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Examining Adaptive E-Learning Approaches to Enhance Learning and Individual Experiences

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Abstract

The concept of individualization has emerged as an essential advance in education, representing a paradigm shift adopted by educational systems worldwide. This paradigm evolution aims to optimize student performance by harnessing the potential of diverse e-learning platforms tailored to individual needs. These platforms enable students to acquire knowledge that matches their unique interests and skills. This not only fosters academic prowess but also proactive engagement of stakeholders invested in talent development endeavours. This paper attempts to provide a holistic overview of adaptive e-learning approaches using a recognized categorization framework. This categorization delineates three main approaches: the macro-adaptive approach, the aptitude-treatment interaction approach and the micro-adaptive approach. Through the exposition of illustrative examples within each category, the paper seeks to elucidate and scrutinize the similarities and differences inherent in these approaches. Furthermore, it endeavours to outline the theoretical foundations of the learning process. It contrasts e-learning with traditional learning modalities and examines the transformative impact of e-learning on the learning process and knowledge generation. By delving into the historical trajectory of adaptive e-learning platforms, the paper reveals a symbiotic relationship between their evolution and the evolving principles of education and cognitive science. Ultimately, the study strives to bring a nuanced understanding of the adaptive e-learning landscape and its evolutionary trajectory over time, thereby contributing to the broader discourse surrounding educational innovation and pedagogical progress.

Keywords

Adaptive Learning Approaches; Macro-Adaptive Approach; Aptitude-Treatment Interaction; ATI; Micro-Adaptive Approach; Learning Process; Knowledge Generation.

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1 Introduction

A decade ago, we saw a marked paradigm shift, wherein the notion of widespread individualization in the realm of learning emerged as an innovative concept (Benkhalfallah & Laouar, 2023b; El-Sabagh, 2021). Nowadays, there is a consensus in academic circles acknowledging that adaptive e-learning platforms, characterized by responsiveness to the distinct needs and requirements of students, can significantly augment their academic performance (Benkhalfallah & Laouar, 2023c).

The use of e-learning tools has empowered students to acquire knowledge aligned with their specific interests and aptitudes. Commendable academic outcomes were realized by meticulously considering the requisites of the learner during the developmental phase of the e-learning platform (Bradac & Walek, 2017). Moreover, this approach facilitated the orchestration of interactive sessions, accommodating myriad stakeholders keen on comprehending the holistic context of talent cultivation (Dolenc & Aberšek, 2015).

To incentivize students towards rigorous study and analytical endeavours, learning platforms have systematically instituted an expansive research environment (Klašnja-Milićević et al., 2017). An imperative within this paradigm is the scrutiny of pedagogical methodologies tailored for the adaptation of distance learning modalities to the heterogeneous distribution of diverse skills and knowledge among the student cohort (Sunkara & Kurra, 2017).

This paper makes a comprehensive exploration of the potentials and constraints inherent in adaptive e-learning platforms, delineating key pedagogical approaches. An exposition follows regarding distinct adaptive e-learning platforms, providing a brief overview of their educational features and the approaches embedded in each of them. Additionally, due emphasis is placed on delineating disparities and commonalities between these techniques, stressing their role in enhancing e-learning platforms. A critique of their evolutionary trajectories is presented for scholarly scrutiny. It also highlights the theoretical foundations of the learning process, comparing e-learning with conventional learning formats and exploring the transformative effect of e-learning on the process of learning and the production of knowledge.

The rest of the paper is organized as follows: Section 2 outlines the theoretical underpinnings of the learning process. Section 3 provides a comparative analysis of e-learning and traditional forms of learning. Section 4 is devoted to exploring the transformative impact of e-learning on the learning process and knowledge creation. Section 5 offers a comprehensive description of the main pedagogical approaches. Section 6 presents a review of pertinent literature, which is subsequently analysed and discussed in Section 7. Section 8 concludes the paper.

