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Shaping future-ready graduates with mindset shifts: studying the impact of integrating critical and design thinking in design innovation education

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In an era marked by rapid change and complex global challenges, Institutes of Higher Learning (IHLs) are tasked with preparing students to navigate and address these evolving demands. This paper explores the critical role of Higher Education (HE) in equipping students with the necessary skills and mindsets to tackle real-world problems through innovative solutions. Integrating critical thinking and design thinking within a Design Innovation module is central to this exploration. The study is undergirded by a conceptual framework that blends critical, design, and futures thinking, focusing exclusively in this paper on applying critical thinking (CT) and design thinking (DT). The research investigates two primary questions: (1) How do students' DT and CT mindsets change after participation in a Design Innovation module? (2) Is CT a prerequisite for developing DT? This study aims to illuminate the shifts in students' mindsets from before to after the completion of the module, highlighting the importance of developing key dispositions for ethical and socially responsible problem-solving. Results show a statistically significant increase in CT and DT disposition scores from pre- to post-test, suggesting a shift to more positive CT and DT mindsets after going through the Design Innovation module. In addition, a significant moderation effect of pre-test CT mindset on the relationship between pre-test and post-test DT mindset scores was observed, implying that CT was a prerequisite for DT. The findings offer insights into the module's effectiveness in fostering future-ready graduates' thinking capabilities on innovating for real-world challenges and highlight the need for our future-ready students to achieve critical competence and creative confidence. Finally, we conclude the paper with recommendations for educators to integrate CT skill development intentionally and in tandem with DT skill development for a balanced approach to developing critical competence and creative confidence in interdisciplinary courses.

KEYWORDS

critical thinking, design thinking, design innovation, 21st-century skills and dispositions, mindset shiftts, interdisciplinary learning

1 Introduction

Higher Education (HE) must transition from the standard 'traditional' discipline-focused curriculum toward one that contributes to sustainable social change by preparing students to be change agents who care for society's well-being. Universities urgently need to prepare graduates and equip young professionals for a myriad of global challenges that lie ahead. From the post-cold war to the coronavirus pandemic, the new world is described as Brittle, Anxious, Nonlinear and Incomprehensible (BANI) (Kraaijenbrink, 2022). To keep abreast with the needs of the future workforce, universities need to rethink their education models and curricula. According to Aoun (2017, p. xviii), "a robot-proof model of higher education is not concerned with topping students off with high-octane facts. Rather, it refits their mental engines, calibrating them with a creative mindset and the mental elasticity to invent, discover or otherwise produce something society deems valuable." To develop those dispositions, scholars have referred to the 4C meta-skills necessary for the success of future professionals: creativity, critical thinking, collaboration, and communication (Pearson, 2018). Bridging the gap between specialized (vertical) and generalised (horizontal) education (e.g., Epstein, 2019), there is a push toward transdisciplinary thinking – an approach to thinking and working that transcends disciplinary boundaries.

Furthermore, developing transferable skills like critical and design thinking is crucial for graduates and the workforce. Critical thinking skills enable individuals to analyze information, evaluate arguments, and make sound judgments, all of which are necessary for success in various fields (Sosu, 2013). Design thinking, on the other hand, is a problem-solving approach that emphasises empathy, creativity, and iterative prototyping (Jakobsone, 2017). This approach is beneficial for addressing complex, multidisciplinary problems that require innovative solutions. Both transferable skills can be applied across disciplines and contexts, enabling students to approach issues from multiple perspectives and develop creative solutions to complex challenges (Suligoj et al., 2020). By integrating critical and design thinking into HE curricula, universities can ensure graduates can innovate in the 21st century.

This paper posits that developing transferable skills, particularly critical thinking and design thinking (CTDT), is essential for preparing students for the challenges of the 21st century. Critical thinking equips students with the ability to analyze, evaluate, and make informed decisions, while design thinking fosters empathy, creativity, and an iterative approach to problem-solving. These skills are crucial for addressing complex, multidisciplinary challenges and fostering innovation across various fields. Our study focuses on a university-wide Design Innovation course underpinned by a conceptual framework that blends critical design, and futures thinking. This course aims to equip students with the necessary skills and knowledge to engage effectively in the design process, from problem definition to ideation and prototyping. The research questions guiding this study are: (1) How do students' DT and CT mindsets change after participation in a Design Innovation module? (2) Is critical thinking a prerequisite for developing design thinking? By investigating these questions, the study seeks to understand the impact of the Design Innovation module on students' mindset shifts and their preparedness to innovate and solve real-world problems. The findings will contribute to the discourse on the importance of transdisciplinary knowledge and skills in HE, particularly in Singapore. They will provide valuable insights for educators and policymakers on effectively preparing future-ready graduates.

2 A review of literature

2.1 Trends of developing transferable skills and their challenges

Today, IHLs face a critical challenge: preparing graduates for success in a workforce that demands a broad set of transferable skills. Among these skills, critical thinking and design thinking have emerged as essential for navigating the complexities of the modern workplace. However, developing these skills in HE presents several challenges.

One challenge is the need for faculty and instructors to understand and be able to teach these skills effectively. Critical thinking and design thinking require a different approach to teaching and learning than traditional lecture-based instruction (Turnali, 2016). For example, critical thinking involves analysing and evaluating information, synthesising ideas from multiple sources, and making informed judgments. This requires a shift away from simply providing students with the knowledge and toward creating opportunities to practice critical thinking skills in various contexts (e.g., Patel, 2021). Similarly, design thinking involves a problem-solving approach emphasising empathy, creativity, and iterative prototyping. This requires shifting from linear problem-solving methods to a more iterative and flexible approach (Mosely et al., 2018). Thus, much evidence-based research has called for universities to spearhead intentional faculty development programmes and training workshops to demystify the development of these thinking skills in students (e.g., Patel and Wong, 2022). These help instructors develop the knowledge and skills necessary to teach critical thinking and design thinking effectively as transferable skills across degree specializations. For example, practical strategies using dialogic scaffolding to model these thinking skills so that instructors can make them explicit and visible to students (Patel, 2022).

Another challenge is the need for appropriate assessment measures to evaluate these skills. Traditional assessment methods, such as multiple-choice exams, may only partially capture the application of critical thinking and design thinking. Therefore, instructors must develop performance-based assessments and portfolio evaluations or adopt a students-as-partners approach as an appropriate assessment method aligned with these skills' learning outcomes. A further challenge is the need for students to understand the value of these skills and be motivated to develop them. Students may not see the immediate relevance of critical thinking and design thinking skills to their future careers or may need to be made aware of how to develop these skills (Ramírez-Montoya et al., 2022). Therefore, IHLs need to rethink and redesign their curricula so that these key transferable skills are embedded intentionally across all specializations. This gives students ample opportunities to develop and internalize them before applying them in their future work.

2.2 Future skills and mindsets

The concept of 21st-century skills emerged as a response to the changing nature of the world and the workforce. It emphasises the

need for graduates to possess a broad set of transferable skills, like critical thinking, creative thinking, communication, and collaboration, to succeed. However, as we move into the 21st century, the landscape continues to evolve, and new skills will likely emerge as essential for success (Dilekçi and Karatay, 2023). The Organization for Economic Co-operation and Development (OECD) launched a project to identify the skills individuals need in the 21st century (Pedro, 2006). The project aimed to define the characteristics of the century and determine how individuals could acquire these skills. Pedro (2006), who participated in the project, grouped the skills that should be incorporated into the educational system into three categories: alternative cognitive skills, changes in cultural practices and social values, and expectations regarding teaching and learning. Another researcher, Wagner (2008), studied the topic and proposed a framework under the concept of "survival skills," which included seven skills: problem-solving and critical thinking, cooperation and leadership, adaptation and agile intelligence, entrepreneurship, effective communication, access to information and analysis of information, and imagination and curiosity. The World Economic Forum, UNESCO, the European Commission, and the OECD have recently focused on researching 21st Century or Future Skills. These skills are the attributes that graduates need to thrive in an increasingly globalized and digitized world in a socially creative, responsible, sustainable way and by the Millennium and Sustainable Development Goals. Despite years of discussion and research, effectively embedding and integrating these skills still needs to be improved (Osmani et al., 2019).

