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Enhancing adaptive expertise in undergraduate design education: evidence from a quasi-experimental intervention

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Abstract
In today's rapidly evolving professional landscape, developing adaptive expertise (AE) has become an essential objective in design education. Adaptive experts not only master domain-specific knowledge but also apply it flexibly and creatively in unfamiliar contexts. This study investigates the impact of contextual design exercises on the development of AE among undergraduate design students. Using a quasi-experimental design, 78 students enrolled in a "Design Communication" course were assigned to two instructional conditions. One group completed contextual modeling tasks involving novel 3D objects, while the other engaged in traditional stylized drawing exercises. Following the intervention, students completed the Adaptive Expertise Survey (AES), which measures four key dimensions of AE: personal epistemology, metacognition, goals and beliefs, and multiple perspectives. Statistical analysis using one-way ANOVA revealed that students in the contextual exercise group scored significantly higher across all AE dimensions compared to those in the traditional exercise group. These findings suggest that integrating real-world, context-rich design tasks can foster adaptive thinking, reflective learning, and innovative problem-solving skills. The study offers practical implications for curriculum development in design education and highlights the importance of experiential learning approaches that go beyond routine skill acquisition.

Keywords Adaptive expertise · Design education · Contextual learning

Introduction

In today's rapidly changing global context, higher education is increasingly expected to prepare students not only with foundational knowledge but also with the ability to navigate complexity, ambiguity, and constant innovation. Graduates must be equipped to respond to emergent challenges across technological, environmental, and social domains. Within

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this context, the concept of adaptive expertise (AE) has emerged as a key competency, especially in fields like design where students must address real-world, ill-structured or wicked problems that lack clear solutions and require creative, context-sensitive responses (Buchanan, 1992; Rittel & Webber, 1973). Unlike routine expertise, which involves applying established procedures to familiar situations, AE allows individuals to flexibly reinterpret knowledge and solve novel problems. AE is particularly important in design education, where practitioners must explore multiple perspectives, respond creatively, and iterate in response to changing constraints (Pelgrim et al., 2022). Drawing from Fisher and Peterson's (2001) framework, AE is often characterized by four interrelated dimensions: personal epistemology, metacognition, goals and beliefs, and multiple perspectives.

However, developing these characteristics in design students is challenging. Pedagogical practices often rely on repetitive technical exercises or stylized outputs, which may inadvertently reinforce routine rather than adaptive thinking (McInerney, 2023; Chaudhuri & Dhar, 2024). Design students, in particular, have been shown to seek structure and avoid ambiguity, which limits the development of adaptive thinking and risk-taking (McInerney, 2023).

To better align pedagogy with the demands of professional design practice, educators are increasingly turning to contextual, real-world exercises that prompt students to apply their learning in novel and meaningful ways. These tasks foster skills such as creativity, reflection, and critical problem-solving, and may provide a fertile ground for developing AE (Pelgrim et al., 2022).

This study contributes to this pedagogical shift by examining the impact of contextual exercises on the development of AE in undergraduate design students. While prior research has explored AE more in engineering and health education (i.e. McKenna et al., 2006; Mylopoulos et al., 2018; Peng et al., 2014; Pusic et al., 2022), empirical evidence from undergraduate design education remains limited.

This quasi-experimental study investigates how the integration of contextual exercises into a foundational design course influences undergraduate students' development of AE. Specifically, the study compares students' AE levels across two instructional conditions: one based on contextual 3D modeling tasks and the other on traditional stylized drawing exercises.

The central research question for this study is; How does the integration of contextual exercises in undergraduate design education impact the development of AE and its four dimensions -personal epistemology, metacognition, goals and beliefs, and multiple perspectives- compared to traditional stylized drawing exercises?

Context of the study

This study was conducted within an undergraduate design course offered by Industrial Design program of a large and recognized public university in Türkiye. In this institutional setting, the term "course" refers to what is often called a "module" in other systems such as UK, namely, a single unit within a broader program of study. The course in this context was a 4-credit foundational component consisting of 2 h of theoretical instruction and 4 h of studio/lab work per week, totaling approximately 84 h over a 14-week semester. The course is typically taken by first- or second-year students and is designed to develop students' visual thinking, technical drawing, and 2D/3D representation skills. The instructional intervention implemented in this study -the contextual design task- was a core assignment that replaced

a traditional studio project in the second half of the semester. It spanned multiple weeks and involved critique sessions and reflective engagement with simulation of real-world design challenges and required students to interpret the object's structure, purpose, and potential use. Its integration into the main structure of the course ensured pedagogical depth and allowed for sustained development of AE.

Adaptive expertise

Foundations and educational relevance

In response to rapidly evolving technological, societal, and professional demands, education is shifting toward preparing learners not only for disciplinary mastery but also for adaptive and innovative thinking. This transformation has brought AE into focus as a key 21st-century educational outcome. AE is broadly defined as the ability to balance efficiency in familiar tasks with the flexibility to respond to novel and ambiguous situations (Hatano & Inagaki, 1986; Bransford et al., 2000). While routine experts apply procedures with speed and accuracy, adaptive experts demonstrate conceptual understanding and the ability to reshape their knowledge when faced with new challenges. This form of expertise is particularly critical in knowledge-intensive and creative fields, such as education, design, engineering, and medicine, where professionals frequently encounter ambiguous or ill-structured problems that cannot be solved by rote procedures alone (Kua et al., 2021).

