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Using behavioral analytics to personalize learning experiences in digital medical education: a case study

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Abstract
Today, digital medical education requires building an individual trajectory and considering the students' needs. Personalized learning is proved to be an effective model as it concerns self-organization learning and customized instruction. The findings show that the implementation of personalized learning model depends on the behavioral analytics and the students' learning styles. The present research is aimed to assess the learning styles among medical students and to substantiate the choice of effective teaching methods. To achieve the research objectives, we applied the case study method among 167 students from three institutions of higher medical education in Ukraine. The findings showed that most students belong to the converger and accommodator learning style groups. Considering the Cohen's approach, we found that implementation of personalized learning model in digital medical education based on behavioral analytics increased the efficiency of learning process in all three institutions. The average efficiency index amounts 3,9 %. This proves the idea of positive impact of personalized learning model based on behavioral analytics upon the enhancement of digital medical education. As a conclusion, we elaborated a set of teaching methods suitable for different groups to provide high-quality digital medical education. In addition, certain recommendations were developed for heterogeneous groups.

Keywords
Personalized learning model, behavioral analytics, digital medical education, learning style.

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Introduction

Currently, dynamic social changes, spread of knowledge and technology, development of new communication strategies promote educational innovations that are essential to respond to global challenges of the unpredictable world and actively improve the quality of education (Stasewitsch et al., 2022; Tsekhmister, 2022). Scholars have long discussed the need for change and innovation in medical education in the conditions of digital transformations that contribute to the implementation of digital tools in the classroom as well as development of digital readiness and computer acceptance (Althubaiti et al., 2022). Today, advances in medical science (Kamel, 2023; Simakhova et al., 2022; Tatarina, 2022; Tsekhmister et al., 2022), rapid introduction of competency-based paradigm (Majumder et al., 2023), incorporation of technology-assisted learning tools (Park et al., 2021), and promotion of new programs (Mittal & Medhi, 2022) construct high-quality models of medical education and enable the learners to achieve academic success. It is even more critical because a number of institutions of higher medical education in Ukraine have been adversely affected by the ongoing war and educational leaders are searching for effective management mechanisms in times of crisis (Barzylovych et al., 2020).Digitalization, manifestly, has the potential to enhance the training of future medical professionals and bring system-wide improvements (Bader et al., 2022).

The role of digital medical education has grown substantially in recent years and it has long been the subject of many studies (Das, et al., 2022; Jun Xin et al., 2021; Rakhimov & Mukhamediev, 2022). The findings suggest that innovative digital solutions are realized through self-directed study (Liu & Sullivan, 2021), blended learning (Hege at al., 2020; Vallée et al., 2020), simulations (Ayaz & Ismail, 2022), gamification (Krishnamurthy et al., 2022; Rohlfsen et al., 2020), cloud technology (Althubaiti et al., 2022; Das, et al., 2022), problem-based learning (Trullàs et al., 2022), Virtual Reality and virtual flipped classroom (Mergen at al., 2023), case study (Tsekhmister, 2023), artificial intelligence (Buabbas et al., 2023), and personalized learning (Conn et al., 2021).

In the modern system of digital medical education it is required to build an individual trajectory reaching the goals for identification of students' certain needs and motivation for future professional growth (Rohlfsen et al., 2020). This fact indicates that personalized learning is an essential vector of contemporary medical education that is

able to respond the existing challenges since we realize that traditional training does not meet the students' demands and the unified approach decreases the efficiency or productivity. Evidently, it is necessary to organize the educational process oriented towards preparation of students to multitask, learning autonomy, gaining innovation skills such as thinking flexibility, teamwork, communication, social responsibility considering their learning styles, type of motivation, and different experiences. Thus, personalized learning has become a "core concept" of digital education due to its focus on result and students' key role within the educational process (Shemshack & Spector, 2020).

Therefore, it is necessary to explore the peculiarities and impacts of implementation of personalized learning in digital medical education through behavioral analytics because a learning style is one of the most important factors for the design of a highly effective learning environment. On the whole, this study aims to (1) understand the concept of personalized learning in digital medical education by the example of 3 institutions of higher medical education in Ukraine; (2) identify different learning styles based on patterns of learning behavior of medical students; (3) prove the dependency between behavioral analytics and methods for teaching medicine.

