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Research paper

Promoting pre-service teachers' learning performance and perceptions of inclusive education: An augmented reality-based training through learning by design approach

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A R T I C L E I N F O

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Inclusive education
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A B S T R A C T

This study aimed to address the deficiency in quantitative research by investigating the effects of an augmented reality (AR)-based learning by design approach on inclusive education. A quasi-experiment was executed by recruiting 128 pre-service teachers. The samples were divided into two groups: the experimental group underwent AR-based learning by design training, while the control group received mobile-based learning by design training. Results indicated significant enhancements in learning performance and perceptions (i.e., higher-order thinking efficacy, attitudes, and perceived support) within the experimental group. This study enhanced the understanding of inclusive education implementation by integrating AR technology and learning by design approach.

Fundings

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Ethics approval

This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Institutional Review Board (IRB) of the South China Normal University approved this study, IRB-SCNU-EIT-2021-016.

1. Introduction

Inclusive education has been identified as Sustainable Development Goal 4 of the UNESCO 2030 Agenda (UNESCO, 2017). More and more teacher education programmes aim to promote teachers' agency to teach in inclusive classrooms (AlMahdi & Bukamal, 2019; Goddard & Evans, 2018; Koay, 2014). Specifically, a key purpose of teacher education for inclusion is to develop teachers' agency in understanding and valuing learner differences, and providing support for all learners' achievements, collaboration, and teamwork (European Agency for Development in Special Needs Education, 2012). Developing teacher agency in inclusive education could be regarded as a bridge between

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beliefs, self-efficacy, and knowledge of meeting the diverse needs of students and inclusive education. (Polatcan et al., 2023; Tao & Gao, 2017; Tinn & Ümarik, 2022). Furthermore, teachers' beliefs and self-efficacy regarding inclusive education are shaped by training or practical experience in their teacher education programmes and professional development (Dignath et al., 2022; Kraska & Boyle, 2014). Therefore, it is important to develop teachers' inclusive practices knowledge and self-efficacy.

Technology has the potential to address the diverse needs of learners by providing multiple representations of information, and multiple means of engagement and expression. As an interactive and immersive technology, Augmented Reality (AR) has been applied in inclusive education for the reasons of catching the attention of students with special educational needs, increasing their motivation and facilitating interaction in learning (Quintero et al., 2019). The number of empirical studies using AR in inclusive education has increased in recent years. AR has been emphasised as an efficient tool to provide useful learning resources and contextual information in flexible technological environments (Velazquez & Mendez, 2018). Koutromanos et al. (2023) suggested that teacher training programmes should emphasise digital learning and AR technology in instructional design. Training teachers to develop AR learning environments aids in providing personalised and prompt feedback to students, fostering contextual interactions between learners and knowledge, and enhancing teachers' capacity to address the diverse needs of their students (Badilla-Quintana et al., 2020; Lin et al., 2023b). Nonetheless, a systematic review of AR in inclusive education reported that few studies had been presented with clear design frameworks (Badilla-Quintana et al., 2020). Having a design framework is useful for teachers to develop better learning environments to address the needs of various learners (Yusof et al., 2014).

Learning by design is an approach centred on learners engaging in collaborative problem-solving experiences within authentic design contexts (Kolodner et al., 2003). This method underscores the learner's role as a designer. They have to engage in activities involving creation, and planning through authentic problems which enable them to construct meaningful knowledge (Van Breukelen et al., 2017). Besides, learning by design offers learners a systematic design process to improve their adaptability in designing adequate activities with support of the motivating conditions and scaffolding (Fleer, 2022). O'Sullivan et al. (2021) applied the learning by design framework to support teachers in designing collaborative, technology-mediated learning, and real-world problem-solving activities for inclusive education. Teachers showed positive perceptions of students with special needs. In another longitudinal study, researchers found that teachers' self-efficacy in inclusive education, regardless of gender or teaching experience, is an important factor in their positive attitudes toward inclusive classrooms (Savolainen et al., 2022). Teacher education programmes should provide a safe and supportive environment for teachers to gain mastery of inclusive education. The potential of AR technology and the systematic learning by design approach seems to be a supportive environment for teachers to develop their knowledge and perceptions of inclusive education. Therefore, this study aimed to explore pre-service teachers' learning performance and perceptions of inclusive education using the AR-based training and learning by design approach.

The literature review in the next section sets the ground for the current study. Section 3 describes the details of AR-based training for inclusive education. Section 4 provides details of the current methodology. Section 5 reports the results of the study, while sections 6 and 7 discuss the results in relation to the existing literature, and summarise the contributions of this study.

2. Literature review

2.1. Teachers' agency for inclusive education

Teacher agency can be regarded as a teacher's capacity to take action to proactively manage instructional conflict and address instructional needs in teaching and learning situations (Dinh & Sannino, 2024; Tao et al., 2024). Some scholars have emphasised the situated nature of teacher agency, noting that teachers are expected to perceive the specific teaching and learning contexts in which they find themselves (Aspbury-Miyanishi, 2022; Jiang, 2021). For complex and dynamic classroom environments, the teachers' agentic practice of having agency is not just about imparting knowledge, but adapting to different students, classes, and student needs to create rich and meaningful educational experiences for students (Aspbury-Miyanishi, 2022; Tao & Gao, 2017; Pantić et al., 2022). Therefore, in inclusive education, it can be considered that teacher agency involves the teachers' ability and tendency to meet different students' needs according to the complexity and variability of the instructional situation with inclusive pedagogy to achieve the instructional objectives.

Inclusive education aims to meet the educational needs of all students with special educational needs, accommodate diversity and differences, and oppose discrimination and rejection (Simui, 2022). From the teacher training perspective, it is crucial to understand how teachers improve their pedagogical knowledge and agency to implement inclusive education (Miller et al., 2022). Teachers' agency for inclusive education refers to their capacity and actions to adjust instructional activities to meet the diverse needs of students (Xue et al., 2023). It is regarded as a crucial factor in the success of inclusive education (Lyons et al., 2016). Literature suggests that teachers' agency can be determined from two perspectives: participatory and perceptual. (1) Participatory perspective: measuring teachers' agency involves agentic engagement, recordable actions, knowledge of the agency, academic status, and observable performance (Xue et al., 2023; Miller et al., 2022; Mu et al., 2015; Tinn & Ümarik, 2022). (2) Perceptual perspective: measurement of teachers' agency involves self-efficacy, personal goals, beliefs, and emotions (Polatcan et al., 2023; Tao & Gao, 2017; Tao et al., 2024). Both perspectives provide a measurement of teacher agency for inclusive education. The participatory perspective is related to describing teachers' involvement in inclusive education, whereas the perceptual perspective relates to describing the teachers' cognitive and affective states. However, Mu et al. (2015) stated that because of limited training in inclusive education, teachers' agency for inclusive education development is constrained. They are typically deficient in inclusive knowledge and the capacity to apply it in complex classroom contexts (Themane & Thobejane, 2019). Specifically, teachers tend to prioritise the delivery of content knowledge following predetermined procedures rather than actively involving and meeting the diverse needs of their students (Evans et al., 2021). They exhibit low adaptability to dynamic and complex classroom contexts (Lin et al., 2022b; Vaughn et al., 2022). In addition, teachers have difficulty providing individualised feedback to each student (Chang & Hwang, 2018) and they lack the knowledge to track students' progress and provide timely individualised guidance (Peruzzo & Allan, 2022). Developing teachers' cognitive knowledge and beliefs on inclusive education in teacher training programmes is important.

A systematic review of teachers' beliefs about inclusive education based on 102 studies with a total sample of about 40,900 teachers found that teachers' cognitive beliefs of inclusive education were average, with no significant difference between pre-service teachers and in-service teachers (Dignath et al., 2022). It also highlighted the importance of interventions to develop teachers' cognitive and affective beliefs about inclusive education (Pov et al., 2024). The practical experience in inclusive classrooms positively moderated the effect of intervention which implied that training programmes including a practicum in an inclusive classroom were better than those without such arrangements. To become literate in inclusive education, teachers should have developed sound teachers' agency, specifically (1) equip themselves with perceptions toward understanding regarding the importance of inclusive educational practices and (2) achieve the performance to implement inclusive education in a practical situation. As illustrated in this section, teachers may not be confident enough to teach inclusive classrooms. Nevertheless, interventions such as training programmes or professional development opportunities that emphasise technology integration can assist teachers in providing timely and individualised feedback to diverse students. These interventions may play a crucial role in helping teachers develop their agency and build up knowledge and positive attitudes toward inclusive education.

2.2. Augmented reality for inclusive education

AR refers to the technology that combines reality with virtuality through superimposed virtual objects, interactions, and interpretations in real-world images (Garzón & Acevedo, 2019). Previous studies have shown that AR, as an emerging technology, enables teachers to design personalised instruction for students with special needs and different backgrounds (Chang & Hwang, 2018; Lin et al., 2023b). Sat et al. (2023) proposed that AR tools provide the availability of instructional learning environments in which teachers can create interactive and immersive instructional materials to support students' learning and development. Chang and Hwang (2018) developed an AR-based flipped learning approach to support teachers in providing students with teaching resources, animated guidance, and instant feedback, which enhanced students' development at various cognitive levels (e.g., learning motivation, critical thinking tendency, and group self-efficacy). Therefore, AR has the potential to offer rich and immersive learning environments to fulfil the specific needs of students and significantly improve their academic performance and high retention of knowledge acquisition (Chang et al., 2023).