Recent studies reinforce this conceptualization across diverse educational settings. Kua et al. (2021) synthesized 48 studies in a scoping review and found that AE is supported by three interacting sets of factors: predisposing factors (e.g., intrinsic motivation, epistemic beliefs), enabling factors (e.g., metacognitive and reflective practices), and reinforcing factors (e.g., feedback and curricular design). The review concludes that AE is not merely a set of skills but an educational orientation grounded in humility, cognitive flexibility, and problem-solving across contexts.

In the context of classroom teaching, Insana (2015) identifies how teachers with AE make responsive decisions based on student needs, integrating epistemic beliefs and pedagogical knowledge. The study shows that instructors who exhibit AE tailor their instructional moves dynamically, shifting from instructional authority to collaborative inquiry when appropriate. Similarly, Crawford et al. (2005) argue that in education, AE enables educators to respond constructively to students' alternative conceptions, using them as opportunities for deeper learning rather than errors to be corrected. This research suggests that AE in teaching is linked with the capacity to work productively within ill-structured problem spaces, a quality also applicable to design education.

A more recent perspective is provided by Zhou (2025), who introduces the Dynamic Interaction Theory based on a grounded theory study of interactive learning environments. Zhou emphasizes that AE is embedded within the evolving nature of the teaching-learning relationship and is strengthened when educators operate as adaptive facilitators rather than static deliverers of content. This model highlights the reciprocal influence between pedagogical conditions and learner engagement, reinforcing the need for adaptive decision-making in design and implementation. Similarly, Pusic et al. (2022) emphasize that AE is grounded in the ability to balance efficiency and innovation -two forces that often exist in

tension but are essential to real-world expertise. Their work in health professions education demonstrates that effective instruction for AE requires not just repeated procedural practice but also opportunities for learners to navigate ambiguity, experiment, and reflect. They argue that "learning to shift between efficient and innovative practice" is a cornerstone of AE and should be a primary goal in curriculum design across disciplines, including education. Further supporting this framework, Opre (2015) claims that AE is deeply tied to the transfer of learning and that educational environments should intentionally balance tasks that build fluency (efficiency) with those that foster insight and flexibility (innovation). Drawing from empirical studies, Opre identifies "preparation for future learning" (PFL) as a particularly effective instructional strategy that facilitates AE. This method promotes learners' ability to extract meaning from prior innovative tasks and later apply structured knowledge more effectively in novel transfer scenarios. According to Opre, this kind of adaptive development is best supported when learning activities are organized to reflect real-world variability, ambiguity, and student agency.

Importantly, these findings align with Kua et al.'s (2021) comprehensive scoping review of AE in education, which highlights three conditions essential to AE development: predisposing factors (e.g., learner motivation, epistemological beliefs), enabling conditions (e.g., authentic problem tasks, feedback, and metacognitive scaffolding), and reinforcing factors (e.g., reflection and iterative engagement). These studies underscore that AE is not a static cognitive trait but rather a dynamic capability shaped by educational culture, task design, and the learner's active engagement with complexity.

Taken together, these findings establish AE as a dynamic, context-sensitive form of learning that is essential for responding to ambiguity and complexity in educational environments. Instructional strategies that balance innovation and efficiency—such as contextual, open-ended problem tasks and PFL-based learning—create the necessary conditions for AE development (Sabzikaran et al., 2024). In design education, where learners must constantly reinterpret problems, integrate user needs, and create novel solutions, these conditions are particularly relevant. As such, AE offers a compelling pedagogical lens for transforming design curricula to better support deep learning and future-ready thinking. To bridge this gap, scholars and practitioners have called for more intentional pedagogical designs—such as contextual modeling tasks—that mirror real-world complexity and support the flexible application of design knowledge (Robertson et al., 2007; Bransford et al., 2000).

Dimensions of adaptive expertise

To better understand how AE can be fostered through learning design, it is essential to explore its underlying dimensions. Drawing on the work of Fisher & Peterson (2001), AE is conceptualized through four interrelated dimensions: personal epistemology, metacognition, goals and beliefs, and multiple perspectives. These dimensions are not isolated traits but overlapping components that collectively support innovation, reflection, and transfer in complex learning environments.

Personal epistemology

Personal epistemology refers to individuals' beliefs about the nature of knowledge and how it is constructed. Adaptive experts often perceive knowledge as evolving, contextual, and

subject to change, which contrasts with viewing knowledge as fixed or absolute. This belief system enables them to stay open to new information and reinterpret established knowledge structures when faced with novel situations (Fisher & Peterson, 2001). Such flexibility, however, is not easily developed through repetitive instruction. Mercier and Higgins (2013), in a study comparing collaborative multi-touch learning environments with traditional methods, found that while both conditions improved students' fluency, only the collaborative, exploratory setting supported growth in flexibility, a core trait of AE. These findings highlight the importance of designing educational activities that challenge learners to reconsider and reconstruct their understanding, rather than simply reinforce prior knowledge.