Theoretical background

Personalized learning in digital medical education

Personalized learning has actually existed for centuries as apprenticeship or mentoring (Shemshack & Spector, 2020) but at present it concerns a complex activity approach related to self-organization learning or customized instruction and takes into account students' individual needs and objectives (Nazempour & Darabi, 2023). According to Walkington and Bernacki (2020), personalized learning is a method that requires the combination of the existing teaching practices, educators' methodological experience, and students' perspectives on future professional activity to modify the learning environment and support the learning processes.

In the context of medical education, personalized learning is associated with instructional flexibility and high level of students' situational "self-awareness", their ability to self-learning or self-organization, and activated motivation as well. (Raeisi et al., 2019). Fowler et al. (2023) mention that the method of personalized learning requires the careful examination of learner's individual characteristics to consider the

delivering and assessment strategies used in the classroom or teacher-student interaction model which could potentially be successful.

The purpose of personalized learning belongs to application of students' practical and personal attitudes and their possibility to choose the learning material (Hernandez Cardenas et al., 2021). In addition, such approach can contribute to establishment and further management of students' individual academic objectives through individual profiles or personalized learning trajectories (Piumatti et al., 2021) supporting students' progressions in learning and development.

Some scholars (Mansur et al., 2019) differentiate four models of personalized learning: differentiated, adaptive, individualized, and competency-based. Differentiated model refers to the facilities and means that each learner has a special tool or tools to interact in the classroom. Adaptive model concerns community engagement and occurs when a learner participates in the educational activities and learns how to apply own communication styles productively. Individualized personalized learning is oriented towards the process of building learners' professional skills and considers their individual characteristics. Lastly, competency-based model focuses on formation of professional skills filtering the learning material and introducing a number of learning approaches.

Conn et al. (2021), rethinking health education affected by digital and technological changes, report that personalized learning appears to be more attractive. Moreover, it provides students with a wide range of opportunities for strengths manifestation, personal expression, and collaborative creativity.

Due to the extensive use of artificial intelligence (AI) in digital medical education, personalized learning is getting more applicable within the educational process as it receives the specific contextual data through intelligent agents, smart tutors, autonomous assessment, and chatbots (Shankar, 2022). As a result, teachers are immediately provided with the information about students' achievements that can be used to predict their specific learning needs (Shankar, 2022).

There appears to be a strong relationship between digital transformation and pedagogical change in medical education when technology contributes to enhancement of efficiency of the educational process (Ali, 2022) since different teaching methods can be applied to deliver the learning material of the same content if we factor in students' needs, competencies, and educational intentions (Conn et al., 2021; Tkachenko et al., 2023).

To implement personalized learning in digital medical education, it is necessary to understand the peculiarities of behavior analysis and explain its usage to detect students' learning styles as it may help to build an effective digital learning environment and involve all the participants into the learning activities. We are sure that detection of students' learning styles is aimed at solving the important pedagogical problems related to achievement of current educational intentions, particularly formation of professional competency among medical students through digital tools considering their behavior patterns and learning experiences.

Behavior analysis to detect students' learning styles

An individual learning style describes how a student receives and processes information and solves learning tasks (Nazempour & Darabi, 2023). Several investigations have been conducted on learning styles. First, we will analyze what the term "learning style" means.

Davies-Kabir and Aitken (2021) define learning style as a set of preferences and aptitudes for different study styles or modes of instruction. According to Rezigalla and Ahmed (2019) it refers to the learner's method of collecting, processing, interpreting, organizing, and thinking about information. Also, learning style concerns a set of factors, behaviors, and attitudes that affect learning.

Findings show that students may have different learning styles (Davies-Kabir & Aitken, 2021; Rezigalla & Ahmed, 2019). Understanding the learning style as learning behavior pattern can optimize teaching process and bring more students to achieve success (Bokhari & Zafar, 2019). Some researchers (Fowler et al., 2023; Shakeri et al., 2022) believe that there is a vivid connection between the learning style and learning outcomes. Therefore, analyzing students' learning behavior and selection of effective teaching model may facilitate the educational process and increase learning across content and performance (Bokhari & Zafar, 2019; Rezigalla & Ahmed, 2019).

