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SHORT REVIEW ON APPLICATIONS OF ADAPTIVE AND PERSONALISED LEARNING IN ENGINEERING EDUCATION

Muhammad Amin Azman[1*], Muhammad Azim Azizi[1], Abdul Hadi Azman[2,3]

[1]Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia
[2]Department of Mechanical & Manufacturing Engineering,
Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia
[3]Centre for Engineering Education Research,
Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia
(*Corresponding author: amin.azman@upm.edu.my)

Abstract

Adaptive and personalized learning are improving engineering education by addressing the shortcomings of traditional, uniform teaching methods. Leveraging technologies such as AI, learning analytics, and real-time feedback, these approaches customize content to match each student's pace, strengths, and needs. This enhances engagement, retention, and mastery of complex technical concepts. Tools like adaptive platforms, tagging systems, and digital portfolios foster autonomy and self-regulated learning. Studies across various engineering fields show improved motivation, understanding, and performance when students learn through personalized, interactive systems. As industry demands evolve, adaptive learning prepares students for interdisciplinary careers and aligns education with modern technological and professional needs.

Keywords: Adaptive learning, Personalized learning, Engineering, Education

Abstrak

Pembelajaran adaptif dan diperibadikan sedang memperbaiki landskap pendidikan kejuruteraan dengan mengatasi kekangan kaedah pengajaran tradisional yang seragam. Pendekatan ini memanfaatkan teknologi seperti AI, analitik pembelajaran, dan maklum balas masa nyata untuk menyesuaikan kandungan mengikut kadar, kekuatan, dan keperluan setiap pelajar. Ini meningkatkan penglibatan, pengekalan, dan penguasaan konsep teknikal yang kompleks. Alat seperti platform adaptif, sistem penandaan, dan portfolio digital turut menggalakkan autonomi dan pembelajaran kendiri. Kajian dalam pelbagai bidang kejuruteraan menunjukkan peningkatan dalam motivasi, kefahaman, dan prestasi apabila pelajar belajar melalui sistem yang diperibadikan dan interaktif. Dengan permintaan industri yang semakin berkembang, pembelajaran adaptif membantu menyediakan pelajar untuk kerjaya antara disiplin dan menyelaraskan pendidikan dengan keperluan teknologi serta profesional moden.

Kata kunci: Pembelajaran Adaptif, Pendidikan Kejuruteraan

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1.0 INTRODUCTION

Engineering education is a dynamic and multidisciplinary field designed to prepare students for solving complex real-world problems by combining theoretical knowledge with practical applications (Bustamante-Mora et al., 2023; Nutwell et al., 2023). It involves a core curriculum in mathematics, science, and engineering fundamentals, alongside specialised courses in various disciplines such as civil, mechanical, and software engineering. Practical components like laboratory work, internships, and team projects are integral, helping students develop problem-solving, teamwork, and communication skills. In recent years, as industries rapidly evolve with advancements in technology and a focus on sustainability, engineering education faces the challenge of equipping students with both foundational knowledge and cutting-edge skills to meet these demands.

Engineering education faces numerous challenges that significantly impact the effectiveness of teaching and learning processes. One of the predominant issues is the difficulty in balancing theoretical knowledge with practical application. Many curricula emphasize theoretical content at the expense of hands-on experiences, which can lead to student disengagement and higher attrition rates. As noted by Mitchell et al. (Mitchell et al., 2021), traditional engineering faculties are urged to provide innovative education while being constrained by existing curricular structures. The need for practical skills, often imparted through hands-on methodologies, is critical for student engagement and retention, but resource limitations frequently hinder the implementation of such strategies (Guerra & Rodriguez-Mesa, 2021).

Another significant challenge is the fast-changing technological landscape, which necessitates continual curriculum updates and shifts in teaching methodologies. The rapid evolution of technology creates pressure on educators to remain current, but faculty preparedness and institutional resources often fail to keep pace with these changes. Liu Liu (Q. Liu, 2019) notes that engineering education research emphasizes the necessity of adapting curricula to include emerging technologies and accommodate various learning methodologies to support all students' learning processes effectively. Diversity in students' backgrounds and learning styles further complicates educational equity. Varied pre-university preparation levels often lead to disparities in students' readiness for engineering studies. Cognitive development and different learning styles, which can range from visual to kinesthetic learners, are not always addressed within traditional, lecture-centric instructional designs (Jalinus et al., 2022; Peng et al., 2019). This mismatch can hinder some students' abilities to absorb and apply course material adequately.