The discourse on skills for the future often emphasises technical competencies and cognitive abilities. However, key dispositions, attributes, or mindsets are equally vital, particularly for critical and design thinkers. These mindsets or dispositions are crucial for navigating the complexities of the 21st century. A critical thinker in this era must embody a disposition of open-minded scepticism – a balance between being open to new ideas and rigorously questioning and evaluating information (Paul and Elder, 2012). This mindset fosters the ability to navigate through misinformation and rapidly evolving knowledge landscapes. For design thinkers, a mindset of empathetic engagement is paramount. This involves profoundly understanding and connecting with the needs and experiences of others, which is essential for human-centred design (Brown, 2009). Empathy enables design thinkers to create solutions that are not only innovative but also resonate deeply with the end-users needs and contexts. Another key disposition is adaptability, flexibility, and resilience in the face of change. This is crucial as the future is marked by rapid technological advancements and shifting socio-economic landscapes (Dweck, 2006). Adaptability allows individuals to thrive in diverse environments and embrace continuous learning.

The literature review on the Design Thinking (DT) Mindset in Dosi et al.'s (2018) study focuses on identifying and categorising the elements that constitute this mindset. The authors conducted a structured research analysis, drawing from the scientific literature on Google Scholar, and applied specific criteria to select relevant publications. This process led to identifying 19 latent constructs of the DT mindset, derived from a comprehensive analysis of 17 selected papers (Table 1). These constructs encompass a range of attitudes and cognitive approaches essential for effective design thinking, such as tolerance for ambiguity, embracing risk, human-centeredness, empathy, mindfulness, holistic view, problem reframing, teamwork, multidisciplinary collaboration, openness to different perspectives, learning orientation, experimentation, experiential intelligence, critical questioning, abductive thinking, envisioning new things, creative confidence, desire to make a difference, and optimism (Schweitzer et al., 2016; Dosi et al., 2018).

This study aims to capture a comprehensive and multifaceted understanding of the DT mindset by selecting representative items from each construct. This approach is grounded in the belief that a holistic representation of the DT mindset is crucial for accurately assessing and understanding student mindset shifts. The authors believe that the rigorous literature review and categorization process by Dosi et al. (2018) ensures that the identified constructs and their representative items are grounded in academic research and practice. For instance, the importance of constructs like empathy and human-centeredness in design thinking is well-documented in the works of authors like Tim Brown (Brown, 2009) and Jeanne Liedtka (Liedtka et al., 2017).

Similarly, the emphasis on critical questioning and abductive thinking aligns with the principles outlined in design thinking literature by scholars such as Nigel Cross (Cross, 2011) and Richard Buchanan (Buchanan, 1992, 2015). The selection of items from each construct is not arbitrary but is informed by the frequency and significance of these elements in the analyzed literature. This methodological approach ensures that the selected items represent the broader concepts and themes within the DT mindset. The empirical backing for this approach is supported by the scholars shared earlier, whose research described their analysis and selection process based on the prevalence and importance of these elements in the design thinking discourse. This forms a deliberate strategy to ensure a comprehensive and nuanced understanding of the design thinking mindset. This approach also reflects the depth and breadth of the design thinking field as documented in academic literature.

TABLE 1 Dosi et al.'s (2018) 19 constructs of design thinking mindset.

A. Tolerance for - being comfortable with ambiguity - uncertainty	J. Open to different perspectives / diversity
B. Embracing risk	K. Learning oriented
C. Human centeredness	L. Experimentation or learn from mistake or from failure
D. Empathy / empathic	M. Experiential intelligence / Bias toward action
E. Mindfulness and awareness of process	N. Critical questioning ("beginners mind," curiosity)
F. Holistic view / consider the problem as a whole	O. Abductive thinking
G. Problem reframing	P. Envisioning new things
H. Team Working	Q. Creative confidence
I. Multi–/ inter–/ cross-disciplinary collaborative teams	R. Desire to make a difference
	S. Optimism to have an impact

2.3 Design thinking and design innovation

Design Innovation is a multidisciplinary approach that integrates design and innovation management principles to address complex challenges and deliver user-centric solutions. Scholars argue that the interplay between innovation and design processes comes from a perspective in which value is defined by and co-created with the user rather than embedded in the output (Concilio et al., 2019). It emphasises applying design principles not only to product aesthetics but also to enhance the functionality and accessibility of solutions, thereby meeting and often anticipating user needs (Verganti, 2009). This approach includes various methodologies, such as user research, prototyping, and usability testing, which are critical for developing successful innovations.

Design Thinking (DT), a core component of design innovation, is an iterative process that seeks to understand users, challenge assumptions, redefine problems, and create innovative solutions to prototype and test. This methodology effectively tackles complex problems that are ill-defined or unknown by re-framing these in human-centric ways, encouraging multiple iterations, and fostering a learning mindset by doing (Brown, 2009). Dosi et al.'s (2018) study on DT Mindset offers valuable insights into the cognitive processes that underlie effective design thinking. The 19 identified latent constructs of the design thinking mindset (See Table 1 earlier), which include empathy, tolerance for ambiguity, risk-taking, openness to experience, and collaborative spirit, are crucial for fostering an environment conducive to innovation and for empowering individuals and teams to approach complex problems creatively (Dosi et al., 2018).

Moreover, embracing a DT mindset involves cultivating certain attitudinal qualities such as optimism and the willingness to fail. These attributes enable practitioners to persist in the iterative cycles of prototyping, testing, and refining ideas. Thus, this study emphasises the need for educational programmes in higher education to integrate these mindset elements to better prepare students for real-world challenges.

2.4 Critical thinking definitions, dispositions and application in design innovation

Facione (1990, p. 2) describes Critical Thinking (CT) as a deliberate and self-regulating judgment encompassing analysis, evaluation, and inference, grounded on various evidential and contextual factors. This comprehensive definition underscores the complexities of educating CT, reflecting teachers' challenges in fostering CT skills (Tsui, 2002). Research consistently recommends teaching methods that emphasise "how to think" rather than "what to think" to effectively cultivate CT skills (Cloete, 2019; Puig et al., 2019). The need for enhanced CT instruction is recognized in higher education, especially as students often struggle to grasp and apply CT in their work, and educators frequently misunderstand how to teach these skills effectively (Abrami et al., 2008, 2015; Janssen et al., 2019). Duro et al. (2013) highlight this issue, noting a discrepancy between student and faculty perceptions of CT, and suggest structured interactive activities to improve students' critical and metacognitive abilities.

Critical thinking (CT) is characterized by a duality of skills and dispositions fundamental for academic and professional success. CT skills involve the ability to analyze, evaluate, and synthesize information, whereas CT dispositions involve the inclination to engage in those cognitive activities (Facione et al., 1992). Recent literature underscores that while CT skills are about performing cognitive tasks, dispositions relate to the willingness to apply such skills in varying contexts, including the readiness to think critically which is pivotal in effective decision-making and problem-solving (Dwyer et al., 2012; Abrami et al., 2015). Simonovic et al. (2022) differentiate between critical thinking skills and dispositions in a research studying the effect of online students' perceptions and attitudes toward CT. It points out that while CT skills relate to the ability to carry out critical thinking functions (such as analysis and evaluation), dispositions involve the willingness to engage in and the attitudes toward such cognitive activities. It stresses that skills and dispositions are important for effective CT, with cognitive reflection and student attitudes and beliefs playing significant roles in their academic performance.

In exploring the relationship between CT readiness and DT tasks, studies have demonstrated that engaging in DT activities enhances students' ability to think critically by fostering an environment that requires iterative learning, problem redefinition, and solution-focused thinking (Johansson-Sköldberg et al., 2013). These design tasks promote a mindset that is open to exploration and encourages a reflective and iterative approach to problem-solving (Carroll et al., 2010). Additionally, research by Wrigley and Straker (2017) suggests that DT activities can significantly impact students' CT dispositions by placing them in real-world problem-solving scenarios that necessitate active engagement and critical appraisal of information. This interaction between CT dispositions and skills through DT tasks has led to improved cognitive processes and outcomes, particularly in complex and ambiguous situations (Koh et al., 2015).

