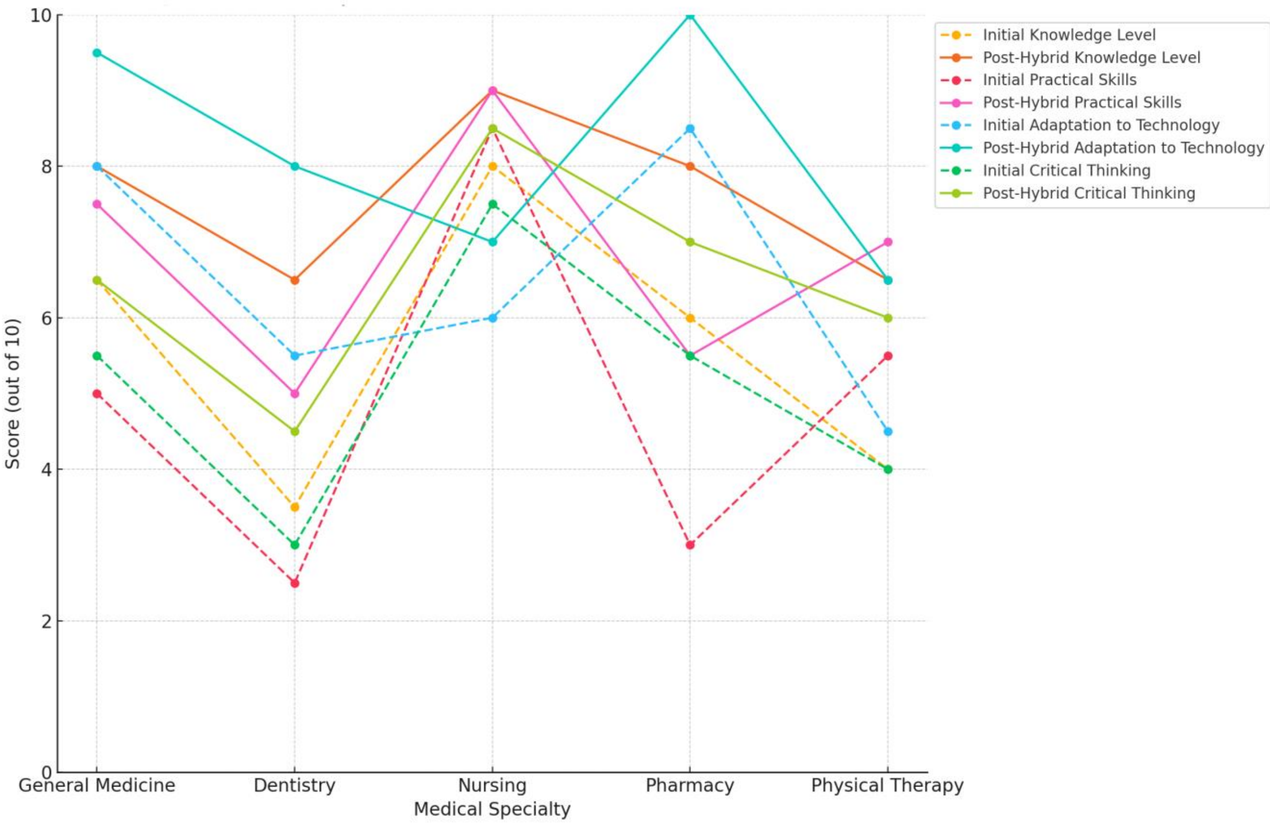

Fig. 7. **Aggregated criteria before and after hybrid algorithm**
Source: **compiled by the authors**

2. Improved adaptation to technology by 1-2.5 points. The algorithm has significantly improved students' ability to work with digital tools and technological resources. This is especially important for modern medical education, where digital tools have become an integral part of practice. PSO provided a comfortable learning pace for mastering technologies, and ACO built an effective sequence of their implementation in the educational process.

4. Increase in the level of critical thinking by 1-2 points. Through GA and ACO, the hybrid algorithm allowed students to develop analytical skills and the ability to make informed decisions. This increase is an important indicator for medical specialties, where critical thinking is key in decision-making and evaluation of clinical situations.

5. Confirmation of the effectiveness of the individualized approach. The results of the study confirmed that individualized learning based on a hybrid algorithm provides a higher level of training for students, allowing them to learn at their own pace and to meet their own needs. This resulted in stable growth rates across all criteria, indicating the benefits of flexible learning.

6. High efficiency of the hybrid algorithm for all groups of students. All study groups showed improvement in key criteria, regardless of their initial level. This demonstrates the versatility and reliability of the hybrid approach, which provides high results even in groups with different levels of training.

Thus, the hybrid evolutionary algorithm is an effective tool for adaptive learning that contributes to significant improvements in medical students' learning. The use of this approach can help educational institutions improve the quality of education and prepare students for the modern requirements of medical practice.

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Гібридний еволюційний алгоритм для ефективного адаптивного навчання студентів медичних спеціальностей

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АНОТАЦІЯ

У статті досліджено застосування еволюційних алгоритмів для оптимізації процесу навчання студентів медичних спеціальностей, з акцентом на індивідуалізацію освітніх траєкторій. Проаналізовано три основні підходи: генетичний алгоритм (GA), алгоритм рою часток (PSO) та мурашиний алгоритм (ACO) – для оцінки їхньої здатності адаптувати навчальні плани відповідно до різних характеристик студентів, зокрема рівня знань, стилю навчання, практичних навичок та темпу засвоєння матеріалу. У ході дослідження порівняно їхню ефективність у створенні гнучких навчальних програм, що відповідають індивідуальним потребам кожного студента. На основі проведеного аналізу запропоновано гібридний алгоритм, який поєднує переваги кожного з розглянутих підходів. У статті обговорено особливості гібридного алгоритму, його здатність швидко адаптувати навчальний процес, покращувати індивідуальну ефективність навчання та підвищувати якість підготовки медичних фахівців. Запропонований гібридний підхід було протестовано у симуляційних умовах, що продемонструвало його переваги в забезпеченні ефективної персоналізації навчання, уникненні локальних мінімумів та гнучкому реагуванні на зміни у потребах студентів.

Ключові слова: ройові алгоритми; оптимізація навчання; медична освіта; генетичний алгоритм; алгоритм рою часток; мурашиний алгоритм; гібридний алгоритм; персоналізація навчання; адаптивне навчання; індивідуальний підхід

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