In summary, engineering education is at a crossroads, where addressing the balance between theory and practice, updating curricula in line with technological advancements, and accommodating diverse learning needs are paramount for ensuring student success and enhancing educational outcomes. Consequently, addressing these challenges requires a shift towards more personalized and adaptive learning environments that consider individual students' differences and needs. The integration of adaptive learning technologies can provide more tailored educational experiences and support varying cognitive abilities, ultimately aiming to foster a more inclusive educational atmosphere within engineering disciplines (C. Liu & Sun, 2025; Mirata et al., 2020).

The objective of this review paper is to examine the applications of adaptive and personalised learning, specifically within engineering education. Figure 1 shows the number of articles retrieved from the Scopus database on the topic, indicating a consistent level of interest in this area in the past 10 years. By synthesising

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current research on this topic, the paper aims to provide educators, researchers, and institutions with actionable insights into integrating these innovative approaches into engineering curricula. This review article follows the structure as presented in Figure 2.

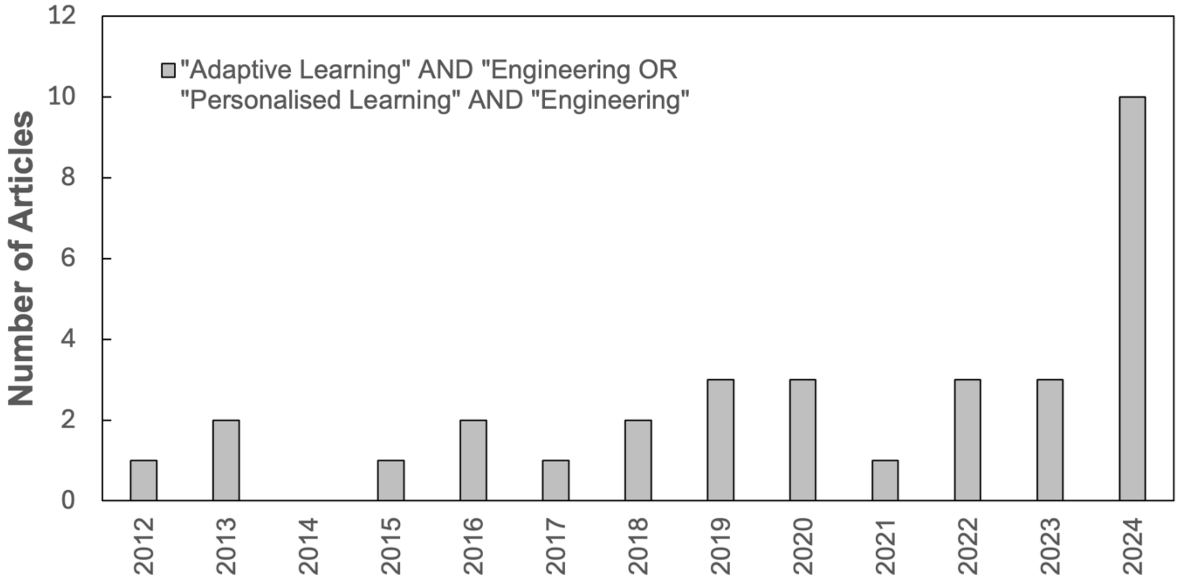

Figure 1: Number of articles searched on the Scopus database on the topic in "Article Title" from 2012-2024. The keywords used are: ("Adaptive learning" AND "Engineering") OR ("Personalised learning" AND "Engineering).