Paul and Elder (2012) define it as the *art* of thinking to improve it. It is essential in design innovation as it provides the analytical backbone for convergent and divergent thinking processes. Convergent thinking involves narrowing down the options discovered in divergent thinking to identify the best solution. It is through this synthesis of creativity and systematic problem-solving that innovative solutions are born (Runco, 2014). CT aids designers in various stages of the design process. For example, during the empathy phase of DT, CT is used to question assumptions about user needs and experiences. This rigorous questioning ensures that solutions are developed based on deep, insightful understandings rather than superficial observations.

CT also plays a crucial role in the testing and implementation phases of design innovation. It helps teams evaluate the effectiveness of their prototypes and refine them based on feedback and critical analysis. This iterative process, underpinned by strong critical thinking, leads to the development of innovative solutions that are viable and sustainable in the long term (Ennis, 2018). Integrating critical thinking into design innovation practices and curricula can significantly enhance students' abilities to engage with complex problems creatively and effectively. It cultivates a mindset that values rigorous evaluation, ethical consideration, and the sustainability of design solutions, thereby fostering a more holistic approach to design innovation (Brookfield, 2012).

2.5 Blending critical and design thinking

Designers have utilized Design Thinking (DT) for decades. However, the truth of DT is that it could need more depth. Although

in the initial stage of employing empathy, where the designers get a feel of the users' problems, the process runs the risk of being solely based on the designers' understanding of the issue. Scholars highlight current applications of DT as lacking criticality (e.g., Turnali, 2016). According to Loewe (2019), DT continues to fail at tackling the most 'wicked' kinds of problems, which are defined as complex problems that lead to unwanted outcomes or even unsolvable problems that include social, technological, economic, and political ones. This is partly because of DT's superficial understanding of the 'wicked' factors to effectively address the multitude of often intertwined contextual factors of the problem (Loewe, 2019). Thus, while DT itself may be able to explore the issue at hand, solutions might still fall short without Critical Thinking (CT). In fact, without unbiased, critical thought, DT is ineffectual. It becomes a design process where all ideas are good, and best intentions overshadow best practices (Bezhnar, 2019). Therefore, CT should be applied to each step of the design process to create the solution carefully without losing the sole purpose and vision (see Figure 1).

While some scholars have posited that design thinking may support critical thinking, empirical research examining the relationship between these two modes of thinking is lacking because their shared conceptual structure has not been articulated in detail, and they have remained siloed in practice. A recent study (Ericson, 2021), reporting on a detailed comparison of the two modes of thinking, suggests that design thinking methods can support and augment traditional critical thinking practices and that design thinking frameworks could be modified to incorporate critical thinking more explicitly. Moreover, scholars have posited that products are often designed to take advantage of human psychology in ways that do not always align with end users' interests (Nodder, 2013).

Blending design and critical thinking work with the premise that design thinking can offer educators creative new approaches to engage students in critical thinking. Second, critical thinking must be more explicitly integrated into product design and development methods. Hence, this research supports other evidence-based studies (e.g., Ericson, 2021) first to clarify the relationship between these two modes of thinking to help educators leverage design thinking methods to support and augment various approaches to critical thinking and then help prepare students for the workplace where they can explicitly integrate essential practices of thinking into their design processes. Furthermore, as design thinking is increasingly used to design the products of the modern world, the environments people inhabit, and even the social interactions that people engage in, it is indeed crucial for educators to understand the relationship between critical thinking and design thinking (Ericson, 2021). Also, critical thinking must be more explicitly integrated into the design thinking process to ensure that design efforts maximize potential benefits and minimize potential harm to society.

2.6 Creative thinking and critical design approach to innovation

The new world facing us demands skilful and creative thinkers to develop new ways of living and solutions to the world's most significant problems. According to Torrance (1966), creative thinking involves generating ideas that demonstrate fluency, flexibility, and originality in response to a problem, event, or situation. Fluency refers to producing many ideas, flexibility entails considering different perspectives, and novelty involves presenting new ideas. Competence in these areas is used to evaluate creativity (Mourtzis et al., 2018).

Contrary to the belief that creativity is a rare talent, creative thinking is a multi-faceted cognitive process in everyone at different levels. Creative thinking and critical thinking are often presented as two distinct approaches to problem-solving. Creative thinking involves expansive and innovative thinking that is free of constraints and is focused on generating new ideas and exploring possibilities (Treffinger and Isaksen, 2005). In contrast, critical thinking is a more disciplined and logical approach focusing on practical and realistic solutions to problems (Brookfield, 2012). The key difference between creative and critical thinking is that generating alternatives is a creative activity while selecting among them requires a critical approach. Although creativity and criticalness are often perceived as opposite ends of a spectrum, they are not mutually exclusive and can often complement one another in problem-solving processes (Nickerson, 1999, p. 397). In fact, in this paper, intentionally blending critical and creative (design) thinking could develop better thinkers among students as they achieve creative confidence and critical competence when ideating solutions to solve real-world problems. The premise for this is based on the evolving debate on the practice of Critical Design (Dunne and Raby, 2001; Malpass, 2013) and critical design thinking (Loewe, 2019).

Critical Design is a design practice that uses provocative designs to stimulate critical thinking and open up discussions about themes and issues raised by the design work (Loewe, 2019). It differs from developing necessary design thinking skills, as critical design is an affective practice that generates questions rather than providing solutions or answers to design problems (Malpass, 2015, 2017). The primary goal of critical design is to provoke debate and engage its audience rather than to simplify or explain complex design issues. Critical design seeks to diversify how people understand design problems and ideas by appealing to their emotions and senses and opening up specific lines of inquiry that lead to a more informed and critical understanding of a given problem (Malpass, 2017). Using this approach, critical design challenges traditional design processes and opens up new ways of thinking about design and its impact on society. Loewe (2019) highlighted the key questions in this discussion: How can critical design, which appeals to emotions, still be critical without rational analysis? How can it transform affect into an analytical assessment? How can critical design achieve more than an accidental emotional connection based on people's tastes, fixed opinions, or moral convictions? *In our research, we asked how HE educators, informed by the literature on critical thinking, design thinking and critical design approach to innovation, can design an instructional approach to develop critical design thinking skills in students so that they will ideate innovative and sustainable solutions for the world's most complex problems. In particular, how would such an instructional approach influence their mindset shifts?*

Critical design is an affective design practice that aims to provoke debate and engage its audience by using provocative designs to stimulate critical thinking (Malpass, 2017). However, critical thinking in this notion is predominantly based on the alleged criticality of the object itself, and the interdependency of deep reflection and critical thinking remains an aporia (Loewe, 2019). While critical design may stimulate debates that lead to broader

Stages	Design Thinking	Critical Thinking
Empathise	Empathy is used to fully understand the context of the users experiencing the problem. Divergent thinking is used at this stage to explore data.	Proper time and resources must be given to research, collecting all relevant data, and applying critical thinking to fully understand those who are in need of a solution. If designers cannot relate to the customer's state of mind, empathy is impossible.
Define	From the data collected earlier, designers will distil insights with convergent thinking to formulate a problem statement.	Critical thinking is used to define the problem from the users' point of view, rather than designers'. Ensure relevance and benefit to the user first.
Ideate	Ideation, where multiple solutions are being ranked, is crucial in the design process. The evaluation and elimination processes, using both divergent and convergent thinking, will lead to an optimal solution selected.	Critical thinking is vital to ensure out-of-the-box ideation that goes beyond creative ways to solve a problem. While it is intended to be inspirational and collaborative, it is easy to become distracted in the process and lose sight of the empathic and well-defined vision.
Prototype	Designing an early version of the solution to reveal how users think and feel. Creating multiple prototypes, low or high fidelity, takes the risk out of innovation by allowing designers to fail quickly.	By including all stakeholders, designers will achieve a more efficient and robust experimental process. With critical thinking, any acceptance, improvements, and even rejections will be driven by user experiences to determine solution constraints and challenges.
Test	As the last stage of the process, tests tend to perform together with the prototyping stage. Through testing, designers can learn more about users, improve the prototype and even refine the problem statement.	The testing stage redefines, informs, and drives changes and refinements. Here, critical thinking—based on perpetual learning—is applied to understand how end-users think, behave, and feel in order to (re)empathize and optimize the experience.