AR has been applied in inclusive education. In a systematic review of AR in inclusive education between 2008 and 2018, researchers found that AR has been used to support students with special needs in terms of increasing their motivation and facilitating interaction in learning (Quintero et al., 2019). However, these studies were mainly qualitative and exploratory in design. One of the challenges of the application of AR in inclusive education is the lack of learning resources for students with special needs. Researchers have emphasised that it is feasible for teachers to design learning resources and scenarios in the AR technology environment and to have the opportunity to advance their own professional development (Velazquez & Mendez, 2018; Yusof et al., 2014). Koutromanos et al. (2023) suggested that teacher training programmes should emphasise digital learning and AR technology in instructional design. Training teachers to develop AR learning environments aids in providing personalised and prompt feedback to students, fostering contextual interactions between learners and knowledge, and enhancing teachers' capacity to address the diverse needs of their students (Badilla-Quintana et al., 2020; Lin et al., 2023b).

2.3. Learning by design as an approach to learning

Learning by design is a learner-centred approach to learning whereby learners actively construct meaning and emphasise the processes necessary to establish a contextually enriched learning environment (An et al., 2022). In such an approach to learning, learners assume the role of designers, engaging in various forms of design, namely creating, planning, and participating (Kolodner et al., 2003). During the design process of technology-mediated instruction, learners may encounter specific difficulties; therefore, real-time and targeted feedback is important (Wang et al., 2023). The main objective of the learning by design approach is to develop learners' design thinking in order to meet the challenges of different classroom situations (Lin et al., 2022).

Studies have applied the learning by design approach in various educational settings. For example, Eysink et al. (2020) employed a digital learning environment that incorporates learning by design to enable gifted and non-gifted students to collaborate together. An et al. (2022) designed an online robotics course to develop in-service teachers' robotic knowledge and problem-solving skills using the learning by design facilitation strategies. The course increased teachers' knowledge and self-efficacy in robotics and collaborative problem-solving skills. Wu et al. (2021) designed a technology-enhanced environment for pre-service teachers to engage in the learning by design process using an authentic case, and found that participants developed knowledge and self-efficacy through such an approach. Therefore, many teacher education programmes are keen to apply the learning by design approach to develop teachers' knowledge and attitudes (Koh et al., 2015).

Studies have been conducted to explore how teachers integrate learning by design into instructional design. Fleer (2022) concluded a basic iterative cycle of designing the learning process including design, making, and assessing/evaluating, implying that teachers are involved in designing their practice, they diagnose and identify problems in the teaching process, and they reflect on the problems that arise in the learning process, and then reposition the design. Weng et al. (2022) proposed an instructional model guided by learning by design for deep learning including creating a situation stage, design scheme stage and evaluation and reflection stage, which emphasises that teachers should pay attention to the three phases: creating a situation, designing a scheme, and evaluating and reflecting. Eysink et al. (2020) developed a BE COOL! digital learning environment that integrated learning by design approaches to implement a science curriculum for students of all ability levels, exploring how technology can be used in learning by design to enable differentiated teaching and learning. Yeh et al. (2021) emphasised that learning by design is an iterative technology mapping process where teachers should design collaborative activities, create authentic contexts, emphasise problem-solving, and engage in a reflective iterative cycle of instructional design.

The above literature provided a reference for this study to extend the learning by design approach in the context of inclusive education-oriented teacher training programmes. Therefore, considering inclusive education implementation needs and potential support from technology, this study operationalised the learning by design approach as a 3-stage iterative cycle based on Fleer's (2022) research, including adaptive lesson plan design, inclusive teaching resource making, and progressive evaluation. Based on insights from previous studies, Fig. 1 shows the guideline of a 3-stage learning by design iterative cycle proposed in this study.

2.4. Research gap

As shown in previous sections, existing studies using AR to facilitate teachers' knowledge and perceptions of inclusive education are mainly qualitative or exploratory in nature. This study aimed to contribute to the existing research by adopting a more rigorous research design, namely a quasi-experimental design. The purpose of this study was to examine the effects of AR-based training through the learning by design approach on pre-service teachers' inclusive knowledge, higher-order thinking efficacy, perceived technology-assisted support, and attitudes towards inclusive education as compared to typical mobile AR-based training (An et al., 2022; Eysink et al., 2020; Yusof et al., 2014). Notably, research has revealed that teachers' efficacy can influence their inclusive education practices (Sharma et al., 2024). Miller et al. (2022) pointed out that teacher agency in inclusive education can be reflected in terms of teachers' efficacy, which emphasises the capacity to use differentiation in the classroom context, while Leaman and Flanagan, 2013 suggested that valuing the different learning needs of students requires teachers to have the capacity to perform complex, higher-order thinking. This suggested that higher-order thinking efficacy is an important variable in predicting pre-service teachers' learning outcomes regarding inclusive education since it reflected teachers' beliefs and confidence in identifying, understanding, and addressing students' individualised needs in higher-order thinking activities. Therefore, this study proposed that teachers' higher-order thinking efficacy in inclusive education is one of the aspects to examine the effectiveness of the proposed approach. The specific research questions (RQs) are listed as

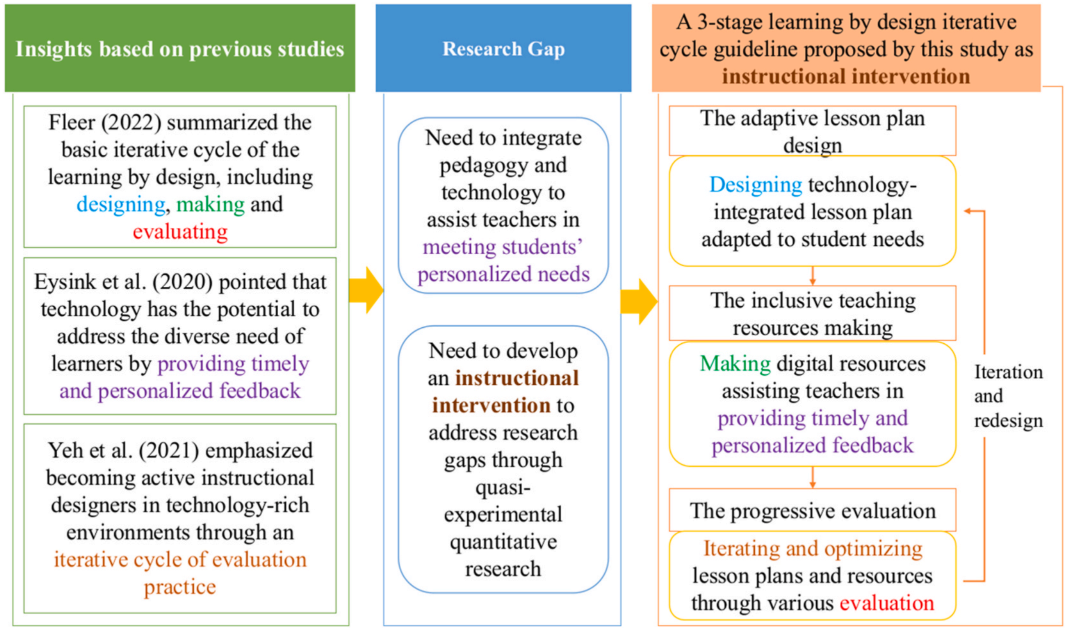

Fig. 1. Learning by design as an approach to develop teachers' agency for inclusive education.

follows.

(RQ1). Is there any difference in inclusive learning gains of pre-service teachers using the AR-based training by design approach and those using the mobile based learning by design approach?

(RQ2). Is there any difference in the higher-order thinking efficacy of pre-service teachers using the AR-based training by design approach and those using the mobile-based learning by design approach?

(RQ3). Is there any difference in the perceived technology-assisted support of pre-service teachers using the AR-based training by design approach and those using the mobile-based learning by design approach?

(RQ4). Is there any difference in the attitudes towards inclusive education of pre-service teachers using the AR-based training by design approach and those using the mobile-based learning by design approach?

3. System design and its associated strategy

3.1. Technology-enabled learning by design (TeLBD) system for inclusion

To solve the practical problems that teachers lack teaching materials and effective support in inclusive education, a Technology-enabled Learning by Design (TeLBD) system for inclusion was developed for the pre-service teachers in both experimental and control groups. As shown in Fig. 2, the TeLBD system is a cloud-based platform, including teaching functions, practice functions, evaluation functions, and database management functions. (1) The teaching functions are primarily utilised by pre-service teachers during their training sessions, encompassing modules such as the educational tasks module, the teaching content module, the teaching resources module composed of AR resources and mobile resources, and the topic discussion module; (2) The practice function is mainly employed by pre-service teachers when crafting their own lesson plans and resources, and includes a teaching content library, teaching design template library, mobile resource library, AR model and maker library, design results presentation, resource editing tools, and so on; (3) The evaluation function aims to offer pre-service teachers various methods to assess teaching effectiveness, and involves the presentation and editing of multiple-choice questions, matching questions, judgment questions and group guessing questions; (4) Database management functions support the functionality of the above functions and administer and store the users' data in the system, including the pre-service teachers' account database, the pre-service teachers' archive, the teaching template resource library, and the pre-service teachers' discussion library.