2 Theoretical Learning Process Definition

The learning process is a dynamic, multi-faceted undertaking that encompasses the acquisition, assimilation, retention and application of knowledge, skills and concepts. Fundamentally, learning involves the internalization and transformation of information, resulting in lasting changes in an individual's cognition, behaviour or ability to perform specific tasks (Oliver & Gershman, 1989). Based on cognitive, behavioural and constructivist perspectives, the learning process is conceptualized as a complex interaction between external stimuli, internal mental processes and environmental factors. At the heart of this conceptualization is the notion of active engagement, according to which learners construct meaning through active exploration, reflection and interaction with their environment (Morton & Johnson, 1991).

From a cognitive standpoint, learning is characterized by processes such as attention, encoding, storage, retrieval and application of information, underpinned by mechanisms such as memory, perception, reasoning and problem solving (O'Donnell & King, 2014). Behaviourally, learning is seen as a product of stimulus-response associations, reinforcement, conditioning and observational learning, with an emphasis

on observable changes in behaviour as indicators of learning (Lückemann et al., 2017). Furthermore, from a constructivist perspective, learning is considered a process of constructing knowledge through interactions with the environment, social interactions and prior experience, with learners actively building their understanding of the world through inquiry, discovery and reflection (Löbler, 2006). It is important to note that the learning process is context-dependent and influenced by individual differences, motivation, socio-cultural factors and the educational environment, with learning outcomes varying according to the interaction of these factors. Thus, the theoretical conceptualization of the learning process underlines its dynamic and multifaceted nature, emphasizing the active, constructive and situated nature of learning as a fundamental aspect of human cognition and development (Zeng et al., 2019).

3 Differences Between E-Learning and Traditional Forms of Learning

E-learning, also known as online learning, and traditional forms of learning differ considerably in several key aspects, affecting the educational experience and learner outcomes. While traditional forms of learning offer valuable face-to-face interaction and social experiences, e-learning offers unrivalled flexibility, accessibility, personalization, interactivity and self-directed learning opportunities, making it an increasingly popular choice for learners seeking convenient, personalized educational opportunities.

Accessibility and flexibility distinguish e-learning from traditional learning methods. With e-learning, learners can access learning materials and participate in learning activities from any location with an Internet connection, offering unrivalled flexibility in terms of time and place. Traditional learning, on the other hand, often requires learners to be physically present in a specific location at specific times, imposing geographical and temporal constraints that can hamper accessibility for people with busy schedules or living in remote regions (Seale & Cooper, 2010). Adaptation and personalization are important features of e-learning platforms. Through adaptive technologies, e-learning platforms can tailor learning experiences to the needs, preferences and learning styles of individual learners. Learners can access customized content, receive personalized feedback and engage in adaptive learning paths that meet their unique needs, promoting a more personalized learning experience compared to traditional classrooms, where teaching is often standardized and less flexible (Klašnja-Milićević & Ivanović, 2021). Moreover, e-learning offers interactive, multimedia-rich content that enhances engagement and understanding. E-learning materials often incorporate multimedia elements such as videos, simulations, interactive quizzes and game-based activities, offering learners diverse modes of representation and opportunities for active participation. In contrast, traditional learning environments may rely more on lectures, which do not always engage learners' interests or adapt to different learning styles (Suarez et al., 2023). Collaborative learning opportunities are also a distinctive feature of e-learning. E-learning platforms facilitate collaboration and communication between learners, instructors and peers through discussion forums, virtual classrooms and collaborative projects. Learners can engage in collaborative learning activities, share resources, exchange ideas and provide feedback to their peers, fostering a sense of community and social interaction that can be lacking in traditional learning environments, where interactions are mainly face-to-face (Suarez et al., 2023). By enabling learners to take control of their learning path and pursue their educational goals autonomously, e-learning fosters essential skills such as self-regulation, time management and information literacy. Conversely, traditional learning may place greater emphasis on instructor-led teaching and the provision of a structured curriculum, offering fewer opportunities for learners to develop these skills independently (Silamut & Petsangsri, 2020).