FIGURE 1
Critical thinking for each of the 5-stage design thinking process (Bezhnar, 2019).

critical knowledge, more is needed to gain deep insights and understanding of complex problems. To do this, HE educators must adopt an instructional approach to develop critical design thinking skills in students. This approach should focus on ideating innovative and sustainable solutions to complex problems by emphasising the importance of deep reflection, broad inquiry, and critical analysis. By doing so, students can become more aware of the complex issues and problems that contextualise the perception and utility of design, leading to more informed and practical solutions to real-world problems.

Criticism of design thinking is common among design scholars, who seek to ensure critical rigor as they scrutinize approaches to design decision-making. Rodgers (2017) advocates for more critical design thinking to provide a means of addressing the complexities of the world. Kimbell (2011) criticises the lack of criticality and the focus on the designer in current design thinking applications. However, few offer practical guidance on implementing a critically informed design thinking approach. Loewe (2019) notes that design thinking cannot substitute for deep critical reflection on the complexity of a design challenge. This reveals a common misconception among those who use design thinking. Critical design thinking should be introduced to guide decision-making, merging critical design practices with design thinking to address 21st-century problems.

However, the biggest challenge for HE to produce better thinkers is, as Halpern (2010) recognized, that "the enhancement of critical and creative thinking is still more of a desirable vision than an empirical outcome" (p. 381). Design thinking requires curiosity, imagination, and creativity to generate, explore, and develop possible solutions, and it might also depend on the skill level of critical thinking (Mosely et al., 2018). As a creative approach, design thinking has become an evolving field in HE, connecting students of various disciplines to solve complex problems as a team (Wrigley and Straker, 2017). Furthermore, IHLs have increasingly incorporated design thinking into the undergraduate curriculum, exposing non-design students to design thinking skills (Avsec and Ferk Savec, 2019).

Therefore, integrating Design Thinking, Critical Thinking, and Critical Design forms a holistic approach that enriches innovation. This integration enhances the ability to address complex challenges by ensuring that solutions are innovative, user-centred, critically evaluated, and socially relevant. The convergence of these methodologies fosters a comprehensive problem-solving framework that is adaptive, reflective, and

inclusive. This approach supports the creation of solutions that are deeply reflective of user needs and societal contexts, thus enhancing the overall effectiveness and sustainability of innovations. The blend of these perspectives encourages a culture of continuous learning and adaptation, which is crucial in today's rapidly changing world (Kolko, 2015).

3 Context: design innovation at the Singapore Institute of Technology

In Singapore, many IHLs have embarked on an ambitious endeavour to foster an interdisciplinary curriculum with identified transferable skills like critical thinking, creative thinking and design thinking. At our university, we developed a Design Innovation university-wide module. For our university, an applied learning autonomous university, up to 3,000 students, regardless of their programmes, would read the module every academic year.

3.1 UDE1001: Introduction to design innovation

This module aims to introduce design innovation and the application of user-centric innovation. Students will learn about design thinking as an ideology and approach that seeks to solve complex real-world problems in any specialized discipline area. You will learn to apply critical thinking tools and a human-centred mindset to understand the key challenges of an identified authentic problem. Throughout the module, students will use several iterations of Critical-Design Thinking (CTDT) exercises to critically question the problem and gain insights. Additionally, students will learn about synthesising preliminary ideas and solutions to the identified problem. Students can look forward to practising CTDT skills in many engaging exercises and applying them later in the four-credit Interdisciplinary Design Innovation module (UDE2001). Students will continue working in teams to ideate further and prototype solutions.

We endeavour to drive creative innovation with the university-wide Design Innovation modules (UDE1001 and UDE2001). Undergirded by a Critical Design Futures Thinking (CDF™) conceptual model, students collaboratively explore real-world sustainability issues and propose creative solutions. In the next section, we will share findings from a research study, where students' needs are at the centre of the enquiry, to propose a conceptual framework of critical design thinking and the tools we develop to develop students' creative confidence and critical competence. Focusing on developing key dispositions for ethical and socially responsible students, we recommend playful learning as the adopted signature pedagogy and using prototypes as critical debates.

3.2 Adopting a critical design futures thinking conceptual framework

The wicked problems we increasingly face require a radically different form of thinking that rigorously questions ideas and assumptions. It demands skilful thinkers to develop new ways of living and solutions. The intentional integration of critical design thinking in our adopted framework allows for an explicit application of a structure. This effectively guides convergent and divergent thinking in the design innovation approach. Thus demystifying the process of creating innovative solutions. When good questions are asked, we reframe how problems are viewed and solved. It is with critical questions that we get to evaluate and achieve the best of our thinking.

In our university, we proposed a conceptual framework to blend critical thinking, design thinking and futures thinking (CDF™) to undergird the design of the Design Innovation module (Figure 2). At the point of this study, we had only piloted the application of critical and design thinking into the curriculum. Thus, the mindset shifts surveys for critical and design thinking were administered. The intentional integration of Critical Design Futures (CDF™) thinking in our framework allows for an explicit application of a structure to help empower students today to innovate for a better world. This effectively guides their convergent and divergent thinking in the design innovation approach. Thus demystifying the process of creating innovative solutions. It is with critical questions that we get to evaluate and achieve the best of our thinking. When good questions are asked, we reframe how problems are viewed and solved.

Undergirded by the model, students are guided by their instructors. They are introduced to "Question Starters" (Figure 3) to ask good questions with a CDF™ mindset to explore multifaceted real-world issues in a humanity-centred approach. This highlights the need for our future-ready students to achieve creative confidence and critical competence when ideating solutions for a sustainable future. We endeavour to design a curriculum incorporating transdisciplinary approaches to ensure students have the necessary skills like curiosity, confidence, creativity, criticality and collaboration to succeed. We posit that undergirded by the CDF™ conceptual framework, using Question Starters will allow students to internalize the skills of critical thinking, design thinking, and futures thinking. This will help guide the iteration of divergent and convergent thinking to ideate for innovative solutions.

In achieving our aims to develop future-ready graduates with the necessary competencies to innovate as they tackle complex real-world problems with transdisciplinary collaborations, we reflected on our curriculum design for the design innovation module. We wanted to ensure that the development of transferable skills of critical design thinking was explicit and visible for students and instructors in the curricular and instructional strategies. Hence, with the CDF™ conceptual framework, we develop the first iteration of a series of *question starters* for students to internalize the critical-design thinking tools, from conceptualising their projects at the discovery stage to testing their prototypes. (Figure 3) These question starters correspond to Elements of Thought and Intellectual Standards from the Paul and Elder (2019) critical thinking framework and the five stages of the Design Thinking process. Instructors first modeled the questions when engaged in discussions and dialogs with students before encouraging them to use them in group discussions and peer reviews.

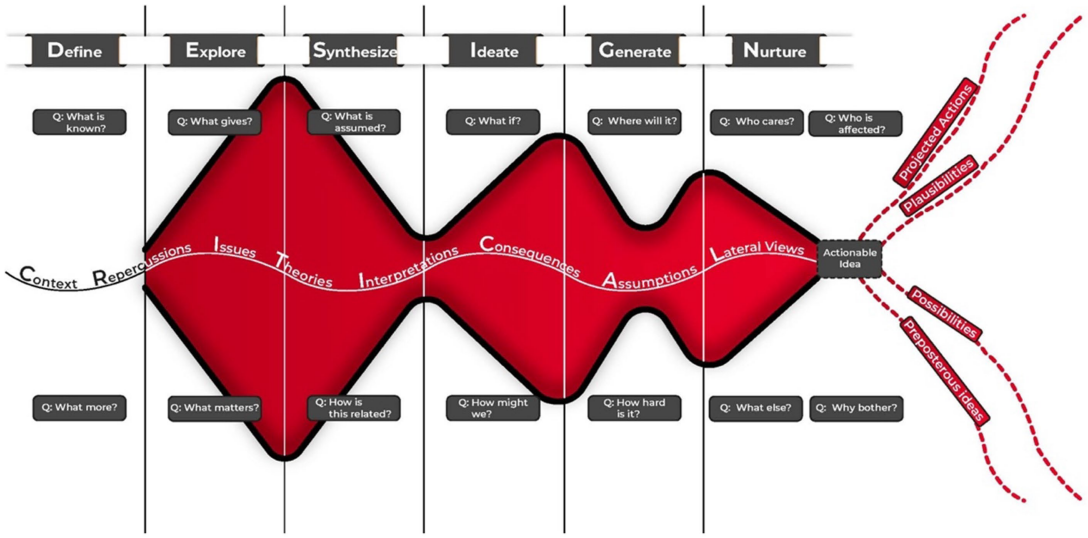

FIGURE 2
Critical design futures thinking (CDF™) framework.