The pre-service teachers in both groups collaboratively created digital teaching resources. Fig. 3 shows the functions for developing digital teaching resources, which featured an easy interface and allowed online real-time collaboration and synchronous discussions. The system offers a range of mobile resource templates preset for different situations, and provides content-specific multimedia resources that combine video, pictures, audio, and text (see Fig. 4). With the editing interface shown in Fig. 3 and the templates shown in Fig. 4, pre-service teachers could design and customise elements within templates from a multi-sensory perspective, making authentic teaching scenarios suitable for inclusive classrooms. These functions empower pre-service teachers to effectively present knowledge points and implement diverse learning activities adaptable to students' individual needs.

In terms of creating AR teaching resources, the TeLBD system provides an AR resource database with various models covering different topics (Fig. 5). The AR model and marker library and resource editing tools enable the pre-service teachers to edit AR scene functions. This study aimed to further elaborate a broader feature of (1) how the system supports pre-service teachers to upload markers, (2) select 3D models and generate 3D scenes, and (3) which technology is adopted. First, this system provides an interactive interface, enabling pre-service teachers to rapidly integrate various resources such as videos, images, 3D models, and web links without the need for professional programming languages. Accordingly, it significantly shortens the production cycle of AR resources to effortlessly upload markers to the system. Second, regarding selecting 3D models and generating 3D scenes, the system provides pre-service teachers with a rich library of 3D models and virtual scene designs to browse and select through simple operations. Therefore, pre-service teachers could generate 3D scenes as easily as creating a PowerPoint presentation, by further interacting with real-time rendering to visualise the generated 3D scenes. Third, in terms of technology adaptation, the TeLBD system supports the integration of resources from a variety of tools for designing AR scenarios and inclusive teaching resources. For example, this study used (a) Photoshop,

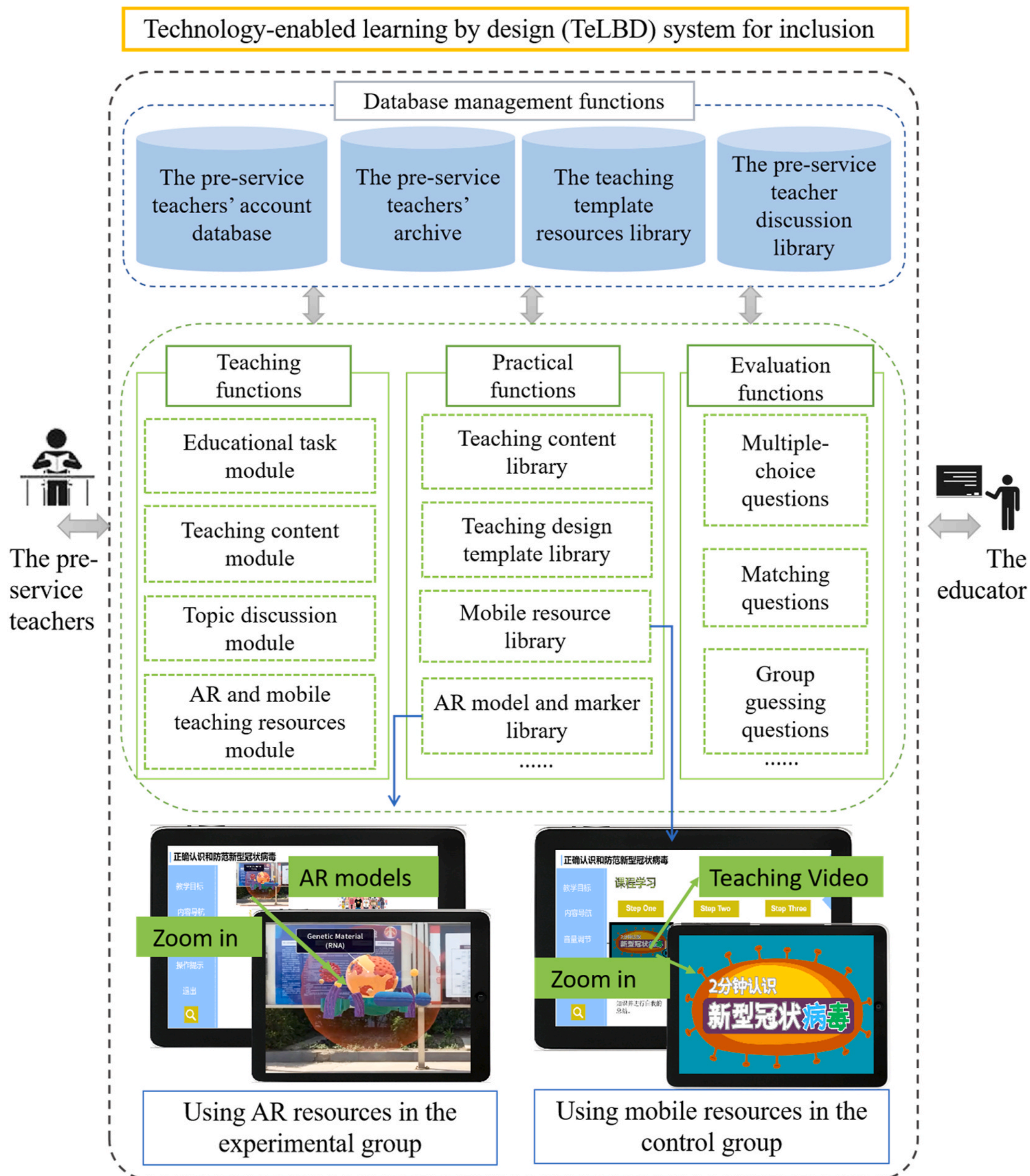

Fig. 2. The Technology-enabled Learning by Design (TeLBD) system for inclusion.

PowerPoint, and Final Cut to design 2D teaching resources, including videos, audio, and images; (b) 3Ds Max and Kivicube to create 3D models and virtual scenes; and (c) Dream Editor (i.e., powerful AR application production software) to integrate inclusive AR reading resources and models into the designed content. Accordingly, with the template resources and technical support, the pre-service teachers no longer have to develop teaching resources from scratch. Instead, they can modify existing templates to design improved resources for inclusive education. This not only reduces the duplication of effort in resource production, but also enables teachers to be more actively involved in instructional design tailored to students' needs.

On the one hand, the pre-service teachers could select relevant functions from templates and create AR resources in a modular manner. They have the flexibility to modify parameters, such as adding contextual information or AR markers, to enhance students' comprehensive understanding of the subject. This customisation also allows optimisation of existing AR resources to align with students' diverse learning needs. For example, AR technology can be used to identify images, so that students can complete the selection of images and judge whether they are right or wrong, achieving personalised feedback and real-time evaluation. By utilising the integrated AR resources, the pre-service teachers could create high-quality resources without the need for advanced programming skills. On the other hand, based on the AR's technical characteristics of 3D registration and virtual-real fusion, the TeLBD system can accurately place virtual objects in the real world, achieving precise integration of the virtual and the real, which enables students to interact with the virtual model in real time in the real learning environment, enhancing the immersion and interactive experience of students' learning. For example, the virtual virus model fuses with the virus samples in the textbook, which enables the interaction and comparison of the virtual virus model and the virus samples in the textbook, improving students' understanding and cognition of viruses.

Besides, the system offered various kinds of evaluation such as multiple-choice questions, matching questions, True or False questions, and group competition questions. To fill the inclusive and diverse needs, the evaluation functions of the system provide evaluation options for the pre-service teachers to suit the needs of diverse students. For example, the system can generate a series of individualised games to help the pre-