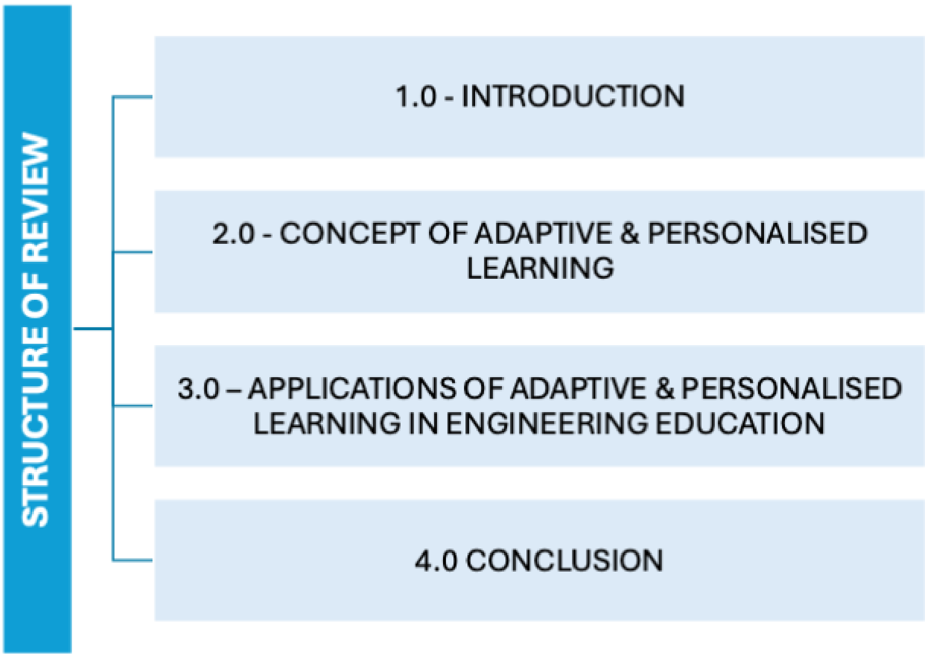

Figure 2: Structure of review

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2.0 CONCEPT OF ADAPTIVE & PERSONALISED LEARNING

As the education eco-system adapts to advancements in technology and society needs, the education system must adapt and accommodate these changes. Future Ready Curriculum (FRC) is an essential part of this approach. There are three main elements in FRC, which are fluid and organic curriculum structure, transformative learning and teaching delivery, and alternative assessment, as shown in Figure 3 (Azman et al., 2024). Adaptive and personalized learning can be found in element 2 and 3, which are transformative learning and teaching delivery, and alternative assessment respectively. Future Ready Curriculum is a flexible and organic education model that can produce adaptable and future-proof graduates to adresss the 21st century challenges.

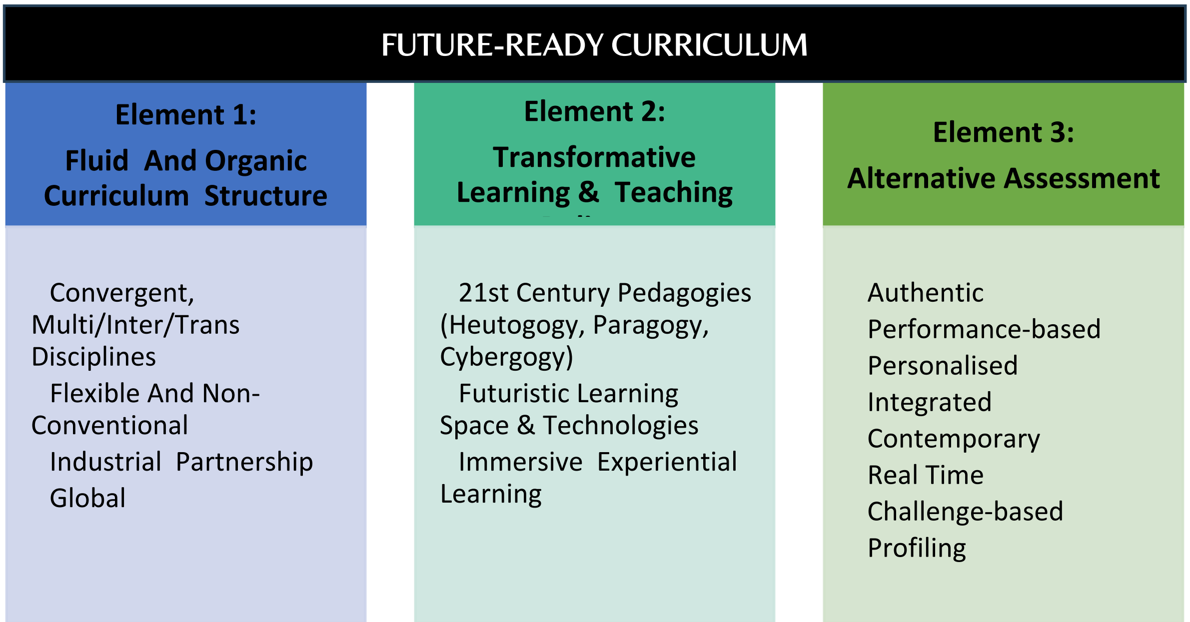

Figure 3: Future-ready curriculum (Azman et al., 2024).