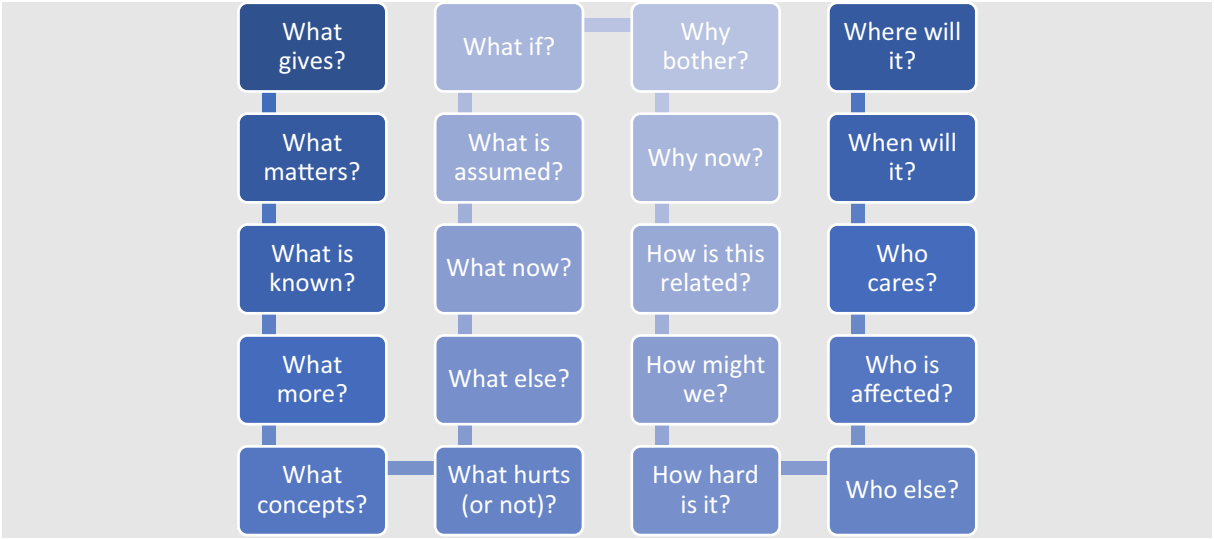

FIGURE 3
Question starters™ as critical design thinking (CTDT) tools.

Integrating Question Starters within the design innovation modules was pivotal in fostering a learning environment of deep, reflective, and innovative thinking among students. This approach aligns with the ethos of CDF™ by encouraging critical engagement with present complexities and shaping proactive thinkers and innovators capable of navigating future uncertainties. Students' design innovation projects explicitly used these Question Starters when conceptualising, framing the problem to be addressed, ideating and evaluating/testing their prototypes. Industry leaders who served as guest judges for students' final presentations gave encouraging feedback on the quality of the students' work. The Question Starters such as "How else?," "What now?," "Why bother?," "What gives?" and "What drives?" were instrumental in making the cognitive processes explicit and visible to students. They serve as cognitive prompts, encouraging students to delve deeper into their thought processes, exploring various dimensions of a problem or concept. By posing such questions, students can articulate their reasoning, assumptions, and conceptual understandings, which might remain implicit or unexamined. This was evident in the quality of their proposed design innovation projects, based on challenge briefs relating to UN Sustainable Developmental Goals. This explicit articulation of thought promotes metacognitive awareness and helps internalize complex thinking skills.

3.3 Sample students' design innovation projects

3.3.1 Project 1: Eat what

Using games to resolve youths' indecisiveness when going out for a meal with peers while at the same time raising awareness on the issue of food security globally (Figure 4).

3.3.2 Project 2: Parenthoodease

Using mobile technology to help low-income first-time parents navigate the challenges of parenthood, particularly on the increased financial responsibility of raising their child/children and receiving emotional support from peers (Figure 5).

4 Methods

4.1 Participants

A longitudinal study was conducted with two cohorts of first-year undergraduate students at a Singapore-based university over two consecutive trimesters. Data for each cohort was collected across two-time points: students completed the survey at the beginning of the trimester (pre-test) and again at the end of the trimester (post-test). The final participant sample matched for completing the pre-test and post-test were 373 students in Cohort 1 and 625 students in Cohort 2. Students were enrolled in various degree programmes (e.g., Accountancy, Diagnostic Radiography, Air Transport Management, Nursing, Electrical Power Engineering).

4.2 Measures and procedures

An online survey was administered via Qualtrics to all students of the "Introduction to Design Innovation" elective module. Ethical approval for data collection was sought and obtained from the Institutional Review Board at the authors' institution (IRB: 2021154). Students were encouraged to complete the pre-test survey in the first week of the study and the post-test survey in the final study week of the trimester. After responding to demographic questions, students completed two survey instruments: a (1) 24-item Critical Thinking Disposition Scale and (2) 21-item Design Thinking Mindset tool.

4.3 Critical thinking disposition

The Critical Thinking Disposition Scale (CTDS; Sosu, 2013) was used to measure characteristics that illustrate a disposition toward

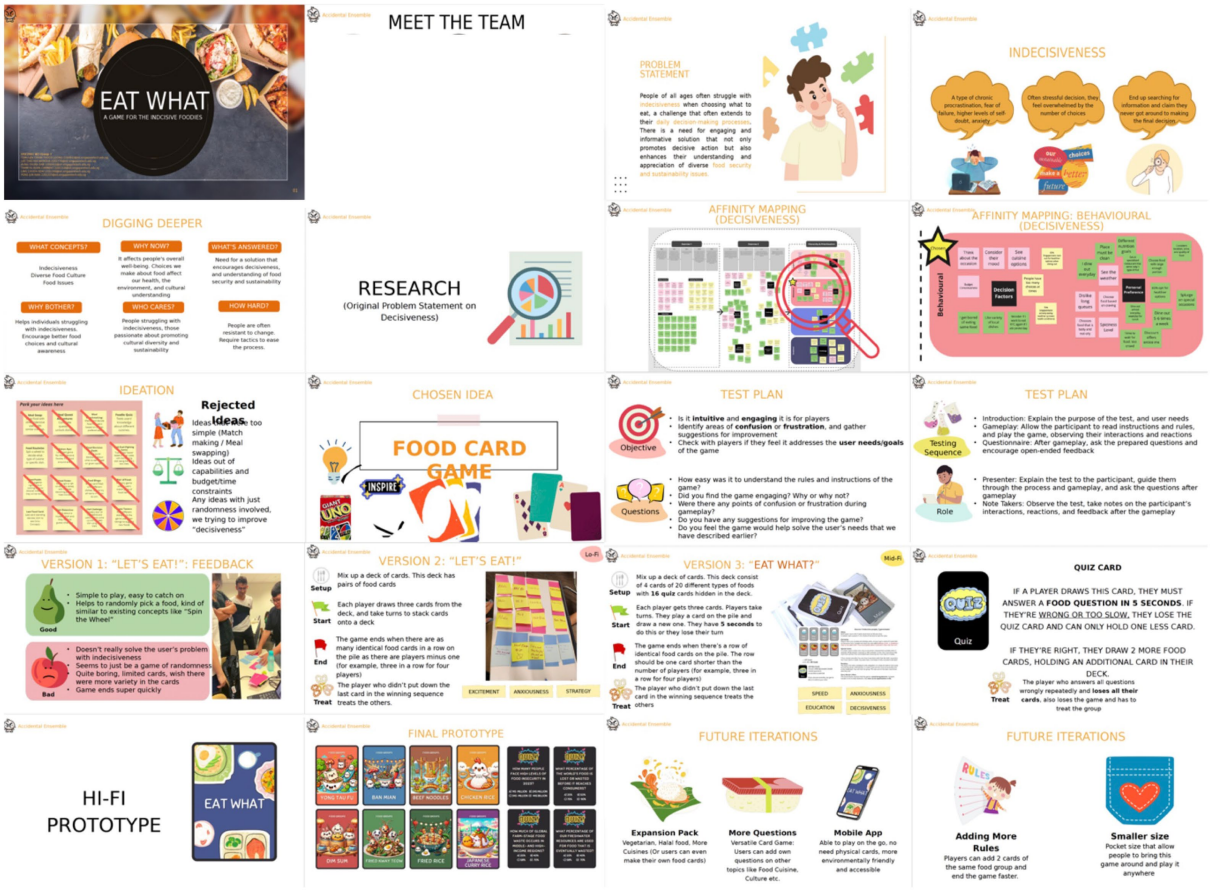

FIGURE 4
Project 1: Eat what (credits: Team accidental ensemble).

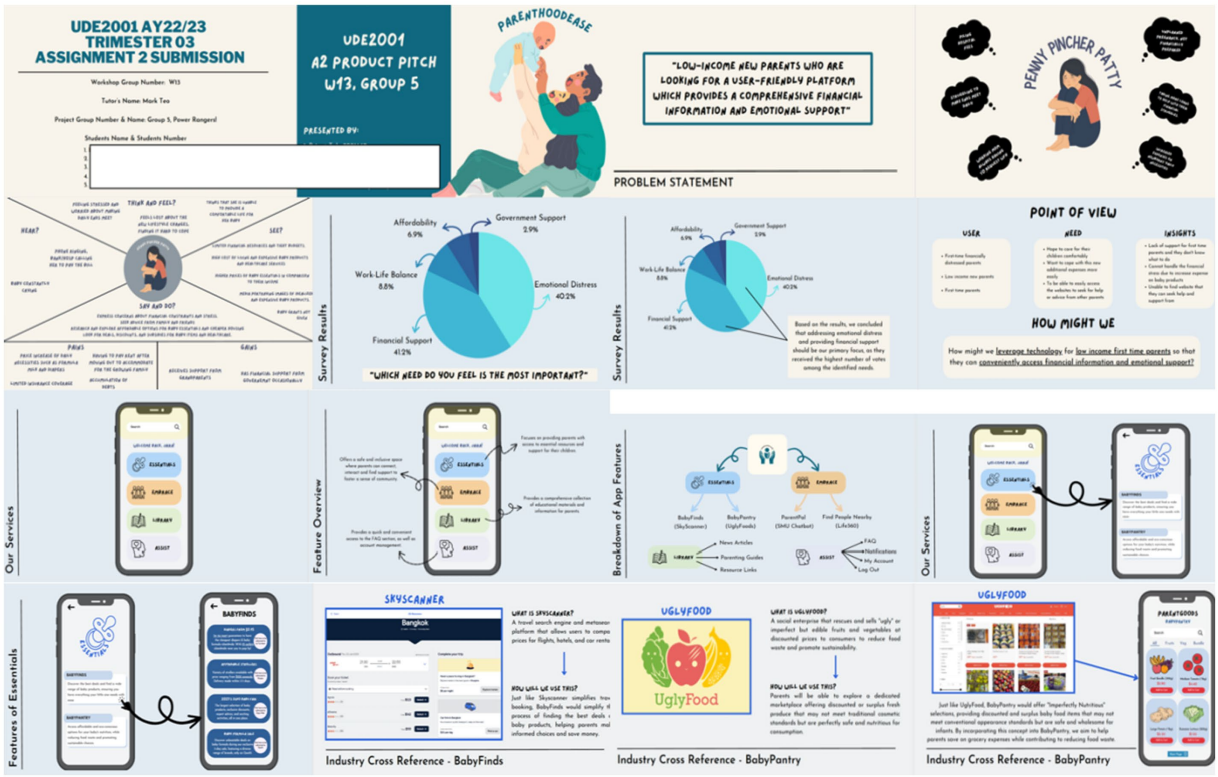

FIGURE 5
Project 2: Parenthoodease (credits: Team W13Grp5).

critical thinking (e.g., "I usually check the credibility of the source of information before making judgments"). The 24 items measuring students' critical thinking disposition were rated on a five-point Likert-type rating scale (1 = *Strongly Disagree*, 5 = *Strongly Agree*). The internal reliability of the 24 items in this study across cohorts and time points ranged from 0.93–0.97, as assessed using Cronbach's alpha.

4.4 Design thinking mindset

The Design Thinking Mindset (DT Mindset; Dosi et al., 2018) tool was used to measure students' metacognitive self-awareness of DT mindset attributes (e.g., "I am comfortable transforming ideas into something tangible"). Of the 71 items clustered in 19 DT mindset constructs of the reported tool, we carefully selected 21 items with at least one item from each construct (Refer to Appendix 1). To ensure that the selected items are representative of their respective latent constructs, we examined their content validity by (a) referring to the conceptual definitions of each element of the DT mindset, (b) identifying the characteristics that define each element of the DT mindset, and (c) seeking inputs from experts in the DT mindset research field. The internal reliability of the 21 items in this study across cohorts and time points ranged from 0.92 to 0.96, as evaluated using Cronbach's alpha.

4.5 Semi-structured focus group discussions (FGDs)

To better understand the changes in design thinking mindset after going through the Design Innovation module, we asked students about the dispositions they developed after the module, valuable takeaways or skills from the module that they could transfer to other settings, how the module sharpens their intellectual muscle, and how design thinking overlaps with critical thinking. We conducted three FGD sessions with 23 students, each lasting 60 min on average. The FGDs were audio-recorded and transcribed verbatim.

4.6 Data analyses

To answer RQ1 ("How do students' DT and CT mindsets change after participation in a Design Innovation module?"), a paired samples *t*-test was used to assess the change in CT disposition and DT mindset from pre-test to post-test for both cohorts. This was followed up with linear regression to examine the degree of change in CT disposition and DT mindset from pre-test to post-test for both cohorts, where appropriate. To answer RQ2, a linear regression of post-test DT mindset on pre-test DT mindset was conducted with pre-test CT disposition as a moderator.

The FGD data were qualitatively coded according to the 19 DT mindset elements (e.g., human centeredness, empathy/empathic, mindfulness and awareness of process) used to develop the items in the DT mindset tool (Dosi et al., 2018). The third author performed the coding, and all authors discussed the results in depth. Although agreement among the authors was high, the outcome was only agreed upon after several rounds of discussion. Table 2 illustrates the number of verbatim quotes extracted for each category of DT mindset element and examples of quotes for each element.

5 Results

5.1 Changes to critical thinking disposition and DT mindset

Prior to conducting the analyses, Levene's test was performed and we found no violation to the assumption of homogeneity of variances between the paired observations ($p > 0.05$). The skewness and kurtosis of each dependent variable also fell within acceptable range. With both cohorts, findings from a paired samples *t*-test showed a significant increase in students' CT disposition from pre-test to post-test, Cohort 1: $t\ (372) = 7.45$, $p < 0.01$, $d = 0.39$; Cohort 2: $t\ (624) = 9.52$, $p < 0.01$, $d = 0.38$. Similarly, with both cohorts, findings from a paired samples *t*-test also showed a significant increase in students' DT mindset from pre-test to post-test, Cohort 1: $t\ (372) = 5.57$, $p < 0.01$, $d = 0.29$; Cohort 2: $t\ (624) = 9.24$, $p < 0.01$, $d = 0.37$. See Figure 6.

As CT disposition and DT mindset were found to have significantly increased from pre-test to post-test for both cohorts, a linear regression conducted on the amount of change in students' CT disposition and DT mindset showed that no significant difference between the degree of change in CT disposition and DT mindset from pre-test to post-test, Cohort 1: $F\ (1, 744) = -0.05$, $p = 0.16$; Cohort 2: $F\ (1, 1{,}248) = 0.04$, $p = 0.84$. See Figure 7.