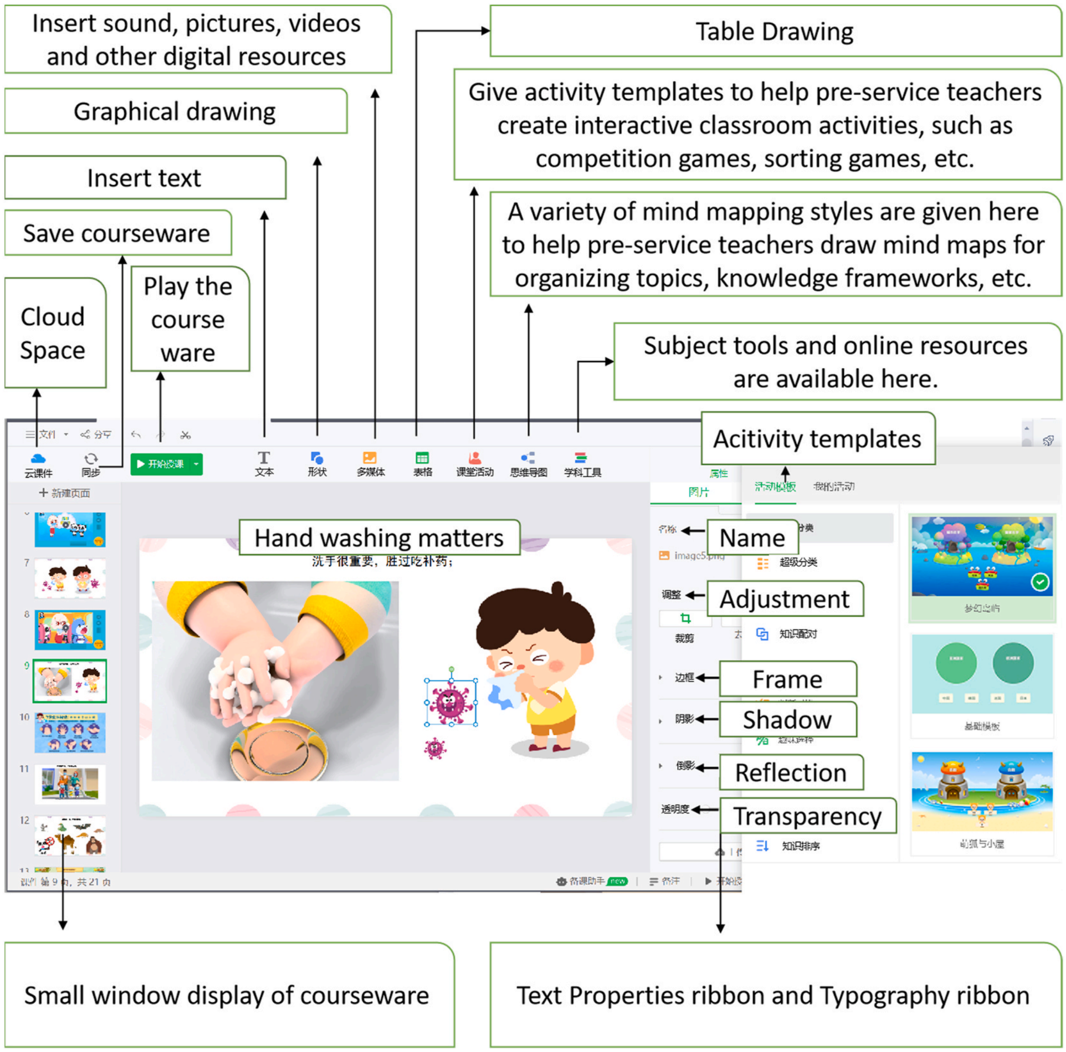

Fig. 3. The editing interface for pre-service teachers to create teaching resources.

service teachers assess students' knowledge. The pre-service teachers develop the assessment by distributing the game, which assists them in providing personalised feedback to the students, and helps them understand what the students still need to work on. The system then provides further targeted games aimed at bridging teaching gaps. As shown in Fig. 6, the pre-service teacher designed a learning activity in the form of True or False questions to identify different variants of SARA-CoV-2. This learning activity was conducted through a group competition, where one can participate in judging whether the option is a variant of the novel coronavirus. After the competition, the system would check the answers to provide individual feedback regarding knowledge gaps.

3.2. Teaching mode design

This study took the theme of "modelling the spread of SARS-CoV-2 for inclusive education" as an example to help the pre-service teachers design lessons about how to prevent the spread of COVID-19. With the support of the TeLBD system, the study extended Fleer's (2022) learning by design iterative circle and integrated it into technology-supported inclusive education. A 3-stage learning by design iterative cycle was proposed with the aim of achieving contextual, problem-driven, collaborative, iterative, and reflective goals. These goals were adopted for the reflection and iteration of instructional design plans, aiding pre-service teachers in designing inclusive and adaptable lesson plans and digital resources. The 3-stage learning by design iterative cycle comprised adaptive lesson plan design, inclusive teaching resource making, and progressive evaluation. The instructional flowchart is shown in Fig. 7.

(1) The adaptive lesson plan design stage involves the pre-service teachers developing inclusive instructional activities tailored to meet the diverse needs of students, thus allowing for customization within the specific teaching context. The TeLBD system's teaching functions can present the pre-service teachers with inclusive teaching design methodologies and offer access to digital resources as reference points, helping them to identify problems of inclusive teaching and develop ideas for lesson plan design accordingly in the process of discussion. During this stage, the instructor divides the pre-service teachers into groups of three to five to engage in collaborative learning activities, and provides them with templates for technology-integrated learning by creating instructional designs. Simultaneously, pre-service teachers undertake two key activities. First, they engage in collaborative discussions to creatively craft inclusive lesson plans, focusing on designing diverse scenario simulations centred around the SARS-CoV-2 epidemic to visualise and understand the virus from various perspectives. Second, they work in teams to search for relevant inclusive information and plan suitable learning activities using the TeLBD system. This includes posing challenging learning problems related to virus transmission and

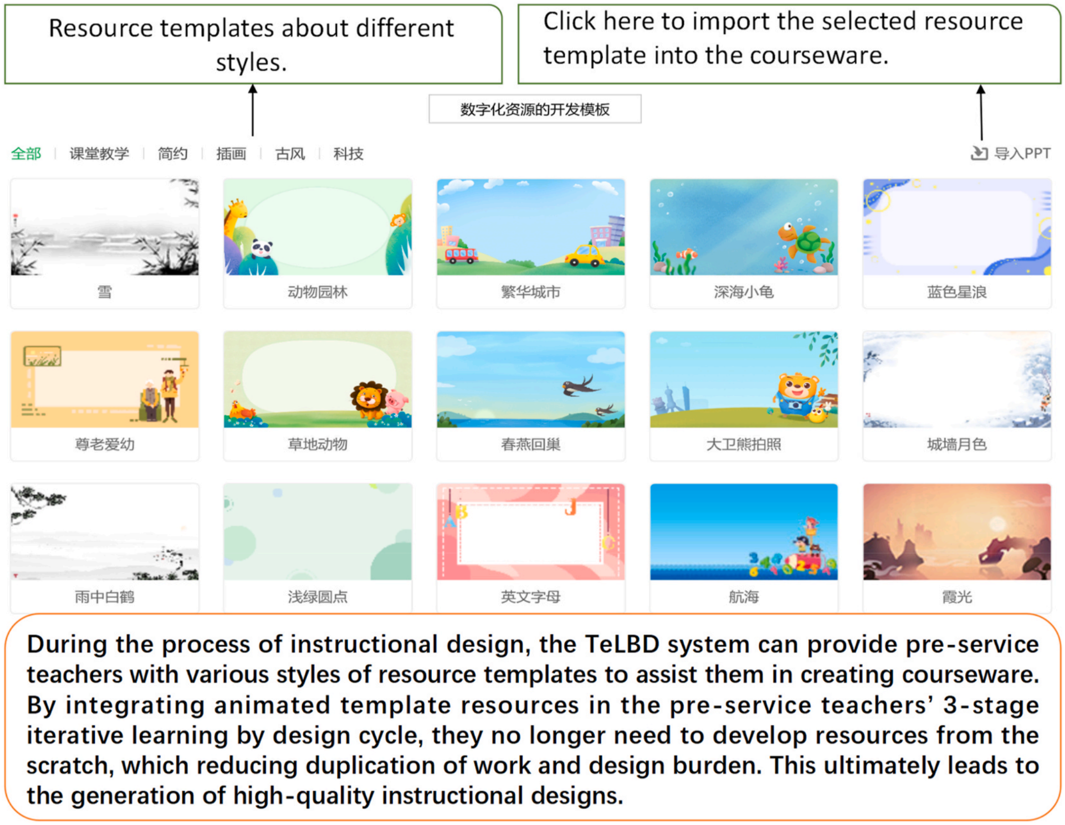

Fig. 4. The existing templates of multimedia digital resources development.

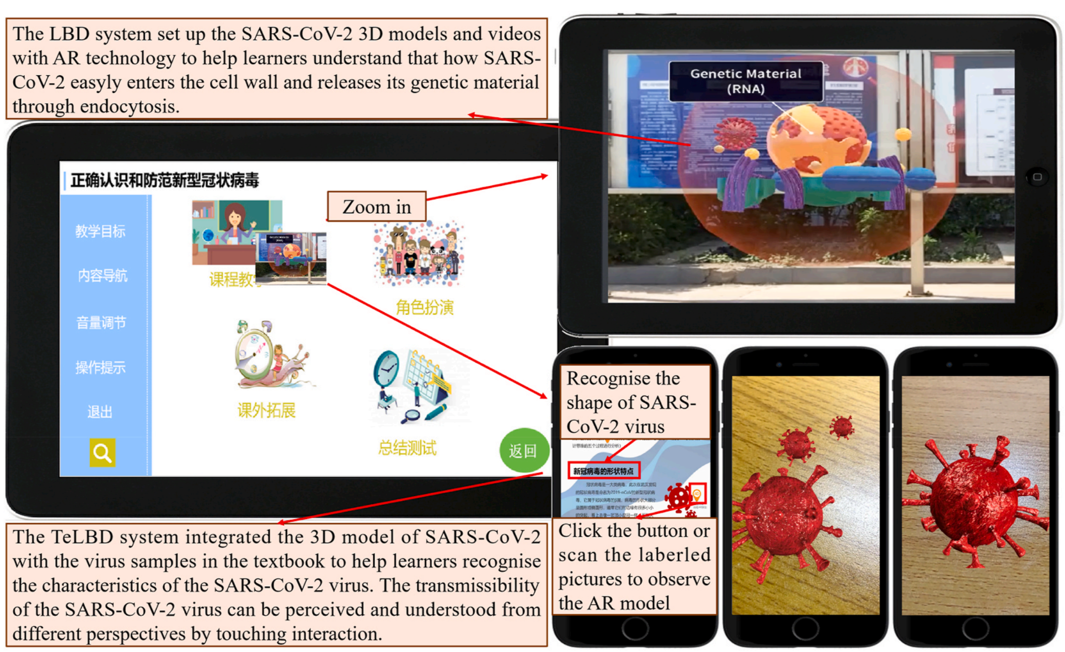

Fig. 5. The Functions and examples of AR-based training through learning by design approach for pre-service teachers.

conducting problem-solving-oriented lesson plan design. Throughout this process, pre-service teachers enhance their higher-order thinking abilities by exploring and designing refined inclusive teaching questions as well as crafting authentic contextualised lesson plans.