Adaptive and personalised learning are educational approaches that tailor the learning experience to individual learners' needs, preferences, and characteristics, often with the support of technology (Peng et al., 2019). Adaptive learning refers to systems that modify their content and instructional strategies based on real-time data about a learner's performance and engagement (Alexsius Pardosi et al., 2024; C. Liu & Sun, 2025; Peng et al., 2019) This adaptability is often driven by algorithms that analyse a learner's interactions with the system, allowing for a dynamic adjustment of learning paths and resources. For instance, adaptive learning systems can provide different types of content or adjust the difficulty level of tasks. This is based on the learner's demonstrated understanding, thereby facilitating a more effective learning process.

Personalised learning, on the other hand, encompasses a broader scope that includes not only the adaptation of content but also the customization of learning experiences based on individual learner profiles. These profiles may include their interests, learning styles, and prior knowledge (Jamia, Millia Islamia & Kem, 2022). Personalised learning systems

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aim to create a unique learning journey for each student, often utilising learner models that capture various attributes such as cognitive abilities, emotional states, and learning preferences (Sunar & Abdullah, 2016). This approach is particularly beneficial in addressing the diverse needs of learners. It allows them to progress at their own pace and engage with materials that resonate with their personal learning goals.

The integration of adaptive and personalised learning is increasingly facilitated by advancements in artificial intelligence and machine learning. These technologies enable systems to analyse vast amounts of data and make informed decisions about how to best support each learner (Orji & Vassileva, 2022). For example, systems can utilize data from previous interactions to predict future learning behaviours and adjust the educational content accordingly, thereby enhancing the overall learning experience (T Alshammari & Qtaish, 2019). Furthermore, the combination of these approaches not only improves engagement and motivation among learners but also fosters better educational outcomes by providing a more tailored and responsive learning environment.

The recent Covid-19 pandemic significantly affected student performance, particularly in engineering courses that rely heavily on strong theoretical understanding and hands-on practice (Asgari et al., 2021). While some students adapted well to online learning, others struggled—especially those with limited access to technology or difficulty concentrating in virtual environments. These challenges were especially evident in science and mathematics subjects. Adaptive and personalized learning emerged as a valuable solution, allowing instruction to be tailored to individual needs and enabling students to learn at their own pace and according to their unique circumstances.

In summary, adaptive and personalised learning represent a significant shift from traditional, one-size-fits-all educational models. By focusing on the unique characteristics and needs of each learner, these approaches aim to create more effective, engaging, and meaningful learning experiences that can lead to improved academic performance and learner satisfaction.

3.0 APPLICATIONS OF ADAPTIVE AND PERSONALISED LEARNING IN ENGINEERING EDUCATION

Adaptive and personalised learning systems are improving engineering education by providing personalized instruction that adjusts based on each student's learning progress and performance. Recent developments have seen artificial intelligence (AI) significantly enhance the effectiveness of adaptive learning systems in engineering education. The integration of artificial intelligence aligns with the Education 4.0 framework, which emerged in response to the demands of Industry 4.0 (Ciolacu et al., 2017). This shift calls for a redefinition of skills, competencies, teaching methods, and assessment strategies to meet the evolving needs of the industrial landscape. As illustrated in Figure 4, Education 4.0 encompasses seven AI-driven features.

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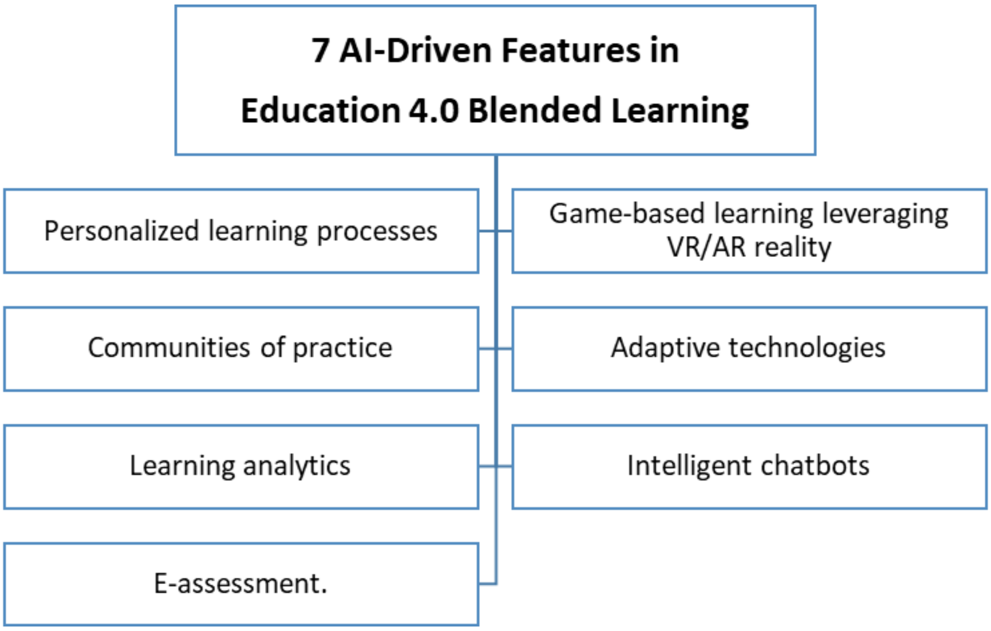

Figure 4: Technological elements & tools of Education 4.0 (Ciolacu et al., 2017)

In another study, a tool using AI and a long short-term memory (LSTM) neural network was developed to provide personalized teaching for engineering education, adapting to the unique learning styles of its users (Isaza Domínguez et al., 2024). Based on the Felder–Silverman Learning Style Model (FSLSM) in Figure 3, learners were categorized across four dimensions: active/reflective, sensing/intuitive, visual/verbal, and sequential/global. A custom survey tracked weekly learning style changes among 72 engineering students at the University of Los Llanos, providing data to train the LSTM model for predicting transitions over a 16-week term. Two interfaces were developed—one for instructors with the LSTM integration and one for students with the survey. Both included an OpenAI API-powered chat to offer learning support and help educators tailor their teaching approaches.

Balfaqih and Balfagih (2024) outlined how AI facilitates real-time data analysis, learning analytics, and immediate customization of content in engineering education. AI algorithms interpret student behaviors, assess their strengths and weaknesses, and dynamically adjust instructional materials accordingly. This constant feedback loop ensures that learners receive support at critical moments of difficulty. Other innovations include using blockchain and AI can be used together to secure and personalize chemical engineering content (Pullanikkattil et al. 2025). Slomp et al. (2024) showed that integrating AI-driven adaptive systems can significantly enhance student academic outcomes in engineering courses. Rajesh et al. (2024) showcased how AI can drive inclusive and personalized learning strategies at scale. Ragab (2025) explored prompt engineering and generative AI as tools for crafting adaptive STEM education environments. These innovations point to a future where learning is both intelligent and deeply personalized. Ultimately, AI-based adaptive systems help transform engineering education into a more personalized and data-driven experience. The integration of AI contributes to more efficient teaching strategies, reducing the burden on educators while increasing precision in learning support.

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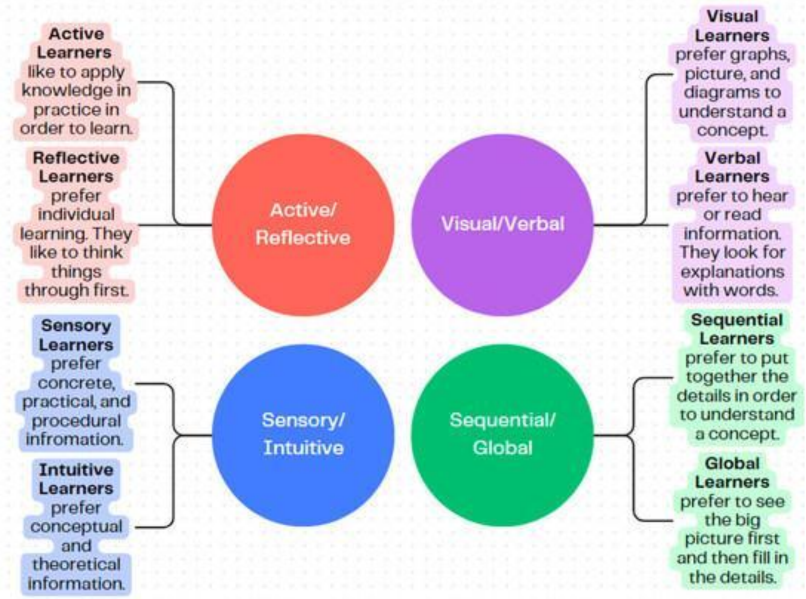

Figure 5: Names of each learning style and their description (Isaza Domínguez et al., 2024) (Reproduced under the terms of CC BY-NC 4.0).

The application of adaptive learning has been particularly beneficial in teaching software engineering. Simmilarly Chikasha et al. (2022) examined multimedia elaboration designs in software engineeringthat adapt to individual cognitive needs, leading to improved learning outcomes. These systems accounted for varying levels of prior knowledge and delivered instructional material at appropriate difficulty levels. The personalized approach helped demystify complex programming concepts for learners. It also increased learners' satisfaction and retention of course content, underscoring the value of adaptive learning in technical fields.

Barclay et al. (2020) presented a case study on implementing adaptive learning in an engineering technology course, which revealed promising outcomes. The study showed that adaptive platforms provided tailored learning paths based on initial diagnostic assessments. This personalization enabled students to bypass content they had already mastered and focus more on challenging areas. The approach significantly improved student performance and engagement in the course. It also facilitated self-regulation and enhanced students' confidence in their learning abilities.

Balakrishnan and Long (2018) explored how personalized learning platforms supported engineering students during the COVID-19 pandemic, particularly in remote and self-paced environments. The self-directed models enabled students to navigate content based on their readiness and mastery, helping them maintain academic continuity. These systems allowed learners to take ownership of their educational journeys, supported by scaffolding tools embedded in the platforms. They also helped instructors monitor progress asynchronously, offering targeted feedback and intervention. Even during times of restricted face-to-face teaching, personalized learning ensured engagement and resilience. Rincon-Flores et al. (2024) emphasized the value of retrieving and building upon students' prior knowledge through adaptive platforms. The findings affirmed the value of adaptive platforms in addressing educational disruptions and individual learning variability. These efforts collectively aim to promote equity, personalization, and continuous improvement in engineering education. As the field evolves, adaptive learning stands as a transformative approach for building future-ready engineers.

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Several frameworks have been developed to support the integration of adaptive learning into engineering curricula. Bayounes et al. (2012) proposed a model focusing on process engineering and continuous learner feedback within adaptive systems. Complementing this, Bordel et al. (2022) introduced gamified competitions to foster collaborative, autonomous, and personalized learning in computer engineering. Cerna et al. (2024) implemented a web application in an engineering graphics course, offering modular and responsive content tailored to user interactions. These frameworks emphasize the importance of learner autonomy, digital feedback, and context-aware interfaces. They contribute to a more engaging and effective engineering education ecosystem.

Miller et al. (2013) focused on integrating metacognitive and motivational strategies within personalized learning to develop more reflective and self-aware engineering students. The study emphasized how explicit instruction on self-monitoring can improve student learning outcomes. Yung et al. (2016) extended this by proposing a holistic framework that combines personalized learning with pedagogy, digital technology, and flexible learning spaces. Their approach encouraged active learning and contextual understanding of engineering principles. The incorporation of personal growth strategies into adaptive learning supports not only academic but also personal development. These insights demonstrate that fostering self-regulation and motivation is as important as delivering content.

Lin and Wang (2019) introduced the use of virtual reality to provide immersive adaptive learning environments in engineering education. This method used predicts students' learning preferences using a learning style index and delivers tailored virtual environments for engineering education. Learning data is automatically collected and analyzed to refine these preferences over time. As students engage in immersive, customized learning scenes and materials, the virtual environment is continuously optimized to meet diverse individual needs. Compared to traditional style-based adaptive methods, experimental results show this approach boosts student engagement and significantly enhances academic performance.

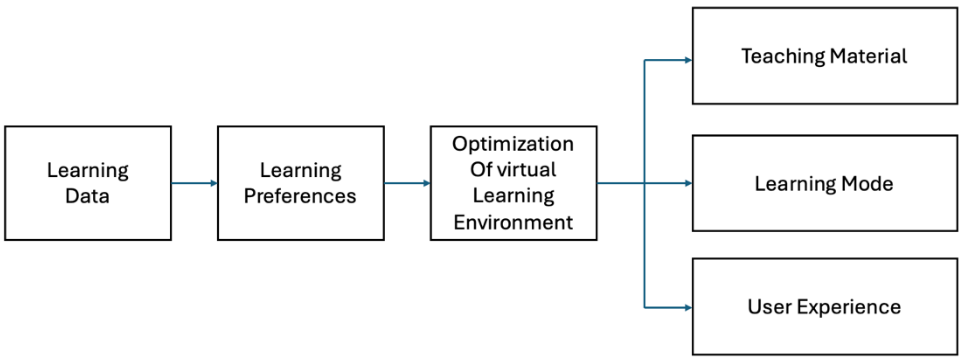

Figure 6: The optimization of virtual learning environment, Figure adapted from (Lin & Wang, 2019)

Mora-Salinas et al. (2023) proposed sensory-based learning systems that deliver real-time, adaptive responses based on physiological and behavioral cues. It uses eye-tracking technology to analyze how students interact with on-screen learning materials and respond to visual stimuli. The information enables teachers to develop adaptive and more effective digital content

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which improves student engagement and comprehension.

Manap et al. (2024) promoted the TUAH digital portfolio framework as a tool for personalized learning in Malaysia's TVET context. The findings show that the TUAH Digital Portfolio supports personalized learning while serving as a comprehensive record of student competencies, ultimately increasing their visibility and employability. This highlight digital portfolios for personalized learning as key tools for advancing equitable and career-ready TVET education.

Balakrishnan (2018) demonstrated that tagging systems within Personalized Learning Environments (PLEs) significantly enhance student motivation and engagement. This study found that the developed Web 2.0-based Personalized Learning Environment (PLE) system effectively enhanced engineering students' motivation and confidence in learning LTE topics. Features like sharing, tagging, rating, and monitoring enabled personalized and collaborative learning, while instructor monitoring further boosted student engagement. Some students still showed low self-efficacy and assessment anxiety, highlighting the need for continued support. Overall, the system shows promise for empowering learners to take control of their education while fostering communication and collaboration skills.

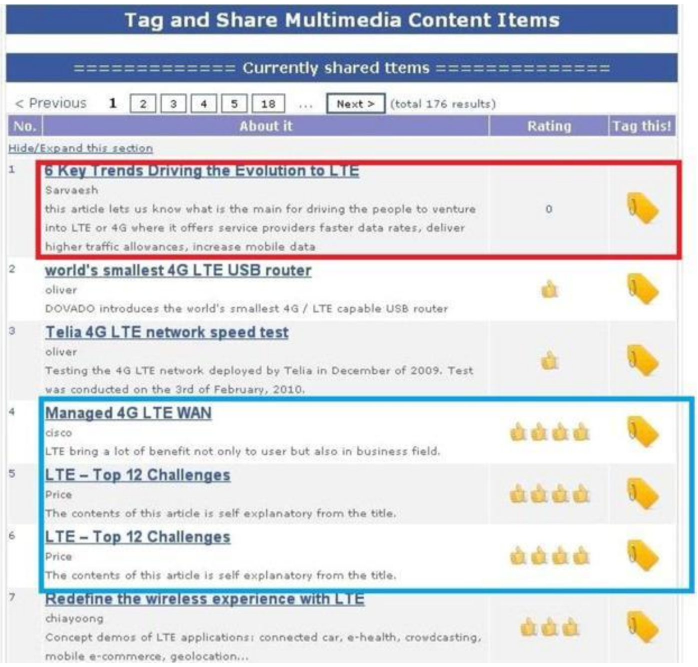

Figure 7: The interface for tagging and rating of shared sources. Reproduced with permission (Balakrishnan, 2018)

Jasute et al. (2016) demonstrated the use of personalized methods and learning activities in computer engineering education to better match student profiles and various learning styles. This study investigated the link between the Felder–Silverman Learning Styles Model (FSLSM) and inquiry-based learning (IBL) strategies. Recognized as highly effective for engineering and e-learning contexts, FSLSM aligns well with IBL, which is beneficial for students in STEM fields, including computer engineering. Dukes et al.

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(2024) explored a pilot project for graduate-level personalized learning in chemical engineering, supporting self-regulated learning. Hu et al. (2023) applied adaptive strategies for non-engineering students in structural systems, illustrating the broad applicability of adaptive methods. Each study reflects a shift toward more learner-centered paradigms in technical education. Together, they validate the effectiveness of personalized pathways in improving comprehension and engagement.

Learning Management Systems (LMS) is an important platform for personalized and adaptive learning. Features in LMS such as in Moodle, have H5P, Lesson and extensions such Level Up. These features contain features which enable students to study step-by-step, at their own pace, based on their progress and understanding of the topic. For example, in mathematics and science subjects, it is important to understand the fundamental knowledge and theories before proceeding to the next stage. Compared to traditional classes, lecturers will cater to the needs of the whole class, therefore, students who are fast learners, are able to follow the topics, while some other may need more time. Therefore, personalized and adaptive learning using LMS is a powerful tool which will help increase students performances.

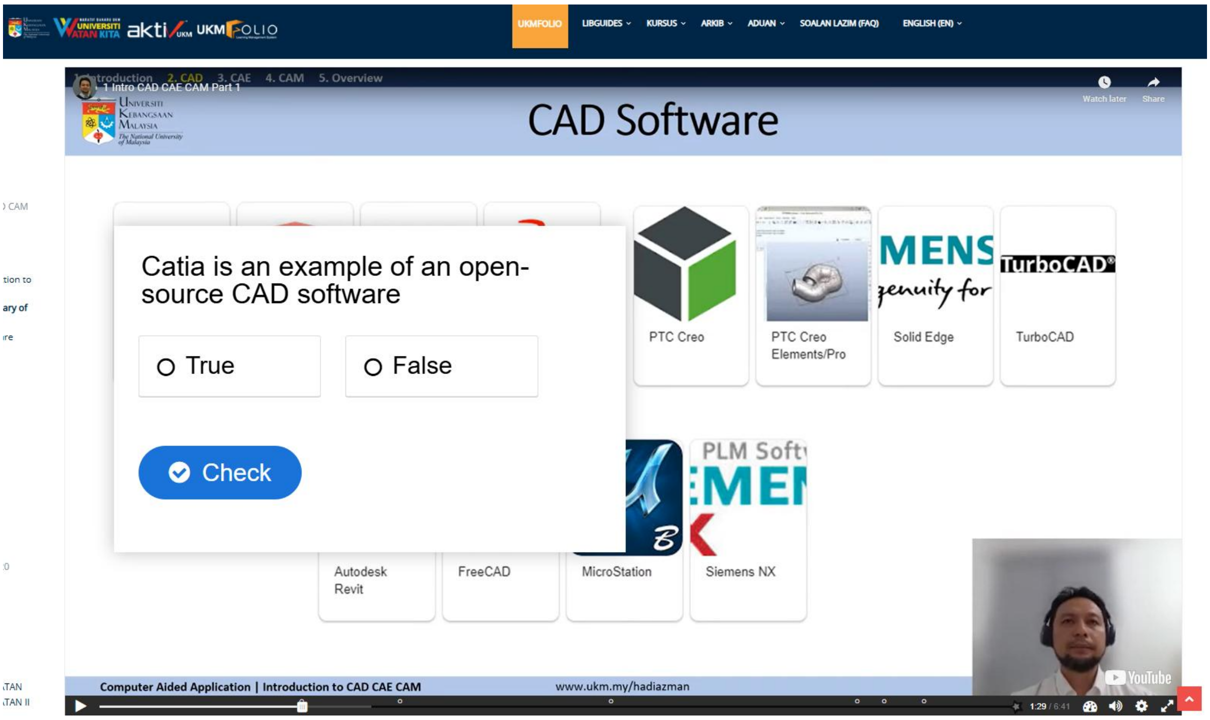

Figure8 **:** Application of H5P in Moodle LMS in UKM to develop interactive video for personalized and adaptive learning

4.0 CONCLUSION

Adaptive and personalized learning have emerged as transformative approaches in engineering education, overcoming the limits of traditional, one-size-fits-all methods. By using technologies like AI, learning analytics, and real-time feedback, these methods tailor content to each student's pace, strengths, and needs. This personalization improves knowledge acquisition, engagement, and retention—critical in fields with complex, technical material. Tools such as tagging systems, adaptive platforms, and digital portfolios have proven effective in promoting learner autonomy and self-regulated learning. As industries demand broader

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and more flexible skill sets, these systems help prepare students for dynamic, interdisciplinary careers. Adaptive learning is not just a teaching upgrade—it is a strategic shift aligned with modern academic and industrial demands.

This review has shown that adaptive and personalized learning increases student engagement through responsive and interactive experiences. Across various engineering disciplines — software, chemical, structural, and automotive—studies report better understanding, motivation, and performance. Students benefit from mastering topics at their own pace, guided by real-time data and AI-based support. These platforms also build on prior knowledge, ensuring better continuity in learning. The potential of adaptive learning in engineering education remains significant. Scalable frameworks and pilot studies in graduate programs have already shown strong promise. Technologies like VR, sensory feedback systems, and gamified modules offer new ways to engage learners and mirror real-world scenarios. These innovations shift learning from passive content delivery to immersive, hands-on experience. Adaptive systems also align with Industry 4.0 by encouraging continuous learning, innovation, and rapid upskilling. Finally, their link to sustainability goals strengthens their role in developing a future-ready, responsible engineering workforce.

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