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Technical Article

Technology-enhanced Personalized Learning Environment: Moving forward from the Research to Practices on Science, Technology, and Mathematics Education

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Abstract: Over the last decade, significant advancements in technology have led researchers to examine the impact of Technology-Enhanced Personalized Learning Systems (TEPL) on conceptual learning in Science, Technology, and Mathematics (STM). Despite developing various TEPL models and methods, defining criteria and strategies for implementation remains challenging due to the complexity of enhancing conceptual learning in STM. Addressing this issue, the concept-effect relationship (CER) model has been applied to TEPL in STM education. This study focuses on using technology to boost learning in STM, guided by the CER model, tailored to individual student needs. It proposed a comprehensive TEPL framework to support STM educators, incorporating a web-based testing and diagnostic system aligned with the CER model, a constructivist learning environment for active engagement, and a continuous web-based formative assessment mechanism. This study provided practical CER model applications within TEPL, showcasing how it can offer a dynamic, responsive educational experience that meets diverse student learning styles and needs. By integrating these tools, TEPL aims to transform STM education into a more accessible, engaging, and effective experience, enhancing students' learning outcomes in the digital age.

Keywords: Adaptive learning system, individual differences, pedagogy, web-based learning environment, innovative education

Introduction

Pedagogy is defined as a series of activities for both teachers and students. The students can practice and get direct experience in such activities facilitated by the teachers to improve their performance. In this light, scholars have proposed strategies to assist students in gaining knowledge, particularly in Science, Technology, and Mathematics (STM). For example, Krajcik and Blumenfeld (2006) suggested that inquiry-based learning, which creates a student-centered learning environment by involving students in authentic conceptions of scientific phenomena, could encourage them to learn about science and build conceptual understanding through authentic investigative activities. The students emphasize presenting questions, acquiring and analyzing data, and constructing evidence-based arguments. In addition, the learning cycle model is grounded in the three phases. The exploration phase coming first implies that the information exposed by the hands-on activities wherein students explore new objects, new materials, new events, or situations with minimal guidance or expectation of accomplishments can be discovered, and questions can be raised for students to attempt to answer. The term introduction phase follows the exploration phase, wherein students are introduced to the main concepts of the topic and the vocabulary related to the concepts gathered from their own exploration experience. In the concept application phase, students are asked to apply the concepts gained from the previous phases in new contexts to verify their understanding of such concepts. The fact that this model provides opportunities for students to inquire and construct knowledge by themselves leads to their better understanding of science concepts in various subjects such as physics, life science, agricultural science, life science (Ketpichainarong et al., 2009), and computer science (Piyayodilokchai et al., 2011; Piyayodilokchai et al., 2013). Those teaching and learning strategies could enable students to reveal their prior knowledge in two ways: they make predictions before exploring and generate hypotheses to explain new phenomena. From the studies of applying those teaching and learning strategies into the realm of STM education, the researchers reported that students still often displayed learning difficulties in understanding and held failures status of conceptual understanding for real-world phenomena. Although learning activities were based on effective teaching and learning strategies, each student has different preferences and needs. These mentions are crucial factors affecting STM conceptual learning, and individualizing the learning experience for each student is an important goal for educational systems. Therefore, thinking about learner differences and personalized learning information and providing the different styles of learners with different learning environments while applying teaching and learning strategies in STM education are more preferred and more efficient to them, it might overcome learning difficulties in conceptual understanding and hold failures status of conceptual understanding for real-world phenomena.

Concerning the learner difference and personalized learning information in large classrooms for STM learning, personalized or adaptive online-based learning has been becoming to overcome that issue in technology-enhanced learning and teaching (Yang & Tsai, 2008; Akbulut & Cardak, 2012; Chookaew et al., 2014; Komalawardhana et al., 2021; Srisuwan et al., 2020). STM-conceptual status and learning style are two key components to realize personalized technology-enhanced learning. The personalized technology-enhanced learning environment (TEPL) enables individual students to improve their learning performance (Chen, 2008; Chen, 2011). With the crucial influences of TEPL environment on students' conceptual learning improvement of Science, Technology, and Mathematics (STM), many researchers applied the concept map-oriented approach to creating concept-effect relationship model in diagnosing conceptual learning problems within TEPL environments for generating learning path to individual students (Chookaew et al., 2014; Srisawasdi & Panjaburee, 2014; Wongwatkit et al., 2017; Li et al., 2019; Wanichsan et al., 2021). Successful uses of this model demonstrated the benefits of applying it for coping with learning diagnosis problems and enhanced individual students' learning performance in several areas, including natural science, mathematics, and health education.

Nevertheless, the criteria for establishing an online personalized learning environment based on that model have not been clearly defined. The criteria for establishing an effective online personalized learning environment based on the concept-effect relationship model have not been well-defined. This ambiguity has hindered the development and implementation TEPL environments optimized for conceptual learning in STM. There is still an absence of established strategies for conducting efficient conceptual learning problem diagnosis and practical learning activities. This gap limits the potential of TEPL environments to address individual learning needs and accordingly effectively adapt teaching methodologies. Currently, there is less recommended framework that integrates formative assessment and personalized learning styles in developing TEPL environments. Such a framework is crucial for creating a more holistic and responsive learning experience that adapts to individual student's preferences and needs. To address existing challenges in

Science, Technology, and Mathematics (STM) education, we propose a framework for Technology-Enhanced Personalized Learning Systems (TEPL) based on the concept-effect relationship (CER) model, outlining essential criteria, strategies, and practical guidelines for innovative online learning environments. This TEPL framework is tailored to support individual student learning and represents an effective alternative to enhance STM education, fostering positive attitudes and motivation in students for 21st-century societal living. By clearly defining TEPL criteria, developing diagnostic strategies for learning, and creating integrated frameworks that merge formative assessment with personalized learning styles, TEPL can substantially improve the quality and effectiveness of STM education. This approach addresses students' diverse learning styles and needs, offering a dynamic, engaging, and customized educational experience. Consequently, TEPL is vital in STM education, providing a crucial solution to current challenges and significantly enhancing the learning experience in these essential and constantly evolving fields (Panjaburee, Komalawardhana, & Ingkavara, 2022; Ingkavara et al., 2022).

Accordingly, to overcome these gaps, the next sections described the characteristics of the concept-effect relationship (CER) model, where the study explored the foundational elements and principles of the CER model. This exploration provided a deeper understanding of how the CER model functions within personalized learning and its potential to enhance conceptual understanding in STM education. Following this section, the applications of the CER Model in TEPL for STM education section illustrated practical implementations of the CER model within TEPL environments. Here, the study examined case studies and examples demonstrating the model's effectiveness in addressing specific learning challenges in STM disciplines, showcasing its adaptability and impact in real-world educational settings. Finally, the study transitioned to proposing a framework for practices of the technology-enhanced personalized learning environment (TEPL) in STM education. This section presented a comprehensive framework that incorporated the insights and methodologies from the CER model. This proposed framework outlined key criteria, strategies, and practical guidelines for developing TEPL environments. It emphasizes a student-centered approach that supports individual learning needs, fosters positive attitudes toward STM education, and aligns with the demands of 21st-century learning. By proposing this framework, the study aims to address students' diverse learning styles and needs, offering a dynamic, engaging, and customized educational experience, thus marking a significant advancement in STM education.

Characteristics of Concept-Effect Relationship Model

Numerous computer-assisted testing and diagnosing system researchers have referred to the concept-effect relationship (CER) model as a potential theoretical basis for developing an individual learning diagnosis system. The diagnostic system based on the CER model is geared to a mechanism of causal relationships among concepts that need to be learned in a particular order, which is considered a prerequisite to understanding the target concept (Panjaburee et al., 2010). Hwang (2003) originally proposed the relationship between new and previously learned concepts and their effect on other concepts as an essential strategy for diagnosing causes of learning failure, students' conceptual learning status, and learning progression. This model offers an overall cognition of the subject contents in a hierarchical order of concepts. However, an additional procedure is required to analyze student conceptual learning status to identify poorly-learned, medium-learned, and well-learned concepts for individual students, such as applying Fuzzy membership functions (Hwang, 2003). Panjaburee et al. (2010) gave an example of CER construction on "Division of Positive Number," as shown in Figure 1.

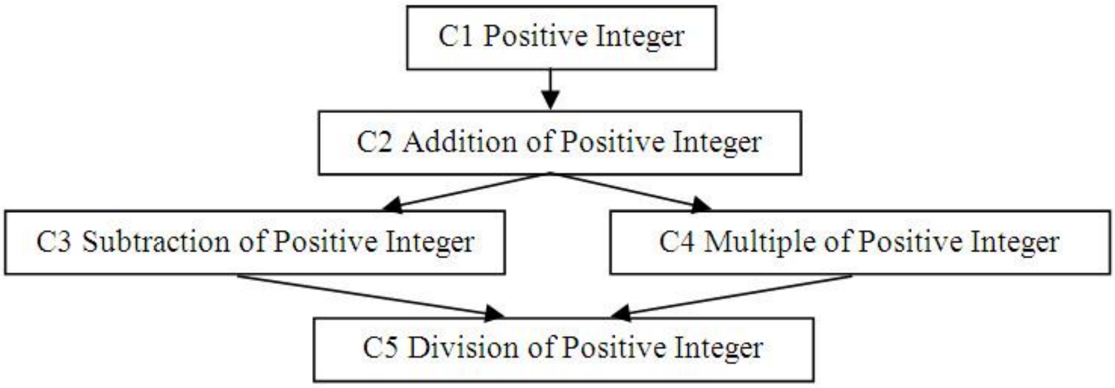

Figure 1 Illustration of CER construction on the topic “Division of Positive Number.”