Metacognition

Metacognition plays a crucial role in adaptive learning by enabling individuals to monitor, regulate, and evaluate their own thinking processes. Learners with strong metacognitive abilities can recognize when their understanding is incomplete, determine when to seek additional information, and assess whether new knowledge aligns with what they already know. Importantly, adaptive experts also know how to switch between routine and innovative strategies depending on the situation, which requires a high level of metacognitive self-assessment (Opre, 2015). This capacity allows learning to take place during problem solving, not just as a precondition to it. By continuously engaging in reflective thought, learners become better equipped to respond to unpredictable challenges, a core demand in creative and complex fields like design education.

Goals and beliefs

Adaptive experts are characterized by a growth-oriented mindset, where challenges are viewed not as threats but as opportunities for learning and improvement. Their goals are mastery-driven, focusing on conceptual understanding and long-term development rather than performance-based outcomes (Fisher & Peterson, 2001). These learners employ self-regulation strategies to track progress, revise ideas, and persist through uncertainty. Research in AE (Pandy, 2004) has also underscored the importance of transfer, conceptual knowledge, and factual recall as pillars of this dimension, each of which contributes to the ability to extend knowledge into unfamiliar domains. The presence of such beliefs influences the learner's motivation to innovate, revise, and engage deeply with difficult problems, rather than avoiding or oversimplifying them.

Multiple perspectives

One of the hallmarks of AE is the ability to consider problems from diverse and often conflicting viewpoints. This capacity allows learners to see beyond single-solution thinking and to explore creative alternatives. Martin et al. (2010) argue that experiences designed to foster both knowledge acquisition and innovation contribute significantly to the development of this dimension. In engineering and design education, for example, students must not only apply technical knowledge but also empathize with users, consider social and environmental constraints, and balance competing priorities. The ability to flexibly move among different ways of framing a problem is tightly linked with both innovation and efficiency,

which must coexist for AE to flourish (McKenna, 2006; Fisher & Peterson, 2001). Moreover, learners who are encouraged to engage in tasks that support both dimensions are more likely to develop the resilience and creativity required to meet real-world challenges.

Together, these four dimensions form a dynamic system through which AE emerges and evolves. Educational practices that nurture epistemic flexibility, foster reflective thinking, encourage growth-oriented goals, and invite multiple perspectives are more likely to produce learners who can respond creatively, think critically, and adapt constructively to novel demands. In design education, these dimensions are particularly salient, as students must continuously apply, reinterpret, and extend their knowledge in ever-changing and ill-defined contexts.

Contextual learner-centered exercises in design education

Contemporary design education increasingly emphasizes the importance of contextual, learner-centered approaches to cultivate students' capacity for innovation, critical thinking, and AE. Moving beyond technical reproduction or stylized outputs, contextual exercises situate learning within authentic, personally meaningful problem spaces; offering students opportunities to explore, experiment, and construct knowledge in ways that mirror real-world design practice.

Contextual learning, grounded in constructivist theory (Piaget, 1970; Schunk, 2012), asserts that individuals develop deeper understanding when they engage with tasks that connect to their prior knowledge, lived experiences, and cognitive frames of reference. Within design education, this translates to project-based activities that invite students to solve complex, open-ended problems that align with their personal interests, communities, or societal issues. As Bransford et al. (2000) highlight, meaningful learning occurs when learners are challenged to apply and reorganize knowledge in context, rather than simply recall abstract information.

Moreover, learner-centered pedagogies prioritize student agency, metacognitive engagement, and relevance. This approach recognizes students not just as recipients of design knowledge, but as active participants in constructing it (Brophy et al., 2004; Kua et al., 2021). Research by Bodnar et al. (2018), for instance, demonstrates that experiential design projects rooted in real-life contexts can foster key AE traits; especially adaptability, reflective thinking, and transfer. Similarly, Hatano and Oura (2003) argue that exposure to variable, uncertain tasks prepare students for future learning by placing them on a developmental trajectory toward AE.

Scaffolding plays a crucial role in contextualized learning environments. According to Rogoff and Gardner (1984), effective scaffolding supports students in transferring knowledge from familiar to unfamiliar contexts by guiding them through increasingly complex decisions and reflections. In design education, this may involve iterative critique sessions, stakeholder engagement, or structured reflection—tools that help students not only refine their solutions but also develop the habits of mind required to adapt, question, and reframe problems.

Contextual tasks can also challenge students' tolerance for uncertainty and ambiguity; conditions that are essential for AE. As Rousseau and Stouten (2025) note, exposure to ill-structured scenarios encourages learners to consider diverse, context-sensitive responses

rather than applying routine solutions. This is particularly critical in design education, where problems rarely have singular or clearly defined answers.

Finally, recent scholarship emphasizes that AE develops most effectively when students are invited to participate in authentic learning cycles that balance efficiency with innovation (Pusic et al., 2022). According to Kua et al. (2021), such environments are characterized by enabling and reinforcing factors -including meaningful feedback, variability in task design, and reflective dialogue- that allow learners to experiment, fail productively, and grow. Design education, with its inherent focus on iteration, prototyping, and user-centered inquiry, provides a fertile context for this kind of development.