In line with the quantitative results, the students also described the development of a DT mindset after going through the module. They reported developing the following 13 DT dispositions: (1) the confidence of being more creative to think "out-of-the-box" (creative confidence), (2) critically questioning to understand the problem deeper, (3) the desire to make an impact on the people around them (desire to make a difference), (4) being more open to treading the unknown (embracing risk), (5) empathising with the concerns of the users (empathy/empathic), (6) being open to ideas and not being fixated with a single idea (envisioning new things) (7) considering the problem from a broader perspective beyond the pros and cons (holistic view/consider the problem as a whole), (8) understanding users' needs (human centeredness), (9) being aware of the design thinking processes (mindfulness and awareness of practice), (10) being open to working with people with diverse perspectives (multi−/inter−/cross-disciplinary collaborative teams), (11) being comfortable with diverse perspectives (open to different perspectives/diversity), (12) becoming more opportunity focused (optimism to have an impact), and (13) valuing the opinions of teammates in the design thinking process (team working). We refer readers to Table 1 for some examples of the quotes relating to the above DT dispositions.

5.2 Critical thinking as a moderator

To answer RQ2, "Is critical thinking a pre-requisite for developing design thinking?" a moderated regression analysis was conducted for each cohort. Results of the linear regression of post-test DT mindset on pre-test DT mindset, with pre-test CT disposition as a moderator, found a significant moderation effect in both cohorts, Cohort 1: $F\ (3, 369) = 2.78$, $p = 0.04$; Cohort 2: $F\ (3, 621) = 47.5$, $p < 0.01$. See Table 3 for more details. In other words, in line with our hypothesis, the change in DT mindset from pre-test to post-test significantly depends on students' level of critical thinking disposition measured before the commencement of the module.

Regarding critical thinking dispositions interacting with design thinking mindsets, students reported in the FGDs that critical thinking skills were part and parcel of the design thinking process. One student described how critical thinking and design thinking blended in the following manner:

> *"It is something that makes us not only use our thinking skills but also we can learn how to come up with a certain prototype. Therefore, I feel that design and critical thinking blends together very well."*

In addition, students described critical thinking as being embedded in the lived human experiences, suggesting that such a skill is generally essential for daily living, regardless of the module taken.

> *"I think everyone throughout their entire life has been applying critical thinking, whether it's in school or whether they are gossiping with their friends to find out more information, so it's just about learning how to apply that same concept of finding out more and seeing whether that information you get is credible and then applying it to different aspects of life."*

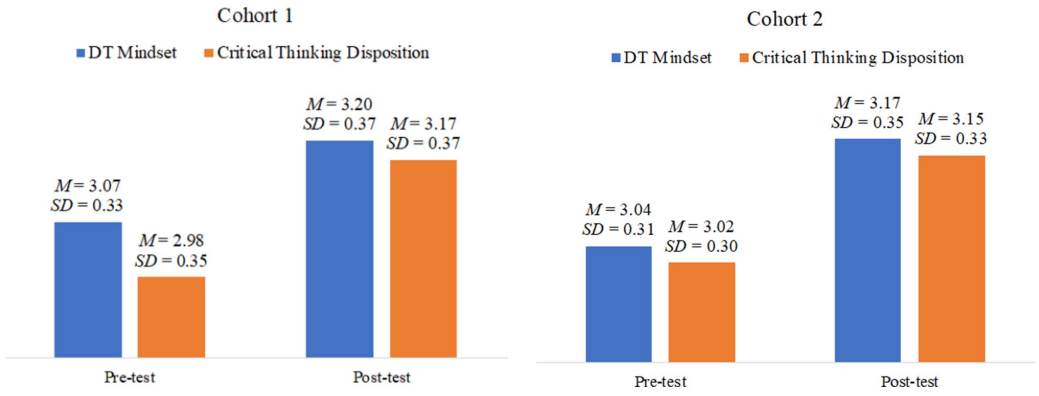

FIGURE 6
Descriptive statistics of changes in critical thinking disposition and DT mindset from pre-test to post-test in Cohort 1 and Cohort 2.

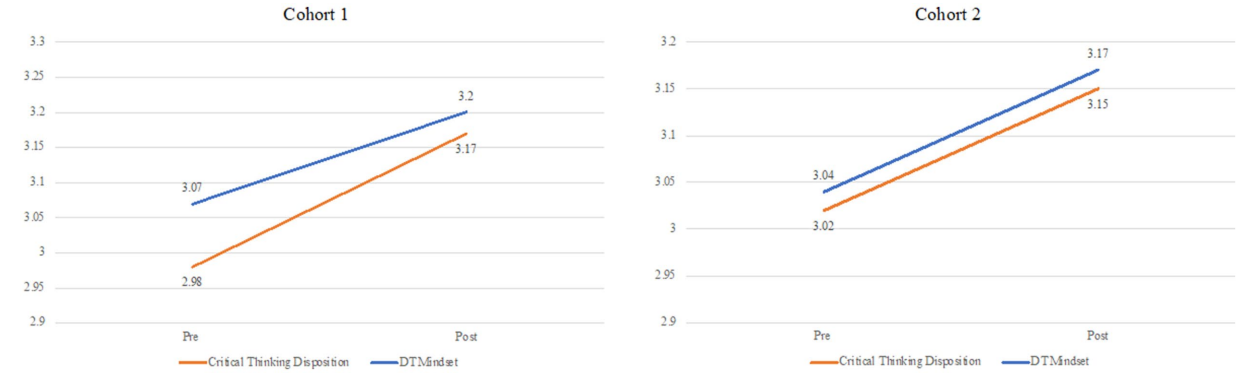

FIGURE 7
Degree of change in critical thinking disposition and DT mindset from pre-test to post-test.

6 Findings

The findings from this study are consistent with previous studies (e.g., Suligoj et al., 2020). The study reveals that students' critical thinking, measured across three subscales, significantly influences their creative design ability. Higher critical thinking perception correlates with increased fluency and flexibility in ideas and greater usefulness in design outcomes. Notably, understanding misconceptions strongly predicts design usefulness and idea fluency, while a high trust in critical thinking negatively impacts design originality. It provides compelling evidence that participation in the Design Innovation module significantly enhances students' critical thinking disposition and design thinking (DT) mindset. The paired samples t-test results indicate a substantial increase in these areas for both cohorts, underscoring the module's effectiveness in fostering these essential skills. Notably, the linear regression analysis revealed no significant difference in the degree of change between critical thinking disposition and DT mindset, suggesting that the module equally contributes to developing both skill sets. This balance is crucial, as it aligns with the emerging educational paradigm that emphasises the integration of critical and design thinking for comprehensive problem-solving and innovation. Furthermore, the qualitative data from focus group discussions support these findings. Students' reflections on their experiences highlight the development of key DT dispositions, such as creative confidence, empathy, and the ability to embrace risk and diversity. These dispositions are critical for navigating the complexities of modern challenges and innovating in a rapidly changing world. The students' ability to articulate their growth in these areas is a testament to the module's impact on their cognitive and affective development.

Moreover, the moderated regression analysis provides an intriguing insight into the relationship between critical thinking and design thinking. The significant moderation effect observed in both cohorts suggests that a student's initial level of critical thinking disposition influences the extent of their development in DT mindset. This finding addresses the second research question, indicating that critical thinking may be a foundational element that enhances the cultivation of design thinking skills. This interdependence highlights the importance of fostering critical thinking as a prerequisite or concurrent skill to maximize the benefits of design thinking education. We have not determined any studies examining such a moderation effect. The focus group discussions further illuminate this interplay, with students perceiving critical thinking as an integral part of the design thinking process. Their descriptions of how these skills blend and apply to real-life scenarios underscore the practical relevance of the module. This real-world applicability is crucial for preparing students to be effective problem-solvers and innovators in their future careers.

Our findings show that the interplay between critical thinking mindset and design thinking dispositions underscores a dynamic teaching and learning experience where both skill sets mutually reinforce each other. The moderated regression results suggest that students predisposed to engage critically are likelier to excel in design thinking instruction that prioritises iterative problem-solving and creativity (Carroll et al., 2010; Johansson-Sköldberg et al., 2013). This synergy is critical in educational settings where the goal is to solve problems and redefine them innovatively. Our study corroborates findings by Wrigley and Straker (2017), who observed that involvement in DT tasks enhances critical thinking by immersing students in situations where they must critically evaluate and navigate complex scenarios. This environment fosters a CT disposition characterized by an active and reflective engagement with problems, potentially leading to more innovative outcomes and a deeper understanding of the problem space.

However, a limitation of the present study is that we have yet to examine what aspects of the module enhance specific elements of DT or CT more significantly than others. Hence, we recommend educators integrate CT skill development intentionally into the curriculum and in tandem with DT skill development so that there is a balanced approach to developing critical competence and creative confidence. We also encourage interdisciplinary learning and real-world problem-solving in collaborative projects that value diverse perspectives. Integrating critical debates and iterative prototyping exercises can also enhance students' application of critical thinking in creative design. Through such practical, applied learning experiences, educators of interdisciplinary design innovation can aim to improve students' CT and DT mindsets.

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TABLE 2 Number of verbatim quotes extracted and examples of quotes for each DT mindset element.

DT mindset element	No. of quotes	Examples of quotes
Creative confidence	7	"When it comes to nursing, in a mental health setting, we create activities for the patient. This requires innovation and creativity. Therefore, the concept of thinking out of the box could be applied to brainstorming of the activities for the patients."
Critical questioning	5	"I think we should not jump to a conclusion. We should try to understand better and ask more questions, instead of coming up with the solution immediately after hearing about the problem."
Desire to make a difference	3	"For me right now, I'm looking at certain things at different perspective. I tend to think about how to make things better for both my patients as well as myself."
Embracing risk	1	"For myself, I feel that this module has offered me in terms of pushing the boundaries, and to challenge the norms being set. For example, let us say you have this set of problem, you must solve it in this manner, but you can also approach it at another angle. I find that this module has drilled me in terms of being open to unknowns, and how I can further learn my terrain in a way I can step out of my comfort zone."
Empathy / empathic	3	"From this course, I learnt to be more empathetic towards the users by putting ourselves in the shoes of other."
Envisioning new things	1	"One of the things that impacted me was that time when we created our first prototype, then we had to tear the paper when the profession told us to. It really helped us to not be so stuck on that single idea. Sometimes we would think that the idea we came up with is the perfect idea, but others may think otherwise. So, this really helped us to get over it and not see the initial idea as final."
Holistic view / consider the problem as a whole	4	"This module taught us to not jump straight to solutions. Usually when you encounter a problem, you would try to think of a solution straight away. However, this module makes you go through the whole process of finding out what other people think, how they feel, and they want to see being changed. By taking all these voices, you make a better holistic solution. It's not about me answering the question but going through the journey to find the answer."
Human centeredness	5	"It allows me to be in the perspective of someone who creates product. We need to think about how the users would use the product by putting ourselves in their perspective and where we can find problems that can be improved upon."
Mindfulness and awareness of practice	2	"In this module, for every slide that are given to us, it makes me think and it really strengthens the muscle, and the brain power. In life, for every step of your journey, for instance, when you go down the stairs, or climb up the stairs, those movements require certain brain muscle to tell you that you have to do this, do that. And with this module, I realize that I start to think why I do this."
Multi−/inter−/cross-disciplinary collaborative teams	4	"I think it's also good to have different people talking about it and sharing ideas and throwing it around is easier to figure out what is the best because everyone has different perspective and background where they grow up in. So, from there, we kind of have more perspective to work with."
Open to different perspectives / diversity	4	"I think regarding DT, I'm quite fixated on the idea itself, but during one of the lessons, the instructor said to let our ideas go wild. I think that's quite good, because sometimes you come up with solutions during the process of coming up with weird ideas. I've become more open minded to view things from various perspective using different lens."
Optimism to have an impact	1	"I feel like this module helps me to be more opportunity focused. I have the opportunity to find any challenges or problems faced by the community. And it helps me to become more of myself as I realize that I can come up with any of the crazy ideas when brainstorming."
Team working	2	"Group discussion allows me to open towards another person and acknowledge that their ideas are better than mine. As a human, we only think that our idea is so much better than anyone else. So, when we have this kind of group discussion, it makes me feel that you have to put yourself down and be willing to listen to other thoughts, like 'Why I did not think of that?'"

7 Discussion

Meta-skills, global competence, and digital literacy are potential directions for future skills development. According to Ehlers (2020), *Future Skills* are defined as competencies that allow individuals to solve complex problems in highly emergent contexts of action in a self-organized way and enable them to act (successfully). They are based on cognitive, motivational, volitional and social resources, are value-based and can be acquired in a learning process (Ehlers, 2020, p. 53). Over the years, approaches to 21st-century skills and Future Skills have often focused on designing policy framework recommendations and may only sometimes be empirically based. Existing approaches to Future Skills generally consist of lists of essential

TABLE 3 Moderated regression analysis results.

Cohort 1		
	β (*SE*)	*p*
(Intercept)	4.42 (0.68)	<0.01
Pre-test DT mindset	−0.46 (0.23)	0.04
Pre-test critical thinking disposition	−0.45 (0.24)	0.06
Pre-test DT mindset * Pre-test critical thinking disposition	0.16 (0.07)	0.02
Cohort 2		
	β (*SE*)	*p*
(Intercept)	2.96 (0.56)	<0.01
Pre-test DT mindset	−0.17 (0.19)	0.38
Pre-test critical thinking disposition	−0.19 (0.19)	0.32
Pre-test DT mindset * Pre-test critical thinking disposition	0.14 (0.06)	0.02

competencies but are based on something other than sound competence theory approaches (Barrie, 2004). While it is necessary to understand the characteristics of students when designing a curriculum so that HE educators can tailor the educational approach to meet their specific learning needs, more still needs to be done to explore the effectiveness of learning processes based on 21st-century skills that cater to the interests and needs of digital natives (Dilekçi and Karatay, 2023).

Today's education system caters to 21st-century students who believe in continually producing new products and using technology to maintain their lives (Duran and Ertan Özen, 2018). If we prioritize future skills in HE, it becomes clear that we need to rethink the traditional roles of research, teaching, and learning in IHLs. In this context, it is essential to recognize that anything easily teachable and assessable is also easily digitized and prone to automation (Mourtzis et al., 2018). On the other hand, future skills like creativity, self-organization, self-reflection, and design thinking require innovative and sophisticated approaches to learning, teaching, and development (Miranda et al., 2020). To successfully integrate future skills into HE, educators must focus on implementing active and creative teaching methods and learning objectives that require complex assessments of competence beyond mere knowledge transfer (Erpenbeck, 2012). This will require a shift from traditional, passive approaches to education toward a more dynamic and engaged learning experience that focuses on developing specific transferable skills.

Furthermore, with the emergence of advanced technologies like AI and automation, graduates need to develop crucial digital literacy skills. Digital literacy refers to the ability to use technology effectively and responsibly, to understand the ethical implications of technology, and to leverage technology to solve problems and create opportunities (Khan et al., 2022). Thus, it is vital for IHLs to remain adaptable and responsive to these changing needs and to continue to prioritize the development of well-prepared graduates for the challenges and opportunities of the future. However, while 21st-century skills continue to be essential, the evolving nature of the world and the workforce means that new skills will likely emerge as critical for success.

8 Conclusion

Investigating mindset shifts is essential because it provides insights into how individuals adapt and evolve thinking processes, which is crucial for developing future-ready graduates. Our data shows significant increases in mindset shifts toward critical and design thinking, indicating a transformative educational impact. These shifts suggest that students are not only acquiring knowledge but are also reshaping their cognitive frameworks to approach problems more innovatively and critically. This transformation is vital for innovation in real-world problem-solving. Future research can explore a complementary framework (e.g., Cross, 2011) for understanding how these mindset shifts can lead to innovative and effective problem-solving in real-world contexts. We plan to continue the present study and investigate students' future thinking mindsets and the changes that have occurred since they participated in the Design Innovation module. Similar to this study, we will administer pre- and post-test surveys for students to self-report their futures thinking mindset shift. The survey adopts the five factors of 33 items of the revised Foresight Styles Assessment (FSA) from Chen et al. (2021). In conclusion, the findings on increased mindset shifts in critical and design thinking among students is a promising indicator of the potential to develop graduates with key dispositions and are equipped with the cognitive frameworks necessary to address the complex challenges of the future.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the Singapore Institute of Technology. Ethics approval was granted on 08 October 2021 (IRB: 2021154). We acknowledge two other co-investigators of the research study who will be named later. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

NP: Conceptualization, Data curation, Project administration, Visualization, Methodology, Writing – original draft, Writing – review & editing. SP: Methodology, Writing – original draft, Writing – review & editing. X-FK: Methodology, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1358431/full#supplementary-material

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