(2) The inclusive teaching resources making stage refers to making digital resources in a collaborative team using the TeLBD system's practical functions. The pre-service teachers have to optimise hardware and software resources based on group discussions. Drawing on the strengths of each team member, they collectively discuss and determine the content, format, and presentation of teaching resources to ensure alignment with the principles of inclusive education. They work together to develop inclusive education resources using the appropriate mobile

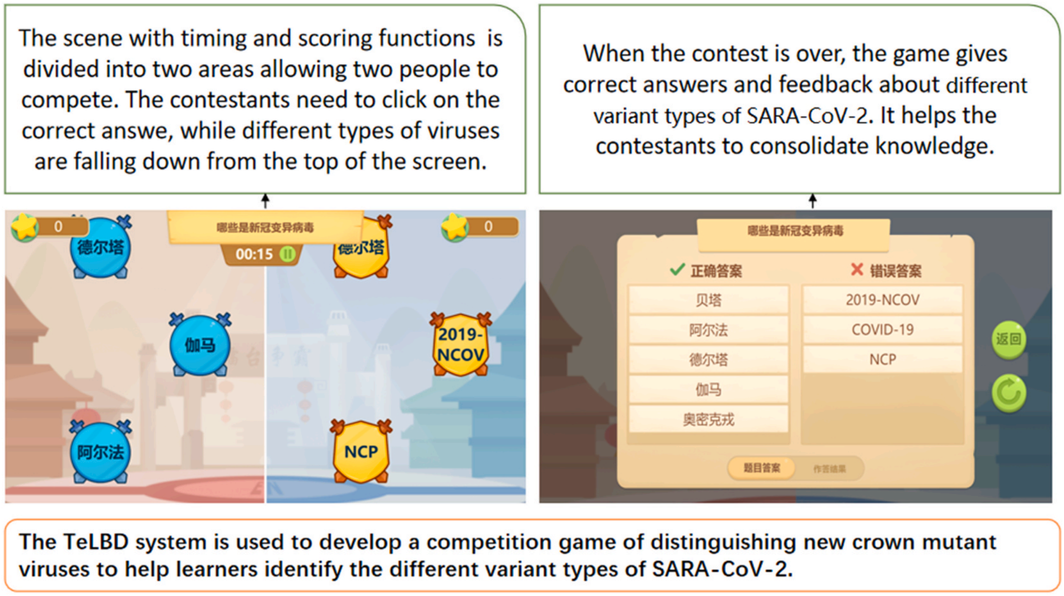

Fig. 6. Examples of evaluation functions.

The 3-stage learning by design iterative cycle			
Stages	**The pre-service teachers activities**	**The instructor activities**	**TeLBD system support**
The adaptive lesson plan design stage	• Exploring inclusive teaching and learning problem • Designing authentic contextual and problem-oriented instructional programs • Developing ideas for the design of digital teaching resources	• Organise collaborative learning activities • Explain the instructional design template	Teaching functions
The inclusive teaching resources making stage	• Collectively discuss and determine the content, format, and presentation of teaching resources • Develop inclusive education resources • Select appropriate assessment methods	• Provide tutorials, hardware and software resources • Organise collaborative discussion	Practical functions Evaluation functions
The progressive evaluation stage	• Presenting their own design work to receive feedback • Discuss and develop important evaluation criteria • Refine their designs based on feedback	• Provide feedback • Guides the group in a reflective process	Topic discussion module

Fig. 7. Instructional flowchart.

resources or AR model libraries in the TeLBD system to support the teaching and learning activities in the lesson plans. Additionally, they select appropriate assessment methods to gauge students' learning progress and provide targeted feedback.

(3) The progressive evaluation stage involves inter-group and intra-group evaluation of the lesson packages designed considering the need for inclusive education. The pre-service teachers initiate this stage by presenting their design work to receive feedback from peers and instructors, which meets the needs of diverse evaluation. Then, supported by the TeLBD system's topic discussion module, team members discuss and develop important evaluation criteria. During this iterative process, pre-service

teachers refine their designs based on feedback from previous rounds. Finally, the instructor guides the group in a reflective process to summarise their experiences and adjust the design process accordingly to ensure the effective implementation of inclusive education aligned with the learning objectives.

In summary, with the goal of achieving contextual, problem-driven, collaborative, iterative, and reflective instructional design, the pre-service teachers iteratively improve their higher-order thinking by repeating the three phases of instructional design stages based on educator evaluation, peer, and self-evaluation using back-and-forth feedback to improve their instructional design plan.

3.3. The strategy of integrating AR into learning by design for inclusive education in the experimental group

The experimental group used the strategy of integrating AR into learning by design for inclusive education. Focusing on the 3-stage learning by design iterative cycle, this study designed an AR-based training through learning by design approach for pre-service teachers in the experimental group and selected the theme “modelling the spread of SARS-CoV-2 for inclusive education”. The pre-service teachers are mandated to attain proficiency in creating flexible lesson plans that are supported by AR technology. These plans should allow for adjustments in response to ill-structured problems that may arise in the classroom. Furthermore, the pre-service teachers are expected to employ AR teaching resources that not only foster student knowledge construction but also offer timely feedback to support the facilitation of teaching activities.

(1) During the adaptive lesson plan design stage, the pre-service teachers learned how to use AR technology and developed instructional designs. They were taught about AR technology use methods and raised awareness regarding how to use AR to visually and multidimensionally represent the SARS-CoV-2 virus in an authentic teaching context. This training sought to help pre-service teachers develop immersive real-life contexts about the transmission of the epidemic. Additionally, pre-service teachers designed teaching activities based on AR games and provided prompt individual feedback for students. This approach effectively addresses the difficulty faced by a single teacher in delivering concurrent feedback to numerous students while catering to their educational requirements.
(2) In the inclusive teaching resources making stage, the pre-service teachers developed AR resources and embedded them with the TeLBD system. During learning, the AR model of the SARS-CoV-2 virus spreading under different conditions is presented in a virtual-reality environment. The pre-service teachers should generate three distinct AR models (see Fig. 5), each portraying a distinct SARS-CoV-2 virus transmission scenario: without any protection, wearing a mask, and being vaccinated. These layered AR models present students with inclusive learning scenarios, enhancing the authenticity of students' experience of real-world problem-solving design activities. By realistically understanding the transmission process of the SARS-CoV-2 virus, students are able to experience more in-depth design learning.
(3) In the progressive evaluation stage, the pre-service teachers identified and analysed issues in the instructional process through mutual evaluation and evaluation by educators. Based on the feedback received during the evaluation process, the pre-service teachers could iterate on the instructional design and resources.

3.4. The strategy of combining mobile learning with learning by design for inclusive education in the control group

The pre-service teachers in the control group did not receive AR support but were trained with the mobile-based approach. The control group similarly utilised the 3-stage learning by design iterative cycle, the educator instructed pre-service teachers on the learning by design procedures' structure, and the control group was taught the same topic as the experimental group, “modelling the spread of SARS-CoV-2 for inclusive education.” The objective of the task was to develop pre-service teachers' performance and perceptions in breaking down digital teaching resources into discrete elements to facilitate the distribution of concepts about what SARS-CoV-2 is and how to prevent it.

(1) In the adaptive instructional design stage, the pre-service teachers engaged in using the TeLBD system for content-based learning with mobile devices, identifying lesson plans with supportive feedback, and designing effective teaching practices through the collaborative team. The pre-service teachers read, listened to, and watched inclusive learning materials, such as e-books and online videos with their smartphones or iPads directed by the educator. This mobile learning also helped the pre-service teachers by providing simple support for forming a feedback loop to figure out how many concepts it would take to shoot their lesson plans and digital teaching resources.
(2) During the inclusive teaching resource making stage, the pre-service teachers develop digital teaching resources, which are integrated with interactive tools based on the teaching plan with the guidance of the educator. This supports the development of instructional activities and enhances resource interactivity to meet the diverse needs of students.
(3) In the progressive evaluation stage, the pre-service teachers iterated the design by actively participating in collaborative teamwork to discuss how to effectively combine concepts of inclusive knowledge and learning materials.

4. Method

4.1. Participants

This study was conducted during the COVID-19 pandemic, specifically from March to April 2022. The participants were 128 pre-service teachers specialising in science education from a public university in southern China, of whom 56.12% were female. The average age of these teachers was 21.12 ($SD = 5.69$). Based on experimental design principles, the participants were randomly assigned to the control and experimental group. The experimental group included 64 pre-service teachers using the AR-based training through learning by design approach, and the control group included 64 pre-service teachers who adopted the mobile-based training through learning by design approach. These pre-service teachers in the science teacher education programme were selected as a sample since they had taken the Introduction to Inclusive Education course, which outlines the principles and practices of implementing inclusive education in the science curriculum. Besides, they had taken a series of courses emphasising the integration of technology and innovative teaching methodologies, and they were characterised by their experience of applying the integration of technology and pedagogy, their familiarity with AR technology, and their prior experience of teaching innovations. With the additional permission of the pre-service teachers, the participants completed the anonymous questionnaires. Participants were informed about the research objectives and procedure, and the data would be used for research and didactical purposes. The privacy and confidentiality of participants were strictly maintained. The experiment stated that participants could suspend and discontinue the experiment at any time if they experienced psychological discomfort.

4.2. Experimental procedure

The experimental procedure is shown in Fig. 8 and lasted for 6 weeks. At the beginning of the experiment, the pre-service teachers in both the experimental and control groups were taught the basic principles of inclusive education and activity creation in the classroom for around 2 weeks. They were trained to operate the learning by design system and conceptual knowledge related to learning by design. Then, all pre-service teachers were required to finish the pre-questionnaires and accomplish a pre-test to ensure an equivalent prior knowledge of inclusive education. During the experiment, the same educator instructed all pre-service teachers and accepted the same learning materials and topics. In the following 3 weeks, both groups exercised the learning by design in the context of inclusive topics in different ways: the experimental group used the AR-based training through learning by design approach while the control group used mobile-based training through learning by design approach. The experimental group mainly constructed AR-based or 3D learning materials to practice their inclusion skills in teaching, whereas the control group designed and implemented mobile learning inclusive teaching assignments and activities. In the final week, all pre-service teachers completed post-tests and post-questionnaires to verify the effectiveness of the different approaches.

4.3. Instruments

In this study, teachers' agency for inclusive education refers to (1) the inclusive knowledge required to deal with students in inclusive classrooms, and (2) the perceptions of inclusive education. Since this study combined the potential support of AR technology and the learning by design approach to develop teachers' agency for inclusive education, teachers' perceptions of inclusive education should include higher-order thinking efficacy, attitudes toward inclusive education, and perceived technology-assisted support (Chai et al., 2015; Jordan et al., 2009; Lin et al., 2019, Lin et al., 2020; Opoku et al., 2021).

4.3.1. Learning performance regarding inclusive knowledge

Learning performance regarding inclusive knowledge denotes the performance of specialised knowledge and skills to work with students with special education needs in inclusive classrooms (Jordan et al., 2009). A knowledge test was constructed to test pre-service teachers' learning performance regarding inclusive knowledge. Two experts in teaching inclusive education evaluated all items' content validity to confirm the validity and reliability of all of the items. The KR20 reliability coefficient for the pre-test and post-test, respectively, yielded 0.84 and 0.85, indicating the test's sufficient reliability. The pre-test and post-test were respectively composed of five single-choice questions (50 scores), two multiple-choice questions (20 scores), and two open-ended questions (30 scores); the total score of each test was 100. Sample questions appearing in each test are listed below. The participants were presented with the following scenario: "The topic of whether the tourism border should be opened in the post-COVID-19 period is still a fierce argument in China as a whole. Opening the border for tourists is widely seen as an appropriate option, showing the potential prosperity and profit that could be derived from it. Nevertheless, a few shortcomings have also been raised, like the increased number of COVID-19 patients. With that in mind, try to picture yourself in the situation below. As the mayor of a marginal town, you have a predicament between declining financial performance and the potential drawbacks of an open tourism border."

4.3.2. Perceptions of inclusive education

The pre-service teachers' higher-order thinking efficacy represents their beliefs and confidence in meeting students' individual needs when engaging in higher-order thinking activities, such as collaboratively and creatively designing inclusive instructional activities (Chai et al., 2015). The pre-service teachers' higher-order thinking efficacy was modelled from the questionnaire of Lin et al. (2019) and consisted of three subscales with a 5-point Likert-type scale: (1) Self-efficacy of collaborative learning (3 items); (2) creative thinking confidence (3 items); and (3)

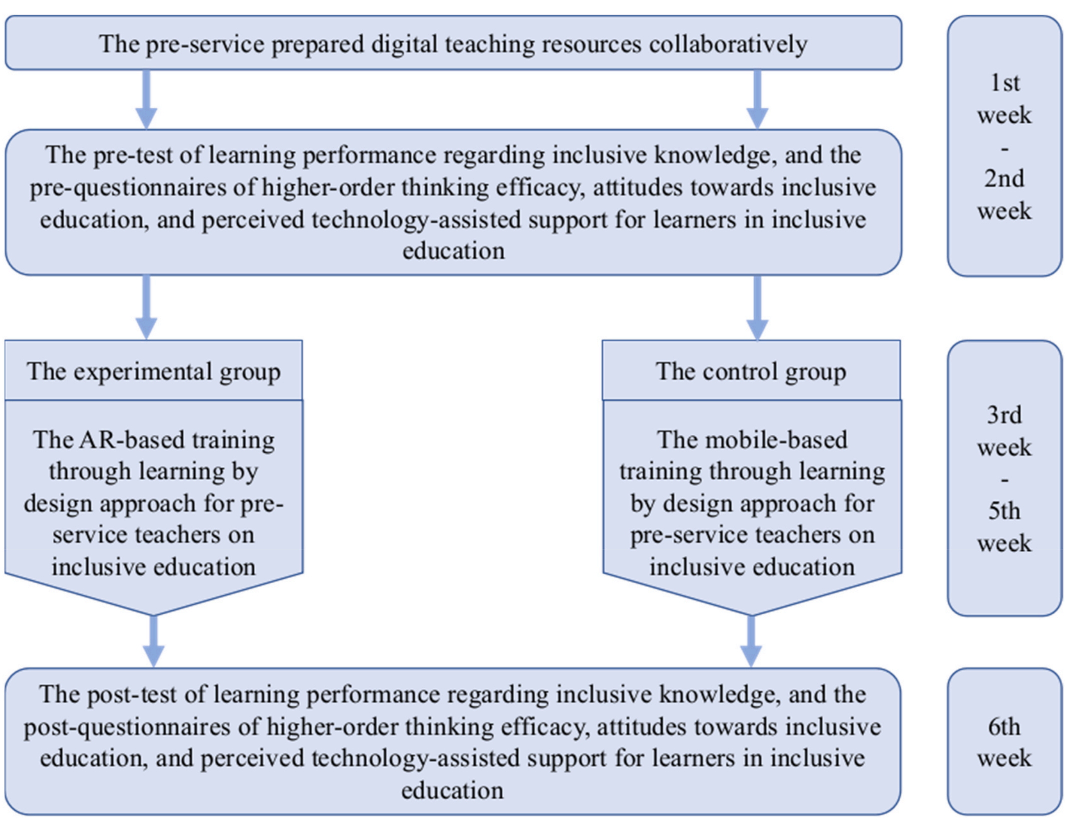

Fig. 8. Experimental procedure.

authentic problem-solving confidence (3 items). The values of each Cronbach's α (0.85, 0.86, and 0.81) showed that the scales were reliable to use. The findings of confirmatory factor analysis (CFA) suggested that the composite reliability (CR) coefficients exceeding 0.88 (ranging from 0.88 to 0.93) and the AVE values higher than 0.68 (ranging from 0.68 to 0.86) indicated adequate convergent validity of the factors. Sample questions corresponding to each subscale are as follows: (1) Self-efficacy of collaborative learning: I think I could express and share my opinions with my peers about how to teach students with individual needs in inclusive classroom; (2) Creative thinking confidence: I think I could implement innovative instructional activities to meet students' individual needs in inclusive classroom; (3) Authentic problem-solving confidence: I think I could evaluate the usefulness of innovative instructional activities to meet students' individual needs in inclusive classrooms. All the items of pre-service teachers' higher-order thinking efficacy are presented in Appendix A.

The pre-service teachers' attitudes toward inclusive education represent their disposition, feelings, or tendency to meet students' individual needs in the technology-enhanced inclusive teaching process (Opoku et al., 2021). The pre-service teachers' attitudes toward inclusive education were collected using the questionnaire from Opoku et al. (2021), which consisted of four scales: sentiments (4 items, α = 0.83), acceptance (4 items, α = 0.83), concerns (4 items, α = 0.85) and engagement (6 items, α = 0.86). Their Cronbach's α values suggested good reliabilities. All items were measured on a 5-point Likert-type scale. The results of the CFA showed sufficient convergent validity, as evidenced by CR coefficients above 0.89 (ranging from 0.89 to 0.94) and AVE values exceeding 0.79 (ranging from 0.79 to 0.87). The items of sentiment and concerns were worded in a negative voice, while the items of acceptance and engagement were worded in a positive voice. All reversed items were coded positively before calculating the reliability and analysing the data. Sample items of each scale are given as follows: (1) Sentiments: I am excited to design diverse teaching solutions to address students' special needs by using the technology-enabled learning by design system; (2) Acceptance: Students' differences in exam performance should be respected and recognised in inclusive classrooms; (3) Concerns: I am optimistic that it will be practicable to give appropriate attention to students with special needs in an inclusive classroom; (4) Engagement: Even if the inclusive teaching task was challenging, I would like to continue to find solutions by using different technology or approaches. All the items of pre-service teachers' attitudes toward inclusive education are presented in Appendix A.