In alignment with this pedagogical rationale, the present study employed a contextual exercise in which students in the experimental group were tasked with designing a novel 3D object derived from an unfamiliar, real-world context. The object was intentionally chosen to possess geometric complexity and ambiguity of purpose, allowing students to interpret its use, function, or potential user needs in diverse ways. Its abstract and open-ended nature encouraged students to relate it to their own interests, life experiences, or imagined design scenarios, such as household functionality, wearable accessories, or everyday tools, depending on what personally resonated with them. This made the task both personally meaningful and cognitively demanding, promoting deeper engagement and interpretive flexibility.

Unlike traditional exercises that emphasize routine efficiency, the contextual 3D design activity was intended to trigger multiple dimensions of AE: personal epistemology (by questioning assumptions about the object's meaning and use), metacognition (through iterative modeling and reflection), goals and beliefs (by presenting ambiguity as a growth-oriented challenge), and multiple perspectives (through diverse user-centered interpretations). By embedding the learning in a task with both relevance and uncertainty, the study aimed to simulate the kind of authentic design problem solving required in professional contexts, thus supporting the development of AE, as recommended by Hatano and Oura (2003) and Brophy et al. (2004).

Fostering adaptive expertise in design education

Design education traditionally emphasizes repetition, stylized technical exercises, and skill acquisition, often sidelining the development of adaptive thinking. While such practices help establish a foundation in technique and discipline-specific norms, they may restrict opportunities for students to engage with ambiguity, open-endedness, or real-world complexity elements essential for fostering AE. McInerney (2023) highlights that novice design students often display "sanctuary-seeking tendencies" characterized by a desire for certainty and fear of failure, both of which hinder creativity and cognitive flexibility. This need for closure often drives learners toward rigid interpretations of design tasks, making them reluctant to take risks or explore alternative solutions.

Similarly, Chaudhuri and Dhar (2024) argue that pedagogical models in design often prioritize end-products over the learning process, thereby reinforcing surface-level engagement and evaluative anxiety rather than reflective exploration. The tension between structure and freedom can create a paradox for design novices: while they are expected to be creative, they are rarely given the scaffolding or psychological safety needed to navigate open-ended challenges. Studies such as Oxman (2001) and Findeli (2001) also caution that

students often engage in mechanical routines, reproducing stylistic norms instead of critically interpreting design briefs, thus undermining their adaptive potential. These limitations point to the need for design curricula that create space for uncertainty, personal relevance, and diverse problem-solving pathways; conditions more conducive to the development of AE.

Creativity, context, and cognitive flexibility in design education

Creativity in design education is inherently linked to students' ability to work within open-ended, contextualized tasks that require innovation, perspective-taking, and adaptability. According to Oxman (2004) and McInerney (2023), these tasks challenge students to move beyond procedural expertise into realms that demand reflective learning and exploration of alternatives. Cognitive flexibility, a defining trait of adaptive experts, is fostered when learners are encouraged to analyze problems from multiple perspectives and are supported in engaging with both personal and collaborative ideation processes. This is echoed in Oxman's (2001) argument that design cognition involves the interplay between conceptual and visual reasoning, requiring students to develop knowledge structures that can be re-represented and flexibly applied across different scenarios.

Design thinking, as a pedagogical approach, supports this transition by situating learners in real-world or simulated environments where ambiguity is not a threat but a generative condition. For example, the use of contextual modeling tasks not only encourages creative exploration but also allows students to personalize their responses, enhancing engagement and emotional investment in the design process. These tasks provide fertile ground for "preparation for future learning (PFL)" (Bransford et al., 2000), which Opre (2015) highlights as a crucial component of AE, balancing both efficiency and innovation.

Instructional design interventions to promote adaptive expertise in design education

As design education evolves to meet the demands of the 21 st century, educators are increasingly questioning whether current instructional models sufficiently foster AE. Traditional design studio pedagogy, while foundational, often emphasizes aesthetic output and technical reproduction over conceptual exploration and transfer. To better align design instruction with the characteristics of AE; such as flexibility, epistemic openness, and context-sensitive problem solving—researchers have advocated for more contextual, experiential, and learner-centered interventions (Oxman, 2004; Findeli, 2001).

One such intervention involves the use of real-world, contextualized design tasks, which embed ambiguity and relevance into the learning process. These tasks prompt students to explore not only how to design, but also why and for whom. In their Delphi study, Brosens et al. (2023) identified "contextual responsiveness" and "critical adaptability" as key future-proofing capabilities for design students, both of which align closely with the core dimensions of AE. Similarly, Oxman (2001) argues that learning environments should stimulate design cognition, involving representational shifts, conceptual reframing, and itera-

tive exploration. Such environments create the cognitive conditions necessary for adaptive thinking to emerge.

In the present study, these pedagogical ideas were operationalized through the integration of a contextual design exercise in which students were asked to interpret and redesign a novel 3D object with no pre-assigned function. The task was intentionally ambiguous, requiring students to determine a purpose for the object and adapt their design decisions based on real-world considerations, such as usability, material constraints, or user needs. By inviting students to draw on their own experiences and interests, this intervention not only promoted engagement but also encouraged the transfer and transformation of prior knowledge, both of which are central to AE (Bransford et al., 2000; Hatano & Oura, 2003).