Observing Figure 1, there are two related concepts, Ci and Cj. That is concept “C2 Addition of Positive Integer” is a prerequisite for learning more advanced concepts “C3 Subtraction of Positive Integer” and “C4 Multiple of Positive Integer”. In this case, if a student fails in C5, it may be caused by incomplete learning in C3 and C4. Following the construction of CER, the main problem is how to diagnose student conceptual learning problems after taking a series of conceptual testing items. Previous research used the CER to diagnose student conceptual learning problems in five steps (Hwang, 2003; Hwang et al., 2008): (1) Constructing the CER for the subject unit; (2) Presetting the weight values between test item and related concepts; (3) Calculating the incorrect answer rate for each student in each concept; (4) Defining a concept which affects the learning of other related concepts; (5) Providing feedback and corresponding learning material to each student. These five steps of using CER are called the CER model in diagnosing student conceptual learning problems in a personalized learning environment.

The researchers developed a testing and diagnostic system based on the usefulness of the CER model for an effective learning environment in many educational levels and subject areas. For example, Chu et al. (2006) presented a CER-based learning diagnosis to provide students with personalized learning suggestions by analyzing their test results and test item-related concepts to develop a testing and diagnosis system in an Internet working environment. The experimental results of a nutrition course demonstrated the feasibility of this approach in enhancing students’ learning performance (Chu et al., 2006). Jong et al. (2007) developed a learning behavior diagnosis system for a university computer course and yielded positive experimental results for both learning status and learning achievement. In the meantime, Tseng et al. (2007) employed this model to provide helpful learning guidance for individual students in the physics course at a junior high school level. Furthermore, Hwang et al. (2008) reported the effectiveness of this model in improving students’ learning achievements in an elementary school mathematics course. This model has been applied widely to detect the learning problems of students succeed and to provide personalized suggestions for several areas, including Natural Science, Mathematics, Physics, Electronic Engineering, and Health courses, as well as for several levels, including elementary school students, high school students, and undergraduate students.

Applications of the Concept-Effect Relationship (CER) Model in TEPL for STM Education

Constructing CER with the cooperation of multiple experts/teachers

An expert system environment is provided to show the cooperation of multiple experts/teachers to construct CER. Consider the “Computations and Applications of

Quadratic Equations” conceptual learning unit in the Mathematics course of a high school. Figure 2 shows a multi-expert CER procedure consisting of four phases within an expert system environment. That is to say; in this study, the expert system was defined as an environment that is a specialized AI-driven platform that supports the collaborative efforts of multiple experts or teachers in creating comprehensive and effective educational resources structured in applications of the CER model. In eliciting concepts from the individual experts’ phase, each expert is asked to determine the concepts that need to be learned in a course. Integrating concepts from the multiple experts phase is then used to incorporate the concepts given by multiple experts using the question base. In other words, it is a phase where the knowledge from different experts is brought together and unified utilizing a set of questions. It could be a part of a procedure where input from multiple experts is essential for CER construction. That is to say, in the case of the Computations and Applications of Quadratic Equations topic, each expert was asked to list relevant concepts. The eliciting <prior-concept, concept> relationships from individual experts phase are used to ask the experts to determine the relationships between the concept and its prior concept. The relationship values range from 1 to 5 and are used to denote “very weak,” “weak,” “no effect,” “strong,” and “very strong” relationships. Moreover, the confidence degree for giving the value is determined as “S” or “N,” where “S” represents “Sure” for providing the value and “N” means “Not sure.” The integrating <prior-concept, concept> relationships from multiple experts phase are then used to integrate the opinions of <prior-concept, concept> relationships given by multiple experts using the rule base.

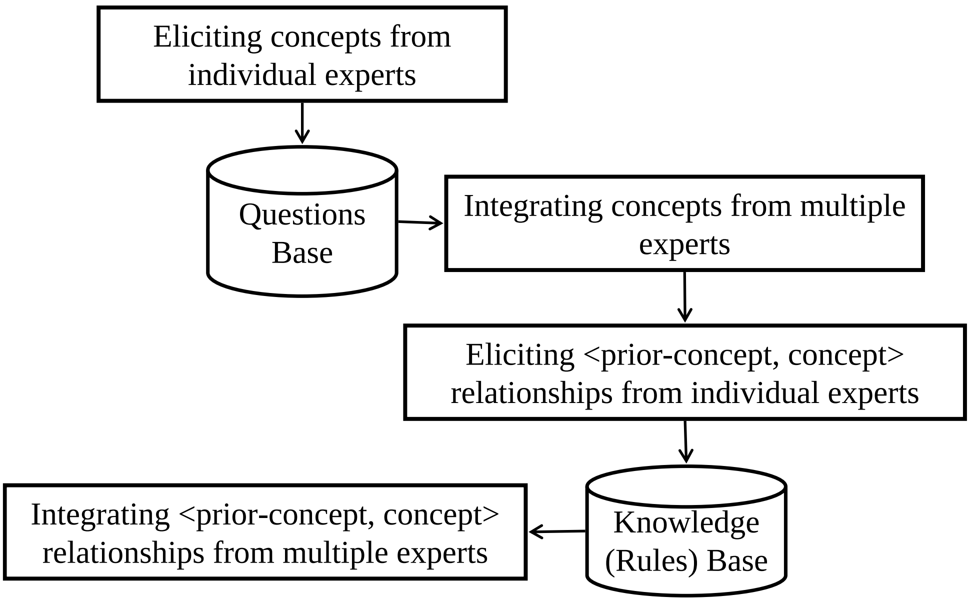

Figure 2 Illustrative examples of a multi-expert CER procedure

Moreover, the system will require them to brainstorm to check and reconsider their weighting and certainty values. The procedure is repeatedly conducted until no further checking and considering the <concept, concept> weighting information is needed. Based on the multi-expert CER procedure, all domain experts are asked to brainstorm to check the final CER for validation. The final CER is then used to analyze the learning problems of individual students and provide learning suggestions to them accordingly.

Presetting weight values between test items and related concepts with the cooperation of multiple experts/teachers

An expert system environment needs to be developed to show multiple experts/teachers' cooperation in presetting weight values between test items and related concepts. After completing the construction of CER, the domain experts/teachers were asked to log in to the expert system to determine weight values between test items and related concepts and assign a degree of confidence. The weight values range from 1 to 5 and are used to denote "very weak," "weak," "no effect," "strong," and "very strong" relationships. The confidence degree for giving the value is determined as "S" or "N," where "S" represents "Sure" for providing the value and "N" means "Not sure."

Consider the "Solving Linear Equation System" conceptual learning unit in the Mathematics course of a secondary school. The interactions between the expert system and experts/teachers during presenting weight values between test items and related concepts on the conceptual learning unit are shown as follows:

An expert system: Please determine weight values between related concepts in this test item: find X in 2X + 5 = 15.
Expert/Teacher 1: Determine value 1 for the concept "Equation" with certainty.
Expert/Teacher 2: Determine values 1 for concept "Equation" with unsure.
Expert/Teacher 3: Determine no relationship for concept "Equation" with sure.
Expert/Teacher 4: Determine no relationship for concept "Equation" with unsure.
Expert/Teacher 5: Determine value 2 for concept "Equation" with sure.
Expert/Teacher 6: Determine values 2 for concept "Equation" with unsure.
An expert system: Integrate their opinion as shown in Figure 3:

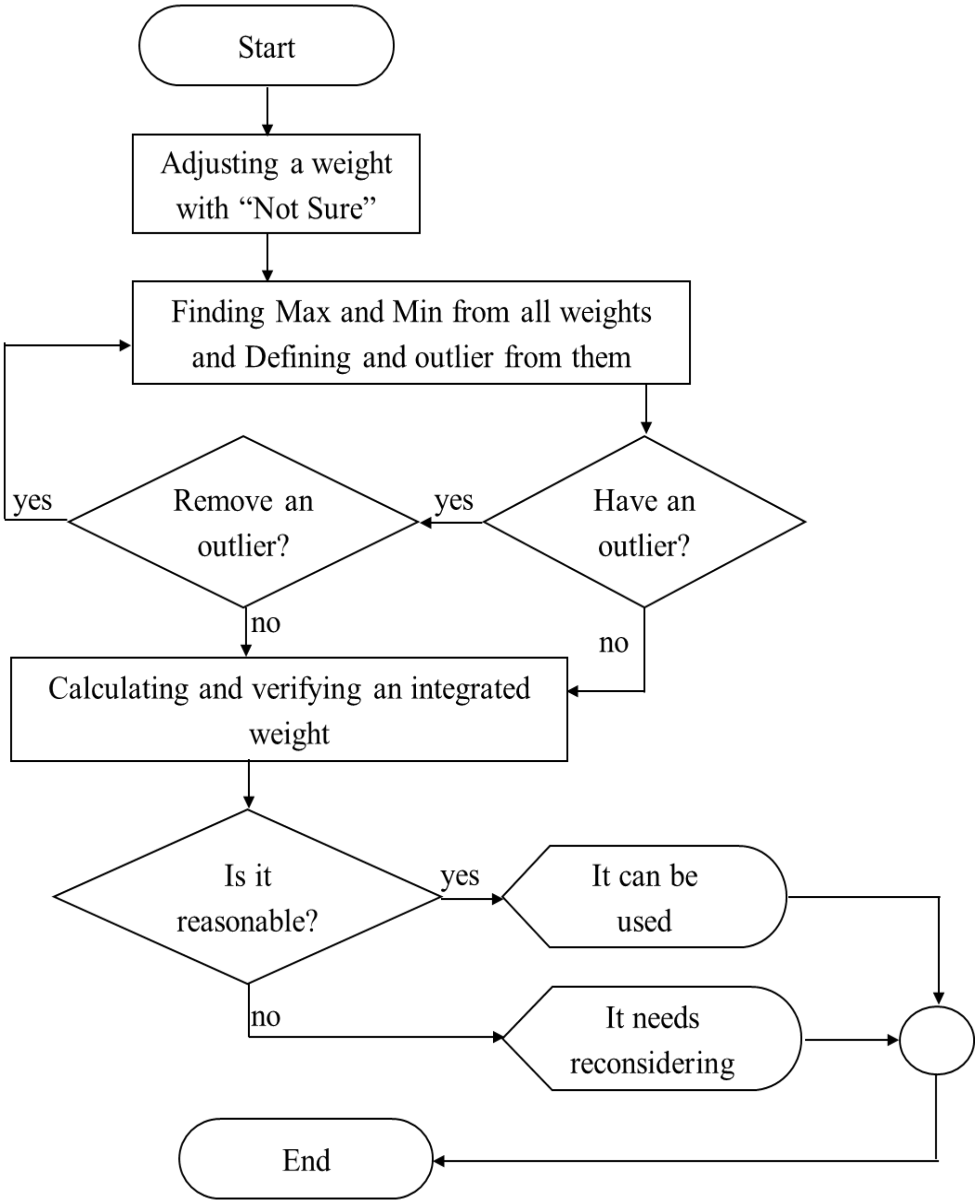

Figure 3 Flow diagram of integrating expert opinion procedure into an expert system (Wanichsan et al., 2021)

Experts/Teachers: Check and reconsider their opinions using online or face-to-face discussions.
An Expert system: No further checking and considering

The system will require them to brainstorm to check and reconsider their weighting and certainty values. The procedure is repeatedly conducted until no further checking and considering the <test item, concept> weighting information is needed. Based on the integrating expert opinion procedure, all domain experts are asked to brainstorm to check the final weight value for validation. The final weight value is then used to analyze the learning problems of individual students and provide learning suggestions to them accordingly as follows:

Testing and Diagnostic System within TEPL: Get a final weight value between related concepts in this test item 1.17, which is then used to detect students' concept learning problems accordingly.

After the students logged into the TEPL, they were asked to take a test. When they submit their answers, the TEPL will diagnose the conceptual learning problems and then provide the conceptual learning status based on the weight value between related concepts in this test item, remedial learning paths based on the CER, and the link to the supplementary materials for each poorly learned concept.

Proposing a framework for practices of the technology-enhanced personalized learning environment (TEPL) in STM education

Although the criteria and strategies for establishing the TEPL based on the CER model have not yet been defined, the examples of applying the CER model in the TEPL were shown, and the research results of the development of TEPL based on the CER model were clarified. Moreover, the integration of formative assessment into technology-enhanced learning (TEL) was discussed in the above sections. However, few studies have recommended integrating formative assessment with personalized student information in developing the TEPL. This shortcoming is probably because conceptual learning improvement of STM in the TEPL is an extremely complex phenomenon. Considering the recent benefits of integrating assessment for learning methods such as web-based formative assessment into the personalized web-based learning system, we propose a conceptual framework to create an innovative learning environment for effective STM education with technology-enhanced personalized learning systems (TEPL). Our framework could be represented as an arrangement among web-based testing and diagnostic systems, constructivist web-based learning environments, and web-based formative assessment, as shown in Figure 4.

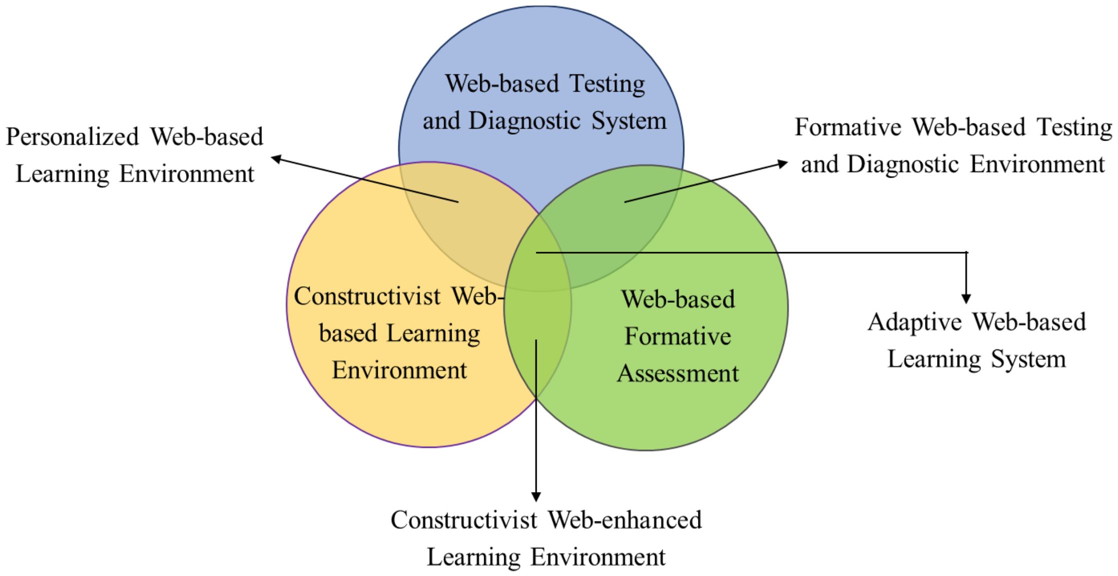

Figure 4 Illustration of a conceptual framework of technology-enhanced personalized learning systems (TEPL) for STM education

The conceptual framework of TEPL, grounded in three fundamental components – web-based testing and diagnostic system, constructivist web-based learning environment, and web-based formative assessment – serves as a cornerstone in personalizing STM education. This innovative framework is further enriched by the integration of these components into four distinct types of technology-based learning environments:

(1) Personalized Web-Based Learning Environment: This environment leverages adaptive technologies to tailor the learning experience to individual student needs and preferences, ensuring a more personalized and effective learning task. This component emphasizes the importance of adapting to individual differences, performance, and adaptive adjustments, recognizing the need for technology-driven solutions to meet the diverse needs of learners. It also delves into the connections between personalized, adaptive, and differentiated instruction, underscoring the importance of individual characteristics and personal development in educational settings.
(2) Constructivist Web-Enhanced Learning Environment: Rooted in constructivist theory, this environment emphasizes active learning, where students construct knowledge through interactions with digital content and collaborative activities, enhancing their understanding and engagement. This component focuses on creating and implementing constructivist web-enhanced learning environments, exploring how digital tools and platforms facilitate active, student-centered learning and how these learning environments impact student engagement, motivation, and learning outcomes, particularly in STM disciplines.
(3) Formative Web-Based Testing and Diagnostic Environment: Focused on continuous assessment, this environment uses web-based tools to evaluate student understanding regularly, provide immediate feedback, and identify areas needing further exploration or support. It demonstrates the effectiveness of formative web-based testing and diagnostic environments in improving learning outcomes, especially in complex and specialized subjects, suggesting that integrating formative assessment in web-based environments can lead to more personalized and effective learning experiences.
(4) Adaptive Web-Based Learning Environment: This dynamic environment adapts to each student's changing needs and progress, using data-driven insights to modify learning paths and resources, thereby optimizing the learning experience. It underlines the challenges and opportunities in designing adaptive environments accommodating individual learning styles. Adaptive e-learning can significantly enhance students' engagement, knowledge acquisition, and higher thinking skills by delivering content that aligns with their learning preferences and needs.

Each type of fundamental component and innovative technology-based learning environment represented in the framework is briefly described in Table 1.

Table 1 Description of the framework for an innovative STM learning environment

Construct	Description
Web-based testing and diagnostic system (WTDS)	WTDS refers to a computerized system, using the Web as the representation and delivery medium, which is used to diagnose learning problems for students according to their test answers. Then, personalized learning guidance is provided to each student - based on Panjaburee et al. (2010).
Constructivist web-based learning environment (CWLE)	CWLE refers to a computerized system using the Web as the representation and delivery medium, in which user interface systems are designed and developed based on constructivist perspectives to support students' learning activities -based on Nam & Smith-Jackson (2007).
Web-based formative assessment (WBFA)	WBFA refers to a computerized system, using the Web as the representation and delivery medium. It continuously engages students in rigorous self-assessment of their understanding and then provides feedback on their understanding of the critical concepts associated with each learning activity based on Henly (2003).
Personalized web-based learning environment (PWLE)	PWLS is a state-of-the-art combination of web-based testing and diagnostic systems and a constructivist web-based learning environment used to diagnose learning problems for students according to their test answers and then support them by suggesting constructivist-based user interface systems to attempt to support their learning.
Constructivist web-enhanced learning environment (CWLE)	CWLE is a state-of-the-art combination of the constructivist web-based learning environment and web-based formative assessment used to engage students in rigorous self-assessment of their understanding, provide feedback to students on their understanding, and support them by suggesting constructivist-based user interface systems attempt to support their learning.
Formative web-based testing and diagnostic environment (FWTDE)	FWTDE is a state-of-the-art combination of web-based testing and diagnostic system and web-based formative assessment that engages students in rigorous self-assessment of their understanding, diagnoses learning problems according to their test answers, and provides learning guidance to each student.

Construct	Description
Adaptive web-based learning environment (AWLE)	AWLE is a state-of-the-art integrative connection among web-based testing and diagnostic systems, constructivist web-based learning environment, and web-based formative assessment, which diagnoses learning problems for students according to their test answers and provides learning guidance to each student. It then guides them into constructivist-based user interface systems. To support their conceptual learning, they continuously engage in rigorous self-assessment of their conceptual understanding and then provide feedback and select particular learning experiences for students based on their understanding of the critical concepts associated with each learning activity.

Conclusions

In this paper, the ultimate objective is to utilize technology effectively to augment learning in science, technology, and mathematics (STM) education, guided by the concept-effect relationship (CER) model tailored for individual student needs. The study delineates key criteria and strategies for integrating the CER model into the development of testing and diagnostic systems, specifically within an online personalized learning framework. Further, the study introduced a comprehensive framework, the Technology-Enhanced Personalized Learning Systems (TEPL), designed to empower STM educators. This framework is underpinned by three core components: a web-based testing and diagnostic system that aligns with the CER model, a constructivist web-based learning environment fostering active learner engagement, and a robust web-based formative assessment mechanism to evaluate and guide student progress continuously. Moreover, this study provided practical examples of the CER model's application within the TEPL framework, serving as a guideline for STM education. These examples demonstrate how TEPL can create a more dynamic and responsive educational experience catering to students' diverse learning styles and needs. By integrating these innovative tools and methodologies, TEPL aims to revolutionize STM education, making it more accessible, engaging, and effective in the digital age.

Tracking the proposed framework emphasizes a web-based testing and diagnostic system aligned with the CER model, a constructivist learning environment, and a robust formative assessment mechanism. Researchers and educators can continue to evolve and refine technology in education, ensuring that it remains relevant, effective, and responsive to the ever-changing needs of students and the educational environment. Therefore, several potential directions could be considered for future work. Firstly, in-depth case studies and pilot implementations of the TEPL framework could be conducted in various educational settings. This investigation would provide empirical data on its effectiveness and insights into how it can be adapted or improved in different contexts. Secondly, further research could be customized to cater to a wide range of learning needs, including students with disabilities or those from diverse cultural backgrounds. Exploring the integration of emerging technologies, such as artificial intelligence, augmented reality, or virtual reality within the TEPL framework could be worked to enhance the learning experience and make it more interactive and engaging. Lastly, longitudinal studies could be conducted to assess the long-term impact of the TEPL framework on student learning outcomes, engagement, and retention in STM subjects.

References

Akbulut, Y. & Cardak, S. C. (2012). Adaptive educational hypermedia accommodating learning styles: A content analysis of publications from 2000 to 201. *Computers & Education, 58*, 835–842. https://doi.org/10.1016/j.compedu.2011.10.008

Chen, C. M. (2008). Intelligent web-based learning system with personalized learning path guidance. *Computers & Education, 51*(2), 787–814. https://doi.org/10.1016/j.compedu.2007.08.004

Chen, L. H. (2011). Enhancement of student learning performance using personalized diagnostic and remedial learning system. *Computers & Education, 56*, 289–299. https://doi.org/10.1016/j.compedu.2010.07.015

Chookaew, S., Panjaburee, P., Wanichsan, D., & Laosinchai, P. (2014). A Personalized e-Learning Environment to Promote Student's Conceptual Learning on Basic Computer Programming. *Procedia - Social and Behavioral Sciences, 116*(21), 815-819. https://doi.org/10.1016/j.sbspro.2014.01.303

Chu, H. C., Hwang, G. J., Tseng, J. C. R., & Hwang, G. H. (2006). A computerized approach to diagnosing student learning problems in health education. *Asian Journal of Health and Information Sciences, 1*(1), 43-60. https://doi.org/10.6412/AJHIS.200604.0043

Henly D. (2003). Use of Web-based formative assessment to support student learning in a metabolism/nutrition unit. *European Journal of Dental Education 7*, 116–122. https://doi.org/10.1034/j.1600-0579.2003.00310.x

Hwang, G. J. (2003). A conceptual map model for developing intelligent tutoring systems. *Computers & Education, 40*(3), 217-235. https://doi.org/10.1016/S0360-1315(02)00121-5

Hwang, G. J., Tseng, J. C. R., & Hwang, G. H. (2008). Diagnosing student learning problems based on historical assessment records. *Innovations in Education and Teaching International, 45*(1), 77-89. https://doi.org/10.1080/14703290701757476

Ingkavara, T., Panjaburee, P., Srisawasdi, N., & Sajjapanroj, S. (2022). The use of a personalized learning approach to implementing self-regulated online learning. *Computers and Education: Artificial Intelligence, 3*, 100086. https://doi.org/10.1016/j.caeai.2022.100086

Jong, B. S., Chan, T. Y., & Wu, Y. L. (2007). Learning log explorer in e-Learning diagnosis. *IEEE Transactions on Education, 50*(3), 216-228. https://doi.org/10.1109/TE.2007.900023

Ketpichainarong, W., Ruenwongsa, P., & Panijpan, B. (2009). Enhanced learning of biotechnology students by an inquiry based cellulase laboratory. *International Journal of Environmental and Science Education, 5*(2), 169-187.

Komalawardhana, N., Panjaburee, P., & Srisawasdi, N. (2021). A mobile gamebased learning system with personalised conceptual level and mastery learning approach to promoting students' learning perceptions and achievements. *International Journal of Mobile Learning and Organisation, 15*(1), 29–49. https://doi.org/10.1504/IJMLO.2021.111596

Krajcik, J. S. & Blumenfeld, P. (2006). *Project-based learning*. In Sawyer, R. K. (Ed.), The Cambridge handbook of the learning sciences. New York: Cambridge.

Li, Y., Shao, Z., Wang, X., Zhao, X., & Guo, Y. (2019). A Concept Map-Based Learning Paths Automatic Generation Algorithm for Adaptive Learning Systems. *IEEE Access, 7*, 245–255. https://doi.org/10.1109/ACCESS.2018.2885339

Nam, C.., & Smith-Jackson, T. (2007). Web-based learning environment: A theory-based design process for development and evaluation. *Journal of Information Technology Education, 6*, 23- 44.

Panjaburee, P., Hwang, G. J., Triampo, W., & Shih, B. Y. (2010). A multi-expert approach for developing testing and diagnostic systems based on the concept-effect model. *Computers and Education, 55*(2), 527–540. https://doi.org/10.1016/j.compedu.2010.02.015

Panjaburee, P., Komalawardhana, N., & Ingkavara, T. (2022). Acceptance of personalized e-learning systems: a case study of concept-effect relationship approach on science, technology, and mathematics courses. *Journal of Computers in Education, 9*(4), 681–705. https://doi.org/10.1007/s40692-021-00216-6

Piyayodilokchai H., Ruenwongsa, P., Ketpichainarong W., Laosinchai, P., Panjaburee, P. (2011). Promoting students' understanding of SQL in a database management course: a learning cycle approach. *International Journal of Learning, 17*(11), 325-337. https://doi.org/10.18848/1447-9494/CGP/v17i11/47345

Piyayodilokchai, H., Panjaburee, P., Laosinchai, P., Ketpichainarong, W., & Ruenwongsa, P. (2013). A 5E Learning Cycle Approach–Based, Multimedia- Supplemented Instructional Unit for Structured Query Language. *Educational Technology & Society, 16*(4), 146–159.

Srisawasdi, N. & Panjaburee, P. (2014). Technology-enhanced Learning in Science, Technology, and Mathematics Education: Results on Supporting Student Learning. *Procedia - Social and Behavioral Sciences, 116*(21), 946-950. https://doi.org/10.1016/j.sbspro.2014.01.325

Srisuwan, C & Panjaburee, P. (2020). Implementation of flipped classroom with personalised ubiquitous learning support system to promote the university student performance of information literacy. *International Journal of Mobile Learning and Organisation*, *14*(3), 398 - 424. https://doi.org/10.1504/IJMLO.2020.108200

Tseng, S. S., Sue, P. C., Su, J. M., Weng, J. F., & Tsai, W. N. (2007). A new approach for constructing the concept map. *Computers & Education, 49*(3), 691-70. https://doi.org/10.1109/ICALT.2004.1357378.

Wanichsan, D., Panjaburee, P., & Chookaew, S. (2021). Enhancing knowledge integration from multiple experts to guiding personalized learning paths for testing and diagnostic systems. *Computers and Education: Artificial Intelligence, 2*, 100013. https://doi.org//10.1016j.caeai.2021.100013

Wongwatkit, C., Srisawasdi, N., Hwang, G.J., & Panjaburee, P. (2017). Influence of an integrated learning diagnosis and formative assessment-based personalized web learning approach on students learning performances and perceptions. *Interactive Learning Environments*, *25*(7), 889–903. https://doi.org/10.1080/10494820.2016.1224255

Yang, F. Y., & Tsai, C. C. (2008). Investigating university student preferences and beliefs about learning in the Web-based context. *Computers and Education*, *50*(4), 1284-1303. https://doi.org/10.1016/j.compedu.2006.12.009