Perceived technology-assisted support refers to the extent to which pre-service teachers perceive the level of support via technologies (e.g. AR technology, internet forums, and triggered feedback) to teach in inclusive classrooms. The questionnaire of pre-service teachers' perceived technology-assisted support for learners was formulated after the original perceived technology-assisted support for learners developed by Lin et al. (2020), including six items. The Cronbach's α value of the subscale was 0.82, indicating that this scale was reliable. Additionally, the CR coefficient was 0.95 and the AVE value was 0.85, which indicated adequate convergent validity of the factors. The questionnaire was rated using a 5-point Likert-type scale. An example item is "I believe that students with individual needs can be supported by timely feedback if the lesson is well-designed with technology (e.g., AR technology)." All the items of perceived technology-assisted support are presented in Appendix.

4.4. Data analysis

First, the data collected using the scales were subjected to descriptive statistical analysis. Second, Levene's test was employed to verify the homogeneity of variances. The independent variables were the AR-based training through learning by design approach for pre-service teachers and the mobile-based training through learning by design approach for pre-service teachers, while the post-test and scales were the dependent variables, and the pre-test and scales were the covariables. Third, this study conducted a one-way analysis of covariance (ANCOVA) to examine the main differences between the control group and the experiment group in the four dimensions (i.e., learning performance regarding inclusive knowledge, perceived technology-assisted support for learners, the pre-service teachers' attitudes towards inclusive education, and higher-order thinking efficacy). The mathematical function of ANCOVA are as follows.

$$Y_{ij} = \beta_0 + \beta_1 G_{ij} + \beta_2 X_{ij} + e_{ij}$$

.

In the mathematical function, Y_{ij} could be regarded as the degree of post-test and questionnaire among person i in group j (i.e., Y_{i1} for the control group and Y_{i2} for the experimental group). G_{ij} is an indicator (i.e., $G_{i1} = 1$ for the control group, $G_{i2} = 2$ for the experimental group). X_{ij} is the covariance, which could be also expressed as the sum of the products of the data of the two variables (i.e., X_{ij} and Y_{ij}) and the difference between their respective means (i.e., $\overline{X}$ and $\overline{Y}$) divided by the total number of data. e_{ij} is normally distributed with zero mean, random error and constant variance. β_1 is the group difference on $\overline{X}$ adjusted for differences on $\overline{Y}$. Practical use of ANCOVA requires estimation of β_2, where β_2 is a function of the within-group variances and correlation between pre-test and pre-questionnaire and post-test and post-questionnaire. β_1 is the difference of post-test and questionnaire minus $\beta_2 \times$ the difference of pre-test and questionnaire.

ANCOVA assumes linearity of the covariate effect and absence of covariate-group interaction. After conducting the ANCOVA analysis as described above, we proceeded to examine the disparity of the treatment between the two groups by assessing the effect sizes. The effect size ($\eta 2$) can be calculated by subtracting the mean of the experimental group from the mean of the control group and dividing it by the pooled standard deviation of the two groups. $\overline{X}$ and $\overline{Y}$ denote the mean of the control group and experimental group, respectively. SD_1 and SD_2 represent the standard deviation of the two groups, respectively. In addition, n_1 and n_2 are the respective sample sizes of the two groups.

5. Results

5.1. Descriptive statistics for each scale of perceptions of inclusive education

Descriptive analyses were conducted to describe each scale of pre-service teachers' higher-order thinking efficacy, attitudes, and perceived technology-assisted support to provide an overview of pre-service teachers' perceptions of inclusive education. The mean and standard deviation for all items in each scale used in the analysis are displayed in Table 1.

Table 1
Means and standard deviations for each item of perceptions of inclusive education.

Scales	Control Group ($n = 64$)		Experimental Group ($n = 64$)	
	Mean	SD	Mean	SD
Higher-order thinking efficacy	3.67	0.67	4.21	0.56
Self-efficacy of collaborative learning	3.60	0.65	4.12	0.57
Creative thinking confidence	3.69	0.70	4.20	0.61
Authentic problem-solving confidence	3.72	0.66	4.31	0.50
Attitudes toward inclusive education	3.56	0.98	3.98	0.67
Sentiments	3.55	0.92	3.99	0.65
Acceptance	3.66	0.97	4.05	0.72
Concerns	3.45	0.99	3.89	0.69
Engagement	3.58	1.04	3.99	0.62
Perceived technology-assisted support	3.81	0.68	4.24	0.56

5.2. Learning performance regarding inclusive knowledge

To answer RQ1, the ANCOVA was conducted to evaluate the difference in learning performance regarding inclusive knowledge between the experimental group and the control group (See Table 2). The homogeneity of variance assumption and the homogeneity of regression coefficients were calculated before conducting ANCOVA. A Levene's test for determining homogeneity of variance was not violated ($F = 2.54$, $p = 0.63 > 0.05$), and specifying homogeneity of regression coefficients did not reach the significant level ($F = 1.037$, $p = 0.86 > 0.05$), which indicated that the data were suitable to employ ANCOVA.

As shown in Table 2, the ANCOVA results suggested a significant difference ($F = 12.98$, $p < 0.05$) in learning performance regarding inclusive knowledge between the experimental group (adjusted mean = 86.97) and the control group (adjusted mean = 79.19). That is, the pre-service teachers in the experimental group had significantly better performance than those in the control group. The effect size (η^2) of the ANCOVA results represented a large effect size ($\eta^2 > 0.138$) based on the categories of Cohen, 1998. This implied that the AR-based training through learning by design approach helped the pre-service teachers gain better learning performance regarding inclusive knowledge than the mobile-based training through learning by design approach.

5.3. Higher-order thinking efficacy

For RQ2, all variables met the assumption of equal variances using a Levene's test ($F = 2.97$, $p = 0.16 > 0.05$), and the slope homogeneity test ($F = 0.97$, $p = 0.38 > 0.05$) indicated no significant results. Therefore, the variances for both groups were assumed to be equal. Table 3 shows a significant difference in higher-order thinking efficacy results between the two groups ($F = 9.97$, $p < 0.05$) with a large effect size ($\eta^2 = 0.167 > 0.138$), which suggested the post-test score of the experimental group outperformed that of the control group. The results revealed that the pre-service teachers in the experimental group ($M = 4.22$, $SD = 0.56$) were exposed to higher-order thinking efficacy, while in the control group ($M = 3.71$, $SD = 0.67$), they experienced less higher-order thinking efficacy. It could be concluded from the comparison that the AR-based training through learning by design approach could enhance higher-order thinking efficacy for the pre-service teachers compared to the mobile-based training through learning by design approach for inclusive education.

5.4. The pre-service teachers' attitudes towards inclusive education

To answer RQ3, a Levene's test was conducted to check the pre-service teachers' attitudes towards inclusive education for the homogeneity of variance assumption with $F = 0.36$ ($p = 0.49 > 0.05$), and the regression coefficients were $F = 0.67$ ($p = 0.68 > 0.05$). The assumptions were met. As presented in Table 4, a significant difference between teachers' attitudes towards inclusive education ($F = 6.98$, $p < 0.01$) was confirmed between the experimental group and the control group. The η^2 was 0.098, indicating a medium effect size. In comparison with the scores of the control group ($M = 3.58$, $SD = 0.59$), teachers in the experimental group ($M = 3.99$, $SD = 0.68$) gave higher scores for attitudes towards inclusive education. Thus, the pre-service teachers with AR-based training through learning by design approach showed more positive attitudes than those with mobile-based training through learning by design approach for inclusive education.

5.5. Perceived technology-assisted support for learners

With regard to teachers' perceived technology-assisted support for learners, i.e. RQ4, a Levene's test for equality of variances was not significant ($F = 0.68$, $p = 0.68 > 0.05$). The variances for both groups were consequently assumed to be equal. Meanwhile, the inspection result of the slope homogeneity test ($F = 0.69$, $p = 0.48 > 0.05$) showed no significant interaction relationship between the independent variables and covariables. Hence, the use of ANCOVA was appropriate, and the results are presented in Table 5. The scores of perceived technology-assisted support for learners between the experimental group ($M = 4.22$, $SD = 0.61$) and the control group ($M = 3.79$, $SD = 0.72$) were significantly different ($F = 15.221$, $p < 0.01$). Moreover, the ANCOVA demonstrated a moderate effect size with $\eta^2 = 0.121$. Together, the results indicated that the pre-service teachers with the AR-based training through learning by design approach showed more perceived technology-assisted support for learners compared with those under the mobile-based training through learning by design approach for inclusive education.

6. Discussion

This study examined the effect of AR-based training through a learning by design approach as compared with the typical mobile AR-based training. As shown in section 5, the AR-based training through learning by design approach for pre-service teachers significantly improved pre-service teachers' learning performance and attitudes towards inclusive education. The finding is consistent with existing literature on teacher training programmes in inclusive education (Badilla-Quintana et al., 2020; Dignath et al., 2022; Lin et al., 2023b; Pov et al., 2024) and the integration of AR in inclusive education (Quintero et al., 2019; Velazquez & Mendez, 2018; Yusof et al., 2014).

This study also found that pre-service teachers had significantly better higher-order thinking efficacy after the AR-based training through learning by design approach. This finding is endorsed by previous study with participants of in-service teachers and primary school students (An et al, 2022; Lin et al., 2023b). Specifically, the AR-based training with design activities promoted higher-order thinking, such as developing creativity efficacy by creating open-ended questions and tasks, and developing complex problem-solving efficacy by working out AR-supported feedback to the students' individual learning needs (Lin et al., 2023a). In addition, pre-service teachers perceived better technology-assisted support in the treatment conditions. As the key difference between the treatment group and the control group is the collaborative learning by design approach, this finding shows that pre-service teachers support AR-based training through the learning by design approach. This study extended the previous study of Callaway-Cole and Kimble (2021), who noted the importance of promoting pre-service teachers' preparation, such as collaborative engagement, inclusive design, and flexibility with mixed reality. It contrasted with the work of O'Sullivan et al. (2021) with quantitative results highlighting the importance and the effect size of designing collaborative and technology-mediated learning activities in interactive learning environments for pre-service teachers to obtain positive attitudes toward inclusive education.

Table 2
The ANCOVA result of learning performance regarding inclusive knowledge.

Group	N	Mean	SD	Adjusted Mean	Adjusted SD	F	η^2
Experimental Group	64	87.12	7.98	86.97	7.99	12.98[a]	0.269
Control Group	64	78.45	9.87	79.19	9.21		

Note.
[a] $p < 0.001$.

Table 3
The ANCOVA result for higher-order thinking efficacy.

Group	*N*	Mean	*SD*	Adjusted Mean	Adjusted SD	*F*	η^2
Experimental Group	64	4.21	0.56	4.22	0.56	9.97[a]	0.167
Control Group	64	3.67	0.67	3.71	0.67		

Note.
[a] $p < 0.05$.

Table 4
The ANCOVA result for the pre-service teachers' attitudes towards inclusive education.

Group	*N*	Mean	*SD*	Adjusted Mean	Adjusted SD	*F*	η^2
Experimental Group	64	3.98	0.67	3.99	0.68	6.98[a]	0.098
Control Group	64	3.56	0.98	3.58	0.59		

Note.
[a] $p < 0.01$.

Table 5
The ANCOVA result of perceived technology-assisted support for learners.

Group	*N*	*Mean*	*SD*	Adjusted Mean	Adjusted *SD*	*F*	η^2
Experimental Group	64	4.24	0.56	4.22	0.61	15.221[a]	0.121
Control Group	64	3.81	0.68	3.79	0.72		

Note.
[a] $p < 0.01$.

Many studies have been conducted to develop teachers' capacity for inclusive education (Dignath et al., 2022). At the same time, a growing number of studies are employing AR technology in inclusive education (Quintero et al., 2019). However, few studies of teacher education programmes or professional development have used AR technology to develop teachers' capacity for inclusive education. This study contributes to the existing research with the AR-based training through the learning by design approach to improve pre-service teachers' capacity for inclusive education with significantly better effect. Therefore, this study enriches our understanding of the adoption of AR-based technology through the learning by design approach in the teacher training context of inclusive education.

7. Contributions and limitations

This quasi-experimental study proposed a system that enabled pre-service teachers to make learning resources for diverse learners through the learning by design approach. It contributes to existing research on teachers' agency for inclusive education through the integration of AR technology and the learning by design approach. It highlights the importance of collaborative and active engagement of pre-service teachers in the interactive learning environment of AR technology. The effect of such a learning approach improves pre-service teachers' capacity for inclusive education both cognitively and effectively, including learning performance in inclusive education, higher-order thinking efficacy, attitudes towards inclusive education, and perceived technology-assisted support for learners. This study sheds light on how teacher education programmes can facilitate pre-service teachers' capacity for inclusive education. It provides teacher educators with clear guidelines for technology-integrated instructional activities by using the learning by design approach. AR serves as a technological aid to enable pre-service teachers to design instructional tasks based on instant feedback elicited by individualised needs. Pre-service teachers are encouraged to participate in in-depth discussions and interactions in a teaching community. To the best of our knowledge, no studies have been presented regarding what design frameworks are effective in terms of applying AR for educational inclusion. Accordingly, this is one of the pioneering studies that alerts teachers to significant new developments in the AR-assisted inclusive education area.

Despite the practical and theoretical findings, the study has some limitations that warrant consideration. We list the limitations with corresponding future research directions as follows. First, the sample of this study primarily consisted of pre-service teachers with science education backgrounds. Thus, the findings may be constrained to this specific population. Additionally, our study did not directly compare the effects of the intervention across different subject areas or educational contexts. Future research endeavours could address these limitations by including a more diverse sample of pre-service teachers from various subject areas and educational backgrounds. Second, this study used a quasi-experiment to examine the effects of AR-based training through learning by design approach for pre-service teachers, thus leading to the lack of long-term application effects. It should be noted that future research requires a longer time to collect data from an experiment to acquire prolonged use of the proposed approach. Third, this study investigated the effects of the AR-based training through learning by design approach for pre-service teachers from four perspectives (i.e., learning performance regarding inclusive knowledge, higher-order thinking efficacy, attitudes towards inclusive education, and perceived technology-assisted support for learners). Future research could probe the relationship between these four perspectives to facilitate inclusive education for pre-service teacher development.

CRediT authorship contribution statement

Xiao-Fan Lin: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Guoyu Luo:** Writing – review & editing, Writing – original draft, Data curation. **Shucheng Luo:** Writing – review & editing. **Jiachun Liu:** Writing – review & editing. **Kan Kan Chan:** Writing – review & editing, Writing – original draft. **Haiqing Chen:** Writing – review & editing, Writing – original draft. **Wei Zhou:** Writing – review & editing, Writing – original draft. **Zhengfu Li:** Writing – review & editing.

Declaration of generative AI and AI-assisted technologies in the writing process

We confirm that the Generative AI and AI-assisted technologies were not used in the writing process. The research and writing of this paper were solely conducted by the human (the authors) involved in the collaboration.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article. All authors have confirmed that no partial financial support was received. There is no potential conflict of interest between the authors in this study.

Data availability

Data will be made available on request.

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Appendix

Higher-order thinking efficacy scale

Self-efficacy of collaborative learning (HS)

HS 1: I think I could comment on my peers' ideas on meeting students' individual needs in inclusive classrooms to improve our work.

HS 2: I think I could contribute to my peers' work on performing inclusive and diverse teaching for students with individual needs.

HS 3: I think I could express and share my opinions with my peers about how to teach students with individual needs in inclusive classrooms.

Creative thinking confidence (HC)

HC 1: I think I could learn how to devise an innovative instructional activity when I come across problems of meeting students' individual needs in inclusive classrooms.

HC 2: I think I could understand many challenging problems related to meeting students' individual needs in inclusive classrooms.

HC 3: I think I could work out innovative plans to meet students' individual needs in inclusive classrooms.

Authentic problem-solving confidence (HA)

HA 1: I think I could implement innovative instructional activities to meet students' individual needs in inclusive classrooms.

HA 2: I think I could suggest new ways in which to teach students with individual needs in inclusive classrooms.

HA 3: I think I could evaluate the usefulness of innovative instructional activities to meet students' individual needs in inclusive classrooms.

Attitudes toward inclusive education scale

Acceptance (AA)

AA 1: Students' differences in exam performance should be respected and recognised in inclusive classrooms.

AA 2: Students' differences in attentiveness should be respected and recognised in inclusive classrooms.

AA3: Students' differences in expressing their thoughts verbally should be respected and supported in inclusive classrooms.

AA4: Students with different requirements of individualised academic programmes should be respected and supported in inclusive classrooms.

Concerns (AC)

AC 1: I am optimistic that having a student with special needs in my class will not increase my stress levels.

AC 2: I am optimistic that having a student with special needs in my class will not increase my workload.

AC 3: I am optimistic that I have the knowledge and skills required to teach students with special needs.

AC 4: I am optimistic that it will be practicable to give appropriate attention to students with special needs in an inclusive classroom.

Sentiments (AS)

AS 1: I am confident that I can provide solutions to meet students with special needs in the inclusive classroom by integrating AR technology.

AS 2: I am excited to design diverse teaching solutions to address students' special needs by using the technology-enabled learning by design system.

AS 3: I enjoy learning new inclusive teaching plans with AR.

AS 4: I love to collaborate with peers to explore inclusive education approaches by using AR.

Engagement (AE)

AE 1: I can overcome my initial discomfort when facing a diverse group of students in an inclusive classroom.

AE 2: I agree with the idea that teachers should pay attention to the differences between various students, especially in inclusive classrooms.

AE 3: I can design different methods to solve problems in inclusive education by using AR technology.

AE 4: I attempt to understand my past mistakes to better apply AR in inclusive education with the learning by design approach.

AE 5: Even if the inclusive teaching task is challenging, I would like to continue finding solutions by using different technologies or approaches.

AE 6: I look forward to designing inclusive teaching activities with AR.

Perceived technology-assisted support scale (PS)

PS 1: I believe that students with individual needs can be supported by timely feedback if the lesson is well-designed with technology (e.g., Augmented Reality).

PS 2: I believe that the skills I gained from the training on how to use technology and digital resources (e.g., Augmented Reality) could meet my teaching needs emphasising respect for student differences.

PS 3: I believe that the educational technology training I participated in regarding how to apply technology (e.g., Augmented Reality) for inclusive education can meet the needs of diverse students.

PS 4: I believe that the school's Augmented Reality system/platform can meet my daily teaching demands of meeting the needs of diverse students.

PS 5: The technology-enabled learning by design system for inclusion can meet my daily teaching demand to solve the practical problems regarding lacking teaching materials or insufficient support.

PS 6: I am satisfied with the AR-based technology training I have participated in to afford me various inclusive teaching resources.

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