The concept of learning style has been developed to distribute students into specific groups or clusters and further to personalize their learning. Today, some approaches to classification of learning styles have been used such as VARK approach (Bokhari & Zafar, 2019), Grasha–Riechmann model (Arbabisarjou et al., 2020), Kolb's theory (Shakeri et al., 2022).

Since we regard behavioral analytics as a main tool to personalize learning experiences in the classroom and to enhance the efficiency of digital medical education, the approach selected must represent the analysis of learner's personal development, professional perspective and be oriented towards adequate learning behavior patterns and correct use of digital tools. Besides, Kolb's learning style inventory is based upon two-bipolar algorithms depending on how a learner perceives and acquires learning information that is applicable for our research. Therefore, regarding the considerations that the Kolb's theory focuses on the learner's personal development, abstract conceptualization and concrete learning experience as well as professional perspective and the fact that it is extensively implemented in online learning design (Cohen, 2023), made it the most appropriate solution to apply it in our study.

According to Kolb's experiential learning model, there are four main learning styles that can be applicable for medical students. They include the following: diverger, assimilator, converger, and accommodator (Shakeri et al., 2022). Figure 1 describes the characteristics of each learning style.

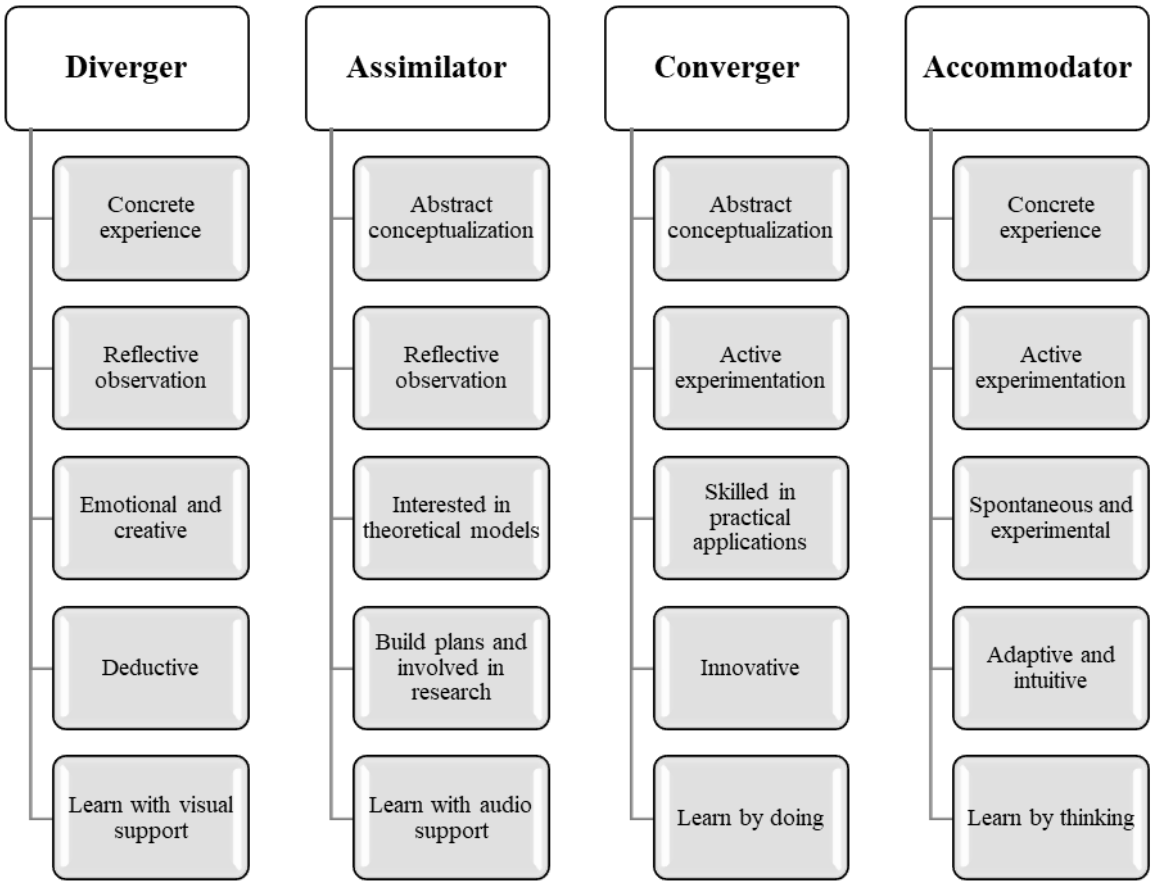

Figure 1. Characteristics of learning styles according to the Kolb's theory

Detection of learning styles may obviously enhance digital medical education through adaptation of teaching strategies, integration of theory and practice, teaching students to apply their learning experience to new professional situations, development of critical thinking and problem-solving skills and fostering the culture of continuous learning among future medical specialists accordingly. At the same time, considering the entrance examination procedures, it is impossible to form groups of students with similar learning styles. But teachers should emphasize their individual learning styles and regard it as an important factor while planning classroom activity and choosing a teaching method since personalized learning approach can provide effective learning and maximize the learning environment.

Thus, in addition to classification of learning styles this study also pays attention towards the evaluation of learners' online behavior through digital technology acceptance. Further, the outcomes propose the methodology of digital medical education based on the principles of personalized learning. Therefore, the *aim* of the present research was to assess learning styles of students in 3 institutions of higher medical education in Ukraine and analyze the preferred teaching methods based on the data obtained. Accordingly, we address the following *research questions*:

1) What are the characteristics of personalized learning in digital medical education?
2) What are the learning styles among medical students according to Kolb's…/on the basis of the Kolb's theory describing their learning behavior?
3) How to design an effective personalized learning model at the institution of higher medical education using behavioral analytics?

Methods

Study design and participants

To answer the research questions, we applied the case study that requires to use a theoretical analysis approach for data collection, empirical investigation to reveal a contemporary phenomenon in a real-life context as well as model-based design to elaborate the most effective teaching strategies (Varela et al., 2021). Appendix shows the detailed description of methods used to answer the research questions and their purposes while doing the educational research.

Participants for the study were chosen among three institutions of higher medical education in Ukraine. All of them were undergoing bachelor's degree programs on the

speciality “General Medicine”. The total number of participants was 167. The selection requirements included: be a student of second or third year in the institutions of higher medical education in Ukraine; have the previous experience of working in digital learning environment and be aware of using the tools for online or virtual learning; be ready to participate in additional classes. All the participants were informed about the case study. The instructors who conducted the questionnaire explained them the purpose of the research and possible applications. The individuals who were responsible for collecting and evaluating the research data were obliged to work on the principles of objectivity and impartiality.

Data collection and analysis

The study tool we used was Kolb learning style inventory online (version 3) that is oriented towards the following objectives: (1) understanding the process of learning from experience; (2) estimate students’ awareness of how they learn; (3) analyze learners’ potentials for self-control of their learning process; (4) enabling teachers to monitor and select the most effective learning approaches in different learning situations; (5) assist teachers to create the most effective digital learning environment; (6) provide the most relevant research tools and interpret the research results appropriately.

The questionnaire consisted of three parts. The first part contained the information about the purpose of the case study and the instruction for students how to use it. The second part included general demographic questions about students’ age, gender, year of study, institution, and form of education. The third part had 80 verified questions of the standardized Kolb questionnaire about students’ internal cognitive processes and their preferred activities while learning in the classroom and learning habits during their individual work. Also, the questions concerned various factors affecting students’ learning styles like social environment, previous educational experience, cognitive structure, internal or external stimuli. The respondents should take a multichoice online test and choose the best option. Each option represented one of the learning styles: 1 = converging, 2 = diverging, 3 = assimilating, and 4 = accommodating.

The results were analyzed using the methods of descriptive statistics according to the Kolb’s theory assessment and analytical statistics that were used further to design the

personalized learning model applicable for the institution of higher medical education and to suggest the most relevant teaching strategies for digital medical education. The model-based designed required the introduction of data on students' learning styles and verification of teaching strategies effect in the classroom through pedagogical observation, immediate students' feedback, analysis of students' learning outcomes, and studying of their behavior in simulated professional situation.

Results

According to the Kolb's theory, the students were divided into four types of learning styles. Figure 1 displays the analysis of students' learning style in the context of representation of different institutions. The findings show that the majority of students belong to the groups from converger and accommodator learning style. Converging style is typical for 37,6% of students (University 1), 43,2% (University 2), and 39,5% (University 3). At the same time 49,8% of students (University 1), 30,6 % (University 2), and 40,3% (University 3) note that they are accommodators when learning. This suggests the necessity to consider the characteristics of converging and accommodating styles while planning educational activities and building a learning environment for medical students. We consider the results to be decisive to selection of appropriate digital tools and teaching strategies. At the same time, if not to take into account students learning styles, the efficiency of educational process at the institutions of higher medical education may decrease significantly.

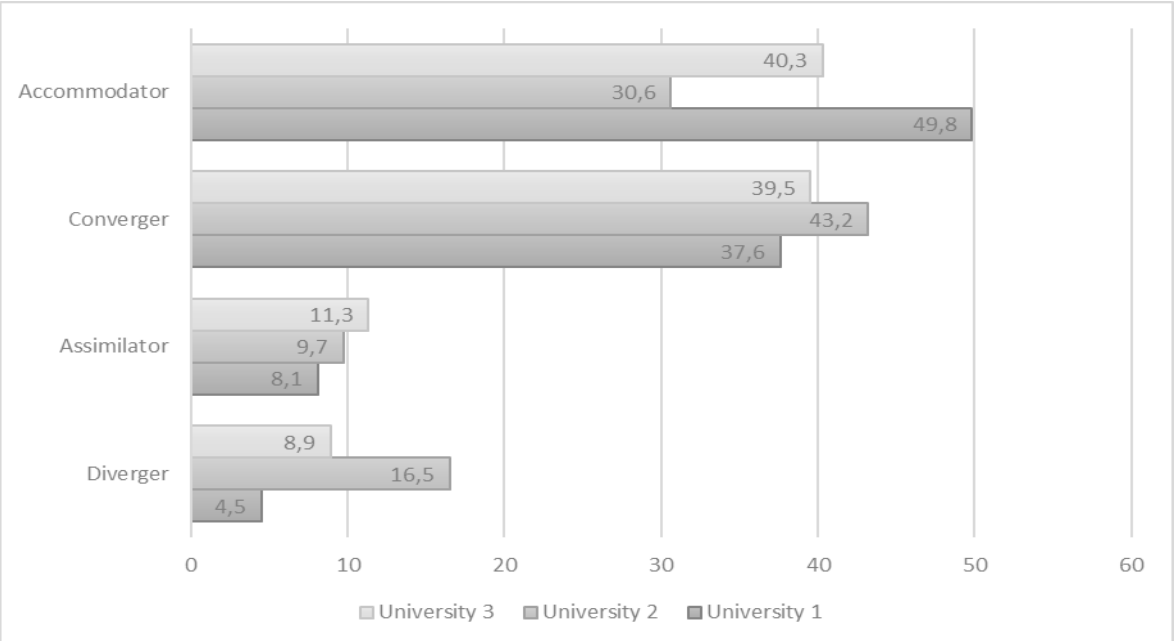

Figure 2. The representation of learning styles among students of institutions of higher medical education

To evaluate the efficiency of learning environment we analyzed the students' learning behavior in the classroom, their learning outcomes. The teaching methods were suggested using the Cohen's approach on format of learning material and optimal teaching methods (Cohen, 2023) that represents the effect size on students' learning outcomes while performing different activities in the classroom. Since the best teaching methods are essential tools to bring desirable changes in the digital learning environment, we attempted to identify the format of learning materials and teaching methods applicable for digital medical education. Table 1 presents the analysis of elements of learning environment by the students' learning styles.

Table 1. Analysis of learning environment according the Cohen's approach

Learning style	**Format of learning material**	**Teaching methods**
Accommodator	Text format	Work with textbook, use of worksheets, problem-based technology, computer-assisted tasks, interactive activities
Diverger	Graphic format	Lecture, brainstorming discussion, focus group work, hand-on activities, project-based technology
Assimilator	Audio or video format	Self-regulated activities, interactive lectures supported by audio or video, demonstration, tutorial
Converger	Multimedia format	Self-regulated exploration with teacher's support, peer learning, practical exercises, case-study, method of real-life situations

The study was conducted in two stages. The first stage referred to the analysis of conventional learning model in digital medical education since a teacher does not consider the students' behavioral analytics while delivering the learning material or carrying out assessments. At the second stage we studied the students' learning outcomes after the personalized learning model was implemented considering when appropriate format of learning material and teaching methods are used. Figure 3 shows the comparative analysis of students' learning outcomes for conventional learning and personalized learning models.

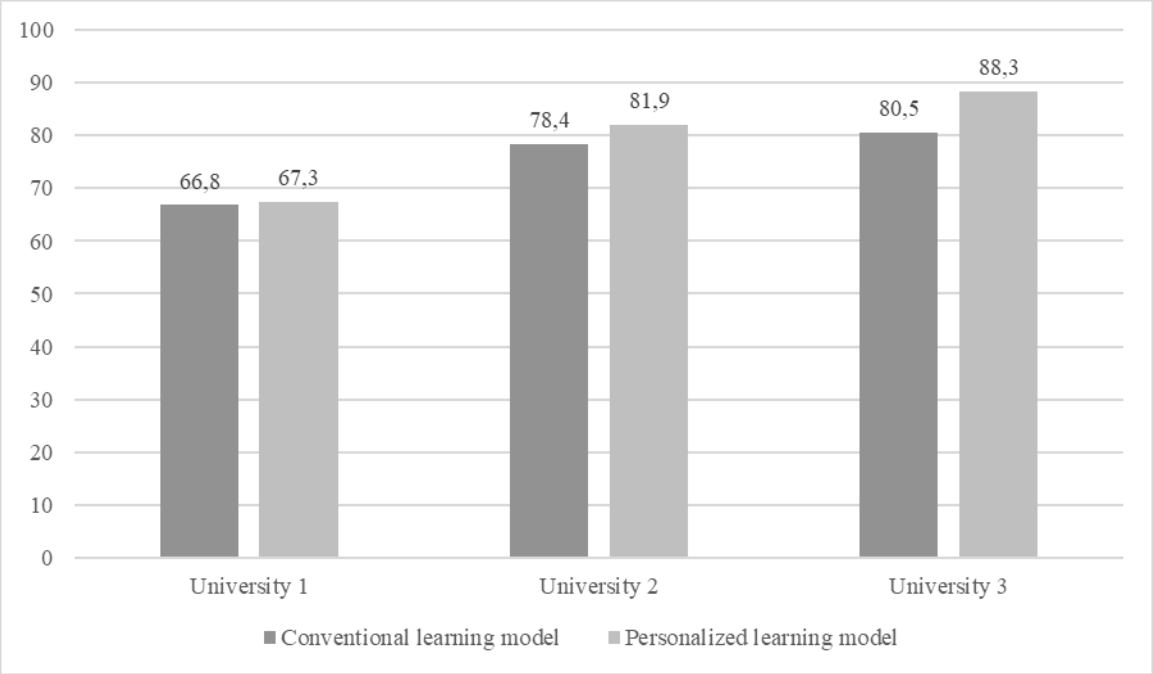

Figure 3. The comparative analysis of efficiency of learning environment in digital medical education

The findings manifest that implementation of personalized learning model in digital medical education based on behavioral analytics increased the efficiency in all three institutions which indicates the importance of case study and applicability of its results. To show the effect size we calculated the efficiency index on the basis of comparison of the data from three universities while applying conventional learning model and personalized learning model. The growth of efficiency index in University 1 is + 0,5%, in University 2 it makes up + 3,5%, and the efficiency index for University 3 counts + 7,8%. Therefore, average efficiency index after implementing the personalized learning model amounts 3,9 %. This reflects the idea of positive impact of personalized

learning model based on behavioral analytics upon the enhancement of digital medical education.

Discussions

The case study results indicated that the prevailing learning styles among students in Ukrainian institutions of higher medical education are converging and accommodating. These findings may help teachers, methodologists and educational administrators orient towards the selection of appropriate teaching strategies and the creation of efficient learning environment within the institutions of higher medical education to maximize students' performance considering their learning experiences and preferred cognitive processes. Personalized learning model is found to be the most correct solution for building the efficient learning environment and selection of the most relevant teaching strategies in the classroom. In addition, personalized learning model provides engaging content, increases motivation, leads to more fulfilling learning experience.

Figure 4 represents the personalized learning model based on behavioral analytics in digital medical education. It indicates the direct correlation between behavioral analytics, learning style and choice of optimal teaching method while delivering in the digital learning environment. Our research showed no relationship between students' learning styles and their age or gender that stipulates for extensive use of the model in different groups and while teaching various courses. Then we come to the description of practical application of the model considering different learning styles among students.

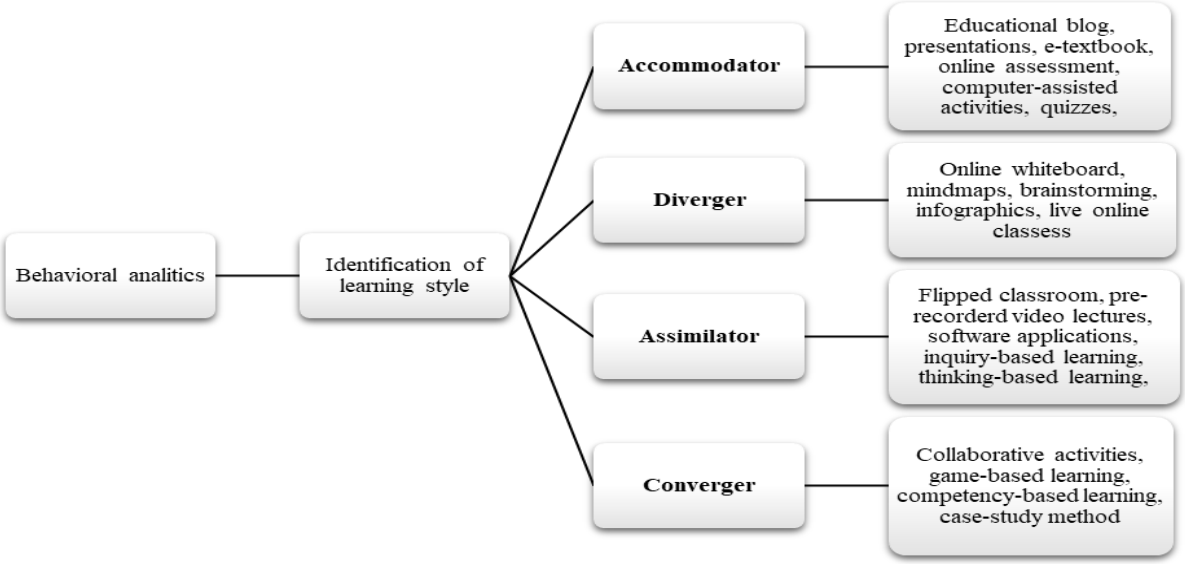

Figure 4. Personalized learning model based on behavioral analytics in digital medical education

Accommodating requires teaching through concrete experimentation. The teacher suggests that students are involved in practical activities in laboratories or using simulations in virtual learning environment. The learners are good at collecting observation data, reading texts, working on professional situation of case studies. Accommodators tend to analyze own errors and study through examples. The best methods for accommodators in digital medical education are the following: educational blog, presentations, work with e-textbooks, online assessment, computer-assisted activities, and quizzes for knowledge revision.

Diverging concerns concrete experience and reflective observation. Divergers are strong at imaginative activities and people-oriented. They are comfortable at communicative exercises like group discussions, brainstorming, pair-work projects, self-correcting interactive online exercises, virtual communication games, group presentation and assignments, live online classes. In addition, the students with diverging learning style prefer graphic format of learning material that indicates the efficiency of learning environment increases when online whiteboard, mindmaps, infographics are used. Short video and group chat are also applicable.

Assimilating is characterized by abstract conceptualization and reflective observation. The activities for students with assimilating learning style include interactive or pre-recordered lectures, flipped classroom, reading with online questionnaires to answer, software applications, inquiry-based learning, thinking-based learning, work in online class discussion groups. Assimilators are good at preparation in self-regulated mode for remote sessions. Also, the students may be asked to create own video mini-lectures or presentations and upload them to the website for group discussion. To increase the learning outcomes, the assimilators require regular individual or group tutorial to reveal the problematic questions.

Converging is related to abstract conceptualization and active experimentation. These students prefer studying by doing which means they are good at collaborative activities, game-based learning, simulation-based activities, competency-based learning, and case-study method. To assess the learning outcomes of convergers multiple-choice tests, performance-based activities, real-time observations are applicable. The students characterized with converging learning style focus on mastery, tend to integrated personal and professional development and study through real-life scenarios.

Converging promotes collaborative learning and contributes to active engagements of all the learners in the classroom.

At the same time, despite the predominance of convergers and accommodators, the study groups are mostly heterogeneous and teachers must develop the strategies to involve all the students and provide high-quality learning process. The case study indicates a number of exercises that can be applicable for the study groups where the students with different learning styles study. In the context of digital medical education, they include the following: massive open online courses (MOOCs) and open educational practices, integrated activities, blended learning, interactive lectures, virtual reality modelling, simulation-based learning, problem-based learning, video games, live patients encounters, e-modules. Assessment in the heterogeneous groups must include computer-assisted tests, real-time observations, interviews, practical activities.

Therefore, due to the using of behavioral analytics the teaching methods in digital medical education may be correlated to enhance the efficiency of learning environment. Moreover, the theory of learning styles and the personalized learning model must be considered while developing educational curriculum in the institutions of higher medical education.

Conclusion

The study provides the analysis of current state using behavioral analytics to personalize learning experiences in digital medical education. We found that due to the increasing role of digital medical education in recent years, a number of innovative digital solutions are implemented, including personalized learning.

Personalized learning is defined as a complex activity approach related to self-organization learning or customized instruction taking into account students' individual needs and objectives. The findings show that in the context of medical education, personalized learning is associated with instructional flexibility, high level of students' situational self-organization, and activated motivation. Theoretical analysis revealed that personalized learning contributes to the enhancement of learning environment and stimulates pedagogical changes in the system digital medical education. The implementation of personalized learning depends on the behavioral analytics and identification of learning styles that actually means a set of preferences and aptitudes for different study styles or modes of instruction. According to the Kolb's theory, there are

four main learning styles that can be applicable for medical students. They include the following: converger, diverger, assimilator, and accommodator.

To assess the learning styles of medical students and to analyze the preferred teaching methods based on the data obtained, we applied the case study method. The research involved 167 students from three institutions of higher medical education in Ukraine. All of them were undergoing bachelor's degree programs on the speciality "General Medicine". The study tool we used was Kolb learning style inventory online (version 3). The findings show that the majority of students belong to the groups from converger and accommodator learning style.

To evaluate the efficiency of learning environment we analyzed the students' learning outcomes, we used the Cohen's approach on format of learning material and optimal teaching methods. The findings manifest that implementation of personalized learning model in digital medical education based on behavioral analytics increased the efficiency in all three institutions. The average efficiency index after implementing the personalized learning model amounts 3,9 %. This proves the idea of positive impact of personalized learning model based on behavioral analytics upon the enhancement of digital medical education.

Study limitations

Our research contains some limitations that should be mentioned in the paper. Hence, the students participating in the case study obtain the bachelor's degrees and study in General Medicine programs. This means the investigation did not consider the behavioral analytics on the students' undergoing master's degree programs and those who study on other specialities such as "Nursing", "Public Health", "Dentistry", or "Pharmacology". This fact may affect the choice of delivering and assessment techniques in different faculties.

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Appendix. The methods used to answer the research questions

No	Research Question	Methods	Purpose
1	What are the characteristics of personalized learning in digital medical education?	Data extraction and analysis in topical order	To characterize the personalized learning model in digital medical education; To reveal its theoretical advantages and elaborate practical orientations for contemporary digital medical education.
2	What are the learning styles among medical students on the basis of the Kolb's theory describing their learning behavior?	Three-part questionnaire	To detect medical students' internal cognitive processes and their preferred activities while learning in the classroom and learning habits during their individual work.
		Methods of	To calculate, describe,

		descriptive statistics	and summarize collected research data on the learning styles among medical students in a logical, meaningful, and efficient way.
3	How to design an effective personalized learning model at the institution of higher medical education using behavioral analytics?	Descriptive model-based design	To design the personalized learning model applicable for the institution of higher medical education through descriptive statistics; To suggest using relevant teaching strategies for digital medical education based on behavioral analytics.
		The methods of empirical educational research (pedagogical observation, immediate students' feedback, analysis of students' learning outcomes)	To verify the effectiveness of teaching strategies.