4 Impact of E-Learning on Learning Process and Knowledge Creation

E-learning has revolutionized the learning process and had a significant impact on knowledge creation by offering innovative approaches to teaching and fostering interactive learning experiences. By employing technology to expand educational opportunities, e-learning enables learners to pursue their educational

goals and contribute to the creation of knowledge in a variety of fields and disciplines. As e-learning evolves, its impact on the learning process and knowledge creation will continue to grow, shaping the future of education and lifelong learning (Al-Emran & Teo, 2020).

One of the main effects of e-learning on the learning process is its ability to improve accessibility and inclusiveness. E-learning platforms offer learners the opportunity to access educational resources and participate in learning activities regardless of their geographical location or physical constraints. This accessibility enables a wider and more diverse audience to participate in learning, including people with disabilities, those living in remote areas and professionals seeking to reconcile their training with other commitments. By removing barriers to access, e-learning expands lifelong learning opportunities and promotes inclusion in education (Seale & Cooper, 2010). Online learning also fosters self-directed learning and empowers learners to take control of their educational journey. Through customizable learning pathways, adaptive technologies and personalized feedback mechanisms, online learning environments allow learners to set their learning objectives, assess their progress and explore topics of interest at their convenience. This autonomy encourages learners to take ownership of their learning, develop critical thinking skills and cultivate a growth mindset, fostering a culture of lifelong learning and knowledge acquisition (Silamut & Petsangsri, 2020). Moreover, e-learning facilitates collaborative and interactive learning experiences that stimulate the creation and exchange of knowledge. Through virtual classrooms, discussion forums and collaborative projects, learners can engage with peers, instructors and subject matter experts from all over the world, sharing ideas, viewpoints and diverse perspectives. Collaborative learning activities encourage active participation, social interaction and collective problem solving, fostering a dynamic learning community where knowledge is co-created through collaborative investigation and peer collaboration (Suarez et al., 2023). Furthermore, e-learning exploits multimedia and interactive technologies to improve commitment and comprehension. By embedding multimedia elements, e-learning platforms cater to diverse learning styles and preferences, making learning more engaging and enjoyable. Interactive learning experiences promote deeper understanding, retention and application of knowledge, as learners actively participate in the learning process and apply their knowledge in real-world contexts (Mayer, 2017).

5 Pedagogical Approaches to Adaptive Learning

Three fundamental adaptive learning approaches are discerned, elucidated in Figure 1: the macro-adaptive approach, the aptitude-treatment interaction (ATI) approach and the micro-adaptive approach.