Unlike stylized drawing exercises that prioritize visual polish, the contextual task emphasized interpretation, iteration, and reflective reasoning, all of which are consistent with the instructional conditions outlined by McInerney (2023) and Chaudhuri and Dhar (2024) as conducive to AE development. Moreover, the open-ended nature of the assignment aligned with learner-centered pedagogical models that call for personal relevance and epistemic agency in the learning process (Oxman, 2004; Findeli, 2001).

Despite increasing calls for reform, many design programs still lack structured models for cultivating AE. This study aims to contribute to that gap by offering a quasi-experimental instructional model grounded in AE theory and tailored to the realities of design studio education.

Methodology

This study employed a quasi-experimental, post-test only design to investigate how contextual, real-world exercises influence the development of AE among undergraduate design students. The quasi-experimental method was selected due to its practical suitability in natural educational settings, where random assignment is often unfeasible (Creswell & Creswell, 2017). This design enabled the comparison of AE outcomes across two instructional formats -contextual 3D object exercises versus traditional stylized drawing exercises- without disrupting the integrity of naturally formed class groups.

According to Fraenkel et al. (2022), quasi-experiments are appropriate when the goal is to examine causal relationships in real-world contexts, especially where ethical or logistical constraints prevent full randomization. As design education typically operates in intact class settings and emphasizes iterative, experience-based learning, this approach allowed for convincing insights without compromising instructional authenticity.

Moreover, this study aligns with Creswell and Creswell's (2017) "post-positivist" paradigm, which acknowledges that while absolute objectivity may be intangible, carefully designed interventions and structured instruments can offer meaningful evidence about outcomes. The quasi-experimental design thus bridges theory and instructional practice, responding directly to gaps in empirical studies that test AE in design education.

Participants

Participants were drawn from two intact sections of an undergraduate "Design Communication" course at a large public university in Türkiye. The study used a non-random purposive

sampling strategy, selecting two intact course sections of the class. This convenience-based but purposeful sampling ensured that both groups shared a similar academic level (first- and second-year students), had no prior formal instruction in AE, were taught by the same instructor, and followed a consistent syllabus, aside from the instructional manipulation. A total of 78 first- and second-year students participated, with 39 assigned to the experimental group and 39 to the control group. Although assignment to groups followed the structure of existing course sections, the manipulation of the instructional method (contextual vs. traditional) was deliberate, aligning with the quasi-experimental framework.

Participation in the research component was voluntary. Students were informed of the study's purpose and assured of anonymity. Research ethical approval was obtained from the institution's Human Subjects Research Board.

Instructional conditions

The study was conducted during the 2023–2024 Fall semester as part of a 14-week, 4-credit foundational course consisting of 2 h of theoretical instruction and 4 h of studio/lab work per week. This course is typically taken by first- and second-year students and is designed to develop visual thinking, technical drawing, and 2D/3D representation skills. The instructional intervention -the contextual design task- was implemented in the second half of the semester and integrated as a central assignment, ensuring deep engagement across multiple sessions.

Experimental group – Contextual design task

The students in the experimental group completed contextualized exercises using a novel 3D object (Fig. 1) with similar geometric complexity to traditional drawings (that control group used). Students were provided with an unfamiliar 3D object with no predefined purpose and asked to complete a stylized drawing exercise where they measure and interpret all dimensions through a ruler by themselves. The task was designed to simulate real-world design challenges and required students to interpret the object's structure, purpose, and potential use. This exercise was intended to foster the characteristics of AE by encouraging flexible thinking, metacognition, and the integration of multiple perspectives (Oxman, 2001; Findeli, 2001; Bransford et al., 2000).

Control group – Stylized drawing exercise

The control group completed a stylized geometric drawing exercise (Fig. 2), traditionally used in foundational design courses. This task emphasized precision, technical execution, and visual replication, focusing on rendering skills without contextual interpretation or design innovation. The aim was to serve as a routine-expertise comparison point, reflective of pedagogies that prioritize efficiency and reproduction.

Both instructional conditions were implemented over several weeks during the semester, with students given equal time, materials, and access to instructor support.

Although the geometric complexity of the 3D object and the stylized drawing were similar, the two tasks differed substantially in their instructional approaches, cognitive demands, and learning goals. Students in the control group worked with stylized technical drawings