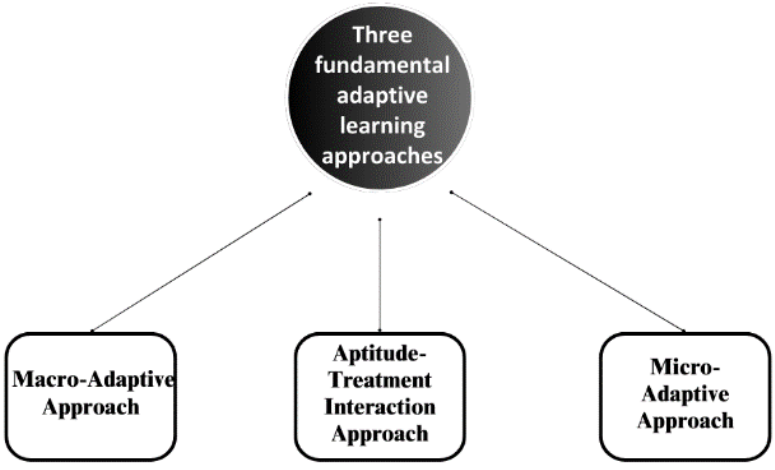

Figure 1. *Pedagogical approaches to adaptive learning.*

5.1 Macro-adaptive approach

The macro-adaptive approach revolves around tailored adaptation of a comprehensive instructional design or curriculum (content) to suit the distinct requisites of varied learner cohorts (Smyrnova-Trybulska et al., 2022). This entails the formulation of manifold pathways and diverse iterations in learning materials, activities and assessments to cater to the heterogeneity inherent in learner profiles. These pathways are strategically delineated based on multifaceted determinants, encompassing prior knowledge, learning predilections, interests and overarching educational objectives. The guidance thus channels learners towards bespoke courses, aligning precisely with their individualized needs, thereby effectuating a nuanced and expansive personalized learning experience (Benkhalfallah & Bourougaa, 2022).

For example, in language learning, disparate versions of instructional content may be conceived to cater to learners exhibiting different levels of language proficiency. Subsequently, learners are methodically allocated to the specific version harmonizing with their proficiency level, thereby facilitating advancement along a trajectory corresponding with their linguistic competencies.

5.2 Aptitude-treatment interaction approach

The ATI approach directs its focus towards appropriateness, conscientiously considering the nuanced interplay among learners' aptitudes, specific characteristics and the instructional treatments and interventions imparted (Smyrnova-Trybulska et al., 2022). Its primary objective lies in meticulous alignment of learners with bespoke teaching strategies and methods, tailored to optimize efficiency according to their distinctive characteristics. This conceptual framework acknowledges the inherent diversity in learners' strengths, preferences and learning modalities, thereby endeavouring to provide them with the most efficient teaching methodologies attuned to these individual factors (Benkhalfallah & Bourougaa, 2022).

For example, within a system predicated on the ATI approach, learners characterized by distinct aptitudes, including visual or auditory dispositions, may be subject to different teaching modalities adapted to their individual preferences. Specifically, individuals showing a pronounced predilection for visual learning may be exposed to more visual aids, such as graphics or videos, as a strategic means to fortify and augment their comprehension. This approach acknowledges the heterogeneity in learner responses to diverse educational methods contingent upon their traits. Consequently, those exhibiting a propensity for critical thinking might be exposed to more intricate and analytically rigorous tasks designed to stimulate and foster their cognitive acumen.

5.2.1 Intelligent tutoring system

Intelligent tutoring systems (ITS), rooted in the ATI approach, serve as computational platforms designed for the discernment of users' proficiencies. Constituting a computer-based learning apparatus, an ITS provides bespoke instructional guidance and feedback to learners. Propelled by artificial intelligence (AI) and other cutting-edge technologies, it emulates the pedagogical role of a human tutor, steering students through diverse learning tasks and providing tailored support depending on their individual requisites and performance metrics. Its chief objective lies in enhancing the learning environment by dynamically accommodating the learner's cognizance level, learning predilections and ongoing progress. Versatile in its scope, the ITS provides tutelage, practice sessions, assessments and feedback across a diverse spectrum of subjects and disciplines, spanning mathematics, sciences, language acquisition and programming, among others. These systems offer the prospect of complementing or supplanting traditional classroom instruction, providing learners with interactive, personalized learning. Widely deployed in education, encompassing both formal academic institutions and individualized self-paced learning trajectories, the

ITS stands as an efficient instrument for improving student comprehension and retention of educational material (Wang et al., 2023).

5.2.2 Adaptive hypermedia system (AHS)

Adaptive hypermedia systems are another example within the ATI approach. This computer-based system orchestrates a dynamic modulation of information display tailored to individual users, based on their inclinations, interests and requisites. This paradigm combines the fundamental principles of hypermedia, i.e., interconnected multimedia documents and adaptability, resulting in bespoke customization of content and structural facets to align with each user's specific needs. Unlike conventional hypermedia systems, characterized by users traversing fixed links and static content, an adaptive hypermedia system uses diverse techniques and technologies to provide a bespoke and interactive environment. Its operational framework includes a systematic analysis of user attributes, behaviour and contextual cues to actively engender and dispense pertinent and meaningful content, thereby enhancing the user's experience, optimizing information retrieval and fostering efficient knowledge acquisition (Suarez et al., 2023).

5.2.3 Adaptive educational hypermedia system (AEHS)

The adaptive educational hypermedia system (AEHS) represents a specialized iteration of the broader adaptive hypermedia system (AHS) paradigm, singularly concentrating on the delivery of educational experiences that are both personalized and adaptive. The AEHS strategically harnesses the tenets underpinning adaptive hypermedia and instructional technologies, providing tailored educational content and support to learners. Its principal aim is augmentation of the learning trajectory through dynamic adaptation of content and educational resources to align with the learner's unique requirements. This strategic alignment is realized through the cultivation of individualized learning pathways, thereby increasing learner engagement and attainment. The AEHS is based on deployment of adaptive technologies and educational principles, resulting in a concerted effort to enhance the learning process and expedite more efficient acquisition of knowledge and skills by learners (Jing et al., 2023).

5.3 Micro-adaptive approach

The micro-adaptive approach is based on real-time adjustments and tailoring within the learning environment in response to the learner's specific responses, behaviour and feedback (Smyrnova-Trybulska et al., 2022). This method utilizes advanced technologies, sophisticated techniques and algorithms rooted in data analysis to monitor and examine learners' interactions during learning activities. Using these accrued data and through a comprehensive tracking of learner performance, engagement and overall progress, the system is adept at dynamically fine-tuning elements such as content, difficulty levels and instructional delivery. The system also provides constructive comments and suggestions, thereby accommodating the learner's needs and providing indispensable support for their ongoing progress. This approach seamlessly facilitates continual modifications, providing instantaneous feedback and personalized recommendations, coupled with precisely targeted interventions geared towards enhancing and refining the overall learning experience (Benkhalfallah & Bourougaa, 2022).

For example, in an online mathematics course based on the micro-adaptive approach, the instructional system presents a sequence of mathematical problems to learners. As the learner successfully negotiates each problem, the system analyses their responses and makes a nuanced adjustment in the difficulty level of ensuing problems to match the demonstrated skills. Furthermore, the system may proactively offer explanatory hints or alternative methodologies, precisely tailored to rectify the learner's particular misconceptions or errors, thereby fostering more fine-grained and targeted learning.

Overall, these adaptive learning approaches aspire to enhance pedagogical efficiency by tailoring the educational encounter to individual learners' specific requirements. The macro-adaptive approach focuses

on the crafting of distinct instructional variants for specific cohorts of learners, operating at a more comprehensive curriculum level. In contrast, the ATI approach aligns teaching methodologies with the inherent aptitudes of learners, based on their individual characteristics. The micro-adaptive approach engenders real-time feedback mechanisms and dynamic adjustments throughout the learning continuum. Each approach harnesses technology, data analytics and educational instrumentation to cultivate a learning environment that is not only personalized but also inherently efficient.

6 Brief Literature Review

Despite its inherent adaptability in assuring accessibility and learning prospects, e-learning is beset by an intrinsic deficiency in providing education attuned to individual learners' specific requisites, aptitudes, proficiencies and learning modalities. To overcome this limitation, adaptive e-learning platforms have emerged, envisaging the provision of bespoke education harmonized with each learner's particular requirements, competencies and attributes. This pursuit has gained noteworthy scholarly attention, especially during the past global pandemic (Benkhalfallah & Bourougaa, 2022). Consequently, there have been attempts to conceive and implement adaptive e-learning platforms that accommodate the multifaceted demands of learners, thereby ensuring a more individualized and tailored educational environment for distinct individuals (Benkhalfallah & Laouar, 2023a).

In this section, we will present adaptive e-learning platforms adapted from various relevant academic databases in December 2023, including Scopus, Web of Science, ACM Digital Library, IEEE Xplore Digital Library and INSPEC, which employ different methods described and suggested in the field to better understand current research into this topic by using the keywords "adaptive e-learning platforms" and adaptive learning approaches".

A recent study (Hamada & Hassan, 2017) introduced an enhanced version of e-learning platforms employing the ATI approach. This advancement builds upon the Felder-Silverman learning style model, introducing an additional dimension that encapsulates the emotional and social learning styles exhibited by individual learners. The study describes the integration of this novel learning style model into an adaptive e-learning platform, explaining its operational integration for increased efficiency. The study emphasizes the need to account for students' learning styles, stating that this consideration substantially contributes to the enhancement of their learning performance through the provision of a gamut of learning activities tailored to individual preferences.

The MALO (model of adaptation of learning objects) solution (Guevara et al., 2017) undertakes customization of content, presentation format and learning trajectory for each learner. Based on the micro-adaptive approach, this solution incorporates individual students' background knowledge and skill sets to dynamically tailor the learning objects. Starting with the evaluation of the user's existing competencies, the adaptation process proceeds to delineate the desired competence as the paramount objective. This specified objective serves as the basis for discerning and implementing the precise adaptation process.

Ciolacu & Beer (2016) introduced an adaptive user interface crafted for online learning in higher education. This interface employs the ATI approach to individualize the learning content in alignment with each learner's specific needs. Accommodating distinct knowledge levels within a heterogeneous student cohort, the mechanism endeavours to provide introductory mathematical courses. This is executed through an initial evaluative test gauging participants' knowledge backgrounds and competencies. Subsequently, the system strategically presents pertinent chapters of the course while judiciously concealing sections deemed superfluous for each participant, ensuring a tailored and efficient learning experience.

The development of an e-learning platform was examined by Mahnane et al. (2013), with an emphasis on its foundation in the micro-adaptive approach. This solution factors in an array of variables, encompassing

the learner's objectives, inclinations, cognitive processes, favoured teaching styles, preferred learning styles, prior knowledge and academic proficiency. Through the dynamic adaptation of learning materials, sequencing of instructional content and navigation pathways within the system, a tailored and personalized learning experience is provided. Furthermore, the framework gives learners the opportunity for introspective evaluation of their understanding and progress, facilitated by assessment tests, contributing to a comprehensive and insightful understanding of their cognitive journey.

Mustafa & Sharif (2011) focused on the formulation of a hypermedia learning system based on the micro-adaptive approach. This system makes nuanced adjustments across diverse dimensions, encompassing the modality of presentation (text, image, audio and video), the structuring of learning content (facilitated by judicious course segmentation) and the navigational dynamics (effected through the creation of hypertext links). These refinements are aligned with the learner's specific requirements, encapsulating their profile, predilections in learning styles and attained knowledge levels. The amalgamation of these personalized adaptations results in an intricate and tailored educational environment, increasing the efficiency of the learning experience.

As expounded by El Bachari et al. (2011), LearnFit is an e-learning framework based on the micro-adaptive approach. Its process starts with judging learners' inclinations, rooted in their distinct personalities. This distinction is facilitated by the application of the Myers-Briggs type indicator (MBTI) method. In conjunction with this psychometric method, LearnFit incorporates considerations such as the learner's objectives, knowledge proficiency, preferred language and unique identity. The ensuing synthesis involves an individualized pairing of each personality type with a congruous learning approach within the LearnFit framework. This synergy serves to not only tailor the learning process but also to mould the structural underpinnings of the support provided. If the learner falls short of the stipulated proficiency in assessment tests, the framework modulates the teaching strategy based on the diagnostic insights from the learner's results.

El-Bakry et al. (2011) presented an intelligent e-learning platform that employs the macro-adaptive approach. This system calibrates the learning sequence and procedural dynamics, attuned to each user's profile. An emphasis is placed on discerning the static attributes of the user's learning style, recognizing the underlying inclinations of their cognitive engagement. Moreover, the process culminates in an assessment test provided for the user after completing each learning unit. This evaluative interlude identifies the gaps and requisites intrinsic to the learner's comprehension, contributing to iterative refinement of the overall approach.

Based on the principles of the ATI approach, Popescu et al. (2010) presented an innovative pedagogical path in the form of web-based educational system with learning style adaptation (WELSA). WELSA is a versatile erudition environment, distinguished by its adaptive prowess, giving it the ability to recalibrate the structure, presentation and sequence of the learning trajectory. Noteworthy in its functionality, this method amalgamates both static and dynamic attributes. It integrates the learner's historical progression, established learning predispositions and interactions and engagements within the educational system. A distinguishing feature of WELSA is its proneness for implicit user identification, engaging in a nuanced analysis and interpretation of user actions to inform a sophisticated adaptation process. In the WELSA framework, the pedagogical content is not just a static repository but a dynamic entity. Teachers, as custodians of academic insight, have the opportunity to contribute to the WELSA database. This symbiotic collaboration enables the calibration of specific parameters for each course, with considerations such as the difficulty level factored into the adaptive process. The educational portal also offers users a discussion forum. These features show that WELSA is committed to fostering an interactive, collaborative environment, where exchange of educational content is facilitated, resulting in a rich e-learning system.

7 Analysis and Discussion

Upon careful examination of the aforementioned adaptive e-learning paradigms, discernible constraints emerge, primarily rooted in the lack of a mechanism that systematically traces a learner's historical trajectory and complex interactions within the e-learning environment. Many existing platforms show a tendency for a collaborative learning environment yet fail to provide a robust infrastructure for educators to easily monitor their pupils' progress. The prevalent way of gauging a learner's time investment in the e-learning interface, while informative, falls short of the potential efficiency that could be gained by predicting the learner's subsequent actions. The envisaged anticipatory approach builds its utility on the learner's spatial disposition and navigational patterns within the platform, providing a more nuanced comprehension of the learner's inclinations. Moreover, the need for a mechanism that carefully evaluates a learner's trajectory through the learning process is a sine qua non for these platforms. This yardstick becomes indispensable for bringing informed insights and making improvements to the overall learning experience. It is noteworthy that the prevalent solutions often hinge on a limited spectrum of learner features, a limitation that could potentially impede the precision of defining optimal learning materials tailored to individual users. To increase efficiency, a wise solution would involve the provision of additional features aligned with the distinct objectives of the system. This addition would strengthen the adaptability of these platforms, making them more attuned to individual learners and increasing the precision of management processes.

For instance Guevara et al. 2017) focused on the adaptation of format, content and learning trajectory, yet it predominantly employed rudimentary skills and knowledge as the core of its adaptive mechanisms. In this context, the identification of the user's learning style would be a strategic improvement, bringing the advantage of recognizing the most appropriate learning trajectory and presentation format. As explained by Hamada & Hassan (2017), another model requires the assimilation of additional aspects, including background knowledge, for the augmentation and provision of an efficient learning environment. A marked contrast appears when comparing these approaches with Mahnane et al. (2013), where the adaptations espoused by Guevara et al. (2017) and Hamada & Hassan (2017) show a lack of real-time information updates. These adaptations primarily pivot on the knowledge level as the preeminent feature for learning accommodation, requiring periodic assessment tests after each learning engagement to check the user's knowledge progress.

Table 1 provides a comparative outline of the educational features and approaches inherent in the selected adaptive e-learning platforms described above. From this table, it can be seen that most of the listed platforms clearly integrate both the ATI and micro-adaptive approaches. In contrast, the macro-adaptive approach is the least recurrent modality among these educational frameworks.

The future of adaptive e-learning platforms requires an educational paradigm shift, characterized by personalized, engaging and effective learning experiences that meet the diverse needs of learners. As technology evolves, these platforms are likely to assume a pivotal role in shaping the future landscape of education and lifelong learning. Within this narrative, several emerging trends and forward-looking solutions have been considered to characterize this field in the coming era (Truong, 2016). Foremost among these is the burgeoning integration of artificial intelligence and machine learning, envisaged to profoundly increase the personalization of learning experiences (Murtaza et al., 2022). In addition, they may offer multimodal learning experiences that incorporate diverse formats such as text, images, videos, simulations and virtual reality (Truong, 2016). Moreover, a move towards the integration of social and collaborative learning features is expected, fostering interactive engagement and knowledge exchange within virtual learning communities (El Mhouti et al., 2017). Furthermore, the ubiquity of mobile technology is likely to facilitate pervasive access and mobile learning, enabling learners to seamlessly access personalized learning content across a variety of devices and platforms and facilitating continuous learning efforts and knowledge retention (Truong, 2016). At the same time, the adaptive e-learning

platforms of the future will be ready to integrate adaptive assessment tools and feedback mechanisms, dynamically adapting the difficulty and format of assessment according to learners' performance and skill levels (Kolekar et al., 2019). Additionally, a great emphasis is placed on personalized learning paths, which are tailored to each learner's objectives, interests, learning styles and prior knowledge (Murtaza et al., 2022). Also, the advent of advanced analytics and learning analytics tools is likely to give educators and administrators in-depth insights into learners' progress, engagement and learning outcomes. Ultimately, ethical considerations and privacy protection are set to become of paramount importance, given the increasing use of learner data in adaptive e-learning platforms (Klašnja-Milićević & Ivanović, 2021).

Table 1. *Comparative overview of educational functionalities and approaches of certain adaptive e-learning platforms.*

Platforms	Educational functionalities	Approaches used		
		Macro-adaptive approach	Aptitude-treatment interaction (ATI) approach	Micro-adaptive approach
Hamada & Hassan (2017), Salau et al. (2022)	Incorporates emotional and social learning styles		✓	
Guevara et al. (2017), Kim et al. (2023)	Customized content, format and learning path			✓
Ciolacu & Beer, (2016), Gu & Amini Behbahani (2021)	Tailoring learning content based on individual needs		✓	
El-Sabagh (2021), Mahnane et al. (2013)	Personalized learning experiences			✓
Khamparia & Pandey (2020), Mustafa & Sharif (2011)	Adjusted presentation type, learning content and navigation			✓
El Bachari et al. (2011), El-Sabagh (2021)	Considers the learner's preferences and objectives			✓
El-Bakry et al. (2011), Pan et al. (2021)	Adapted learning sequence and process	✓		
Arsovic & Stefanovic (2020), Popescu et al. (2010)	Adjusted structure, format and order of the learning process		✓	

8 Conclusion

Educational paradigms and platforms have undergone profound transformations, catalysed by factors such as technological advancements and the burgeoning expansion of knowledge. Within the domain of adaptive learning, we examined various pedagogical approaches, including micro and macro-adaptive approaches, delving into their influences on the learning process. Notably, the deployment of intelligent systems, exemplified in the ATI approach, is acknowledged for its substantive impact on students' aptitude development and cognitive autonomy. This influence becomes particularly pronounced when these intelligent systems are harmonized with the specific objectives and purposes delineated by individual students.

The findings of this research indicate that adaptive e-learning platforms systematically employ three primary adaptation modalities: macro-adaptive approaches, micro-adaptive approaches and the ATI

approach. Macro-adaptive approaches are distinguished by their static nature, allowing students to learn at a self-directed pace. Conversely, micro-adaptive approaches manifest as dynamic processes, closely tracking student behaviour during application engagement, thereby facilitating system adjustments through judicious modifications of links. The ATI approach, on the other hand, involves providing students with diverse materials based on their individual skills and proficiency levels. The incorporation of these adaptation approaches enables the creation of fully adaptive systems, offering a comprehensive approach to personalized learning experiences.

Additional Information and Declarations

Conflict of Interests: The authors declare no conflict of interest.

Author Contributions: F.B.: Conceptualization, Methodology, Formal Analysis, Writing – Original draft. M.L.: Supervision. M.B.: Validation, Writing – Reviewing and Editing.

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