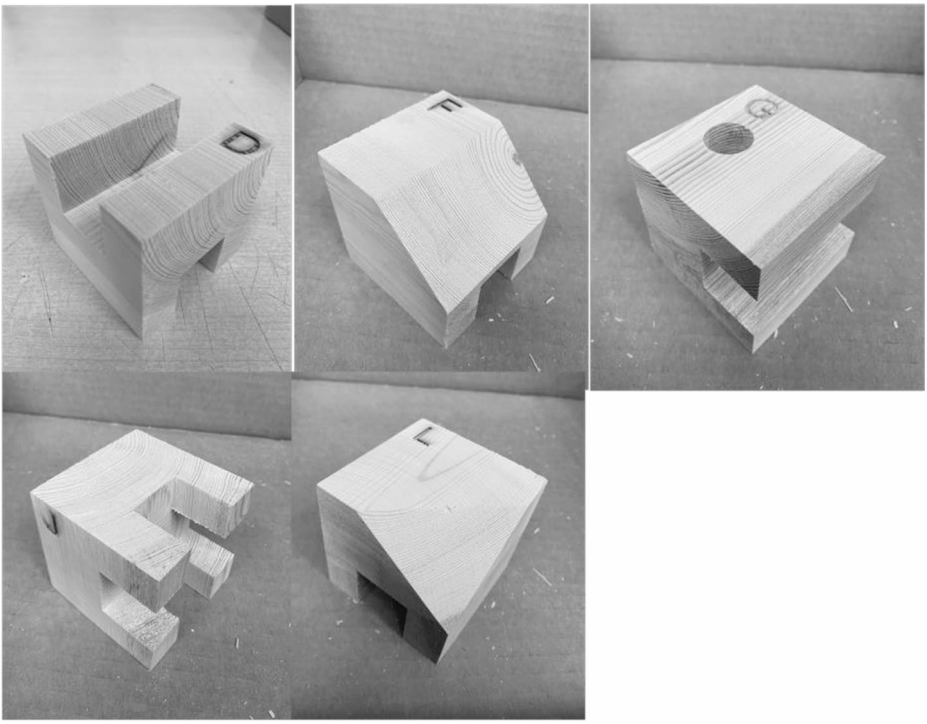

Fig. 1 3D object with similar geometric complexity to traditional drawings

commonly used in foundational design instruction. They were provided with a detailed reference image and followed step-by-step procedures to replicate geometric forms using measurement tools such as rulers and compasses. The emphasis was on precision, proportion, and technique, with little room for interpretation. Here in stylized drawing, students focused on mastering line weight, orthographic projection, and drawing conventions which are all core technical skills, but largely routine and product-oriented. Peer or instructor feedback was limited to visual accuracy and adherence to predefined outcomes. This approach aligns with a technical-reproduction model of instruction, where learning emphasizes efficiency and procedural fluency (Eiriksdottir & Catrambone, 2011).

In contrast, students in the experimental group were given a small 3D object with unfamiliar geometry and no predetermined function. The object, resembling a hybrid between mechanical and organic forms, was deliberately chosen to spark interpretation and ambiguity and also to keep the consistency between stylized drawing objects and 3D objects. Students began by closely observing and measuring the object independently -no predefined measures-, but without a reference drawing to copy. They were asked to determine what the object could represent, who might use it, and in what context. Some students imagined it as part of a wearable device, others as a tool, a toy, or even a kitchen accessory; interpretations varied widely. They then created freehand and scaled technical drawings based on their envisioned function, iterating across sessions to refine both form and meaning. Throughout the process, students engaged in peer critique, reflection, and revision, with instructor guidance focused on design rationale, user needs, and visual communication strategies,

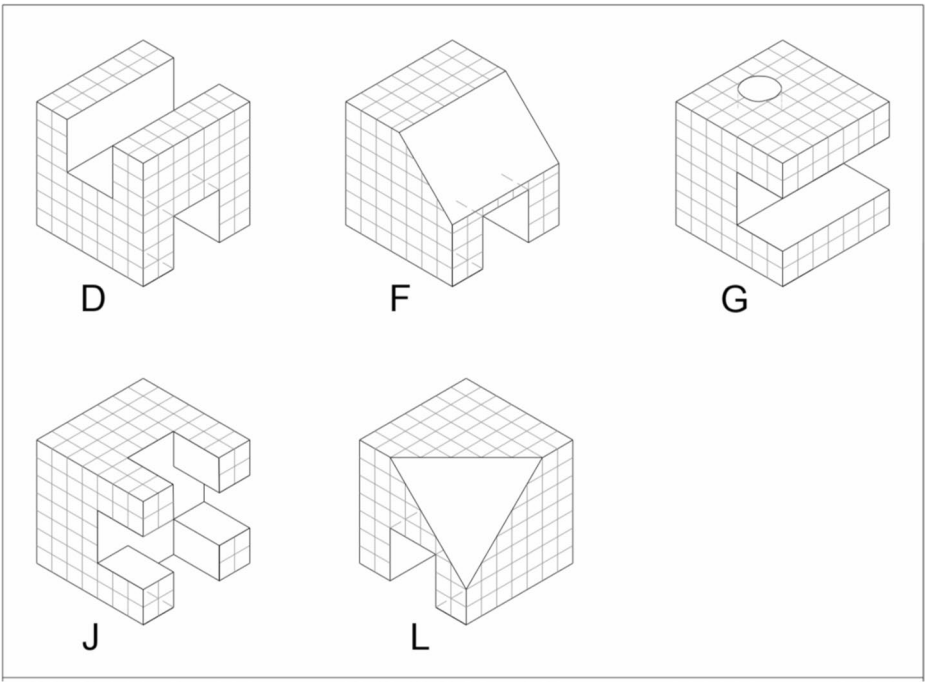

Fig. 2 Stylized drawings which are a standard part of the course

rather than simply execution. This contextual task aligns with the How People Learn framework (Bransford et al., 2000), which emphasizes active meaning-making, prior knowledge integration, and transfer-oriented learning. It also draws from contextual learning theory (Schunk, 2012), which highlights that learning is more effective when situated in authentic, personally meaningful, and interpretive tasks. The novelty of the treatment task lies not in the tools or materials used, but in how it framed ambiguity as a learning opportunity. By positioning students as both analysts and authors of meaning, the task invited metacognitive regulation, epistemic openness, and adaptive reasoning. It moved beyond technical proficiency and created conditions for the emergence of AE where students were required not just to represent, but to reimagine.

Instrumentation and measures

To measure AE, the Adaptive Expertise Survey (AES) (Fisher & Peterson, 2001) was used. This validated 42 items rated on a 6-point Likert scale (1 = strongly disagree to 6 = strongly agree) captures four core dimensions of AE: Personal Epistemology, Metacognition, Goals and Beliefs, Multiple Perspectives.

The AES items were adapted slightly for relevance to the design education context (e.g., referencing "design problems" instead of generic "problems"), and a panel of three design education researchers reviewed the revised items to establish content validity. The AES was administered after the completion of the exercises. The overall reliability (internal consistency) of the instrument was acceptable (Cronbach's alpha = 0.795) with acceptable thresh-

olds ($\alpha \geq 0.70$) confirmed across subscales. In addition, construct validity was supported by alignment with AE literature (i.e. Bransford et al., 2000; Kua et al., 2021; McKenna, 2014; McKenna et al., 2006) and consistent factor structures from previous uses.

Data collection procedure

Data were collected in the final week of the course after the completion of the instructional intervention. Students in both groups completed the AES under standardized conditions. To avoid priming or testing effects, no pre-test was administered; this decision aligns with best practices in quasi-experimental designs aimed at measuring post-intervention change (Creswell & Creswell, 2017; Fraenkel et al., 2022).

Data analysis

To assess the impact of the instructional intervention on students' AE, a one-way analysis of variance (ANOVA) was conducted. The analysis compared the mean scores of the experimental and control groups across the four key dimensions of the AES. In addition to subscale comparisons, an overall composite AES score was calculated and analyzed. The ANOVA test was selected to determine whether statistically significant differences existed between the two instructional conditions, thereby evaluating the effectiveness of the contextual exercise in fostering AE development. Prior to analysis, effect sizes (Cohen's d) were calculated as well to assess the magnitude of observed differences.

Results

This study aimed to investigate whether students who engaged in a contextual design task -interpreting and drawing a novel 3D object- demonstrated significantly higher development of AE than those who completed a traditional stylized drawing task. Group differences were assessed using one-way ANOVA, with significance set at $p < .05$. Additionally, Cohen's d was calculated to assess the magnitude of the instructional effect. The results indicated large to very large effect sizes across all AE dimensions, with d values ranging from 1.00 to 1.53, suggesting that the contextual 3D object exercise had a substantial impact on students' development of AE characteristics.

The results indicated statistically significant differences between the experimental and control groups across all four AE sub-dimensions:

Multiple perspectives

Students who used the contextual 3D object ($N = 39$, $M = 5.45$, $SD = 0.55$) had more multiple perspectives sub-dimensions score than students who used stylized drawing ($N = 39$, $M = 4.74$, $SD = 0.44$, $F(1, 76) = 39.88$, $p < .001$). (Cohen's $d = 1.43$, indicating a very large effect).

This finding indicates that students in the experimental group were more likely to engage in perspective-taking and consider diverse interpretations and user needs. In fact, the contextual 3D object task promoted significantly higher development in students' ability to

consider and integrate multiple viewpoints during the design process. This contextual task, with its open-ended and ambiguous structure, appeared to stimulate students to explore alternative uses, scenarios, and stakeholders, thereby broadening their design framing. The very large effect size (Cohen's $d = 1.43$) suggests that contextual design tasks are particularly powerful in fostering design empathy and framing flexibility.

Metacognition

Students who students who used the contextual 3D object ($N = 39$, $M = 5.29$, $SD = 0.61$) had more metacognition sub-dimensions score than students who used stylized drawing ($N = 39$, $M = 4.51$, $SD = 0.54$, $F(1, 76) = 35.44$, $p < .001$). (Cohen's $d = 1.35$, also reflecting a very large effect).

This finding indicates that the contextual task facilitated higher levels of self-awareness and self-regulation during the learning process. Students had to monitor their own understanding of the object, evaluate the clarity of their ideas, and adjust their drawings based on iterative critique and reflection. Unlike the control task, which followed a known procedure with predictable steps, the experimental activity required students to set their own cognitive path; evaluating possibilities, questioning assumptions, and refining their decisions. This aligns with research suggesting that metacognition thrives when learners are given autonomy to plan, test, and revise their thinking across uncertain tasks. The large effect size (Cohen's $d = 1.35$) reflects how the task structure invited students not only to design but to reflect on how they were designing that is a core aspect of developing AE.

Goals and beliefs

Students who students who used the contextual 3D object ($N = 39$, $M = 4.94$, $SD = 0.54$) had more goals and beliefs sub-dimensions score than students who used stylized drawing ($N = 39$, $M = 4.15$, $SD = .49$, $F(1, 76) = 46.99$, $p < .001$). (Cohen's $d = 1.53$, the largest effect size observed among the four sub-dimensions).

This result points to a meaningful shift in how students approached the task in terms of motivation and belief. The contextual activity was framed not as a task to complete for correctness, but as a challenge to interpret, explore, and personalize. This orientation appeared to promote a stronger mastery-based approach to learning, where students valued growth and understanding over performance or external evaluation. Many students might engage deeply with their chosen function or context for the object, investing cognitive and emotional energy in the process of discovery. The largest effect size among all dimensions (Cohen's $d = 1.53$) suggests that contextual design tasks may have unique motivational benefits like helping students to reframe uncertainty as an opportunity, rather than a threat. Such beliefs are foundational to AE, where innovation and persistence are valued over compliance and repetition.

Epistemology

Students who students who used the contextual 3D object ($N = 39$, $M = 5.29$, $SD = 0.67$) had more epistemology sub-dimensions score than students who used stylized drawing ($N = 39$, $M = 4.69$, $SD = 0.52$, $F(1, 76) = 60.61$, $p < .001$). (Cohen's $d = 1.00$, denoting a large effect).

This finding shows that the intervention positively influenced students' beliefs about the nature of knowledge and how it is constructed. Participants in the experimental group were more likely to view knowledge as evolving, context-dependent, and interpretive rather than fixed or absolute. The nature of the task itself required them to invent meaning, justify decisions, and iterate toward new insights, reinforcing the idea that design knowledge is generated through experience and exploration. By contrast, the stylized drawing task may have reinforced a view of knowledge as procedural or rule-based. This shift in epistemological beliefs is essential for encouraging AE who can navigate ill-structured or wicked problems and transfer learning across situations.

Taken together, these findings suggest that the contextual, open-ended design task had a substantial impact on the development of AE, especially in promoting metacognitive engagement, personal motivation (goals and beliefs), and perspective-taking (multiple perspectives). The large to very large effect sizes -ranged from 1.00 to 1.53, - which according to Cohen's (1988) guidelines, are considered 'large' to 'very large' in magnitude- across all dimensions means that the differences between the experimental and control groups were not only statistically significant but also practically meaningful, with the contextual design task having a substantial impact on students' cognitive, motivational, and epistemic development. This large effect sizes reinforce the instructional value of contextual exercises in undergraduate design education particularly as a means to help students move beyond technical fluency toward reflective, and adaptive design practice.

Discussion

This study aimed to empirically investigate how contextual exercises embedded within foundational design course influence the development of AE. The results not only affirm the instructional value of these exercises but also offer theoretical and practical contributions to the evolving discourse on design education.

The findings revealed significant difference across all four AE dimensions -personal epistemology, metacognition, goals and beliefs, and multiple perspectives- for students engaged in contextual design tasks compared to those following traditional stylized drawing tasks. The large to very large effect sizes observed (Cohen's d ranging from 1.00 to 1.53) emphasize that these differences were not minor but significant, indicating that the contextual exercises meaningfully shifted students' cognitive and epistemic development. For example, the highest gains were observed in the "goals and beliefs" dimension, suggesting that the open-ended and ambiguous nature of the contextual task encouraged students to adopt an expertise oriented, growth-focused approach. Similarly, the significant improvement in "multiple perspectives" shows how the activity promoted design empathy and widened problem framing. The enhancement in metacognitive self-awareness points to the task's success in encouraging students to reflect on their strategies and judgments, while the shift in epistemological beliefs reflects deeper engagement with the interpretive nature of design knowledge.

These results support and extend Hatano and Inagaki's (1986) initial distinction between routine and AE, reinforcing the idea that AE is not merely a function of experience but of how learners interact with complexity and novelty. For example, the strongest gains were observed in the goals and beliefs dimension ($d = 1.53$), suggesting that the contextual task

significantly enhanced students' motivation and willingness to persist through uncertainty. Therefore, current findings provide empirical evidence that AE can be fostered even in early stages of design education when students are provided with opportunities to navigate uncertainty, generate original solutions, and reflect on the learning process.

The tasks in this study required students to engage with a novel 3D object, interpret its dimensions and complete the drawing exercises (which was also a novel procedure in that class). This interpretive process directly maps onto the observed improvement in the "multiple perspectives" dimension ($d = 1.43$), as students considered diverse user needs, functions, and contexts for the object. The contextual exercise activated students' prior knowledge, epistemological beliefs, and ability to take alternative perspectives (as highlighted in the results section). These mechanisms align with AE development models described by Mylopoulos et. al., 2018) and Kua et al. (2021). The effectiveness of these tasks underscores the centrality of contextualization and learner-centered engagement in fostering AE, supporting the recommendations of educational researchers across both design and science education domains (Pusic et al., 2022; Carbonell et al., 2014).

These findings also align with a growing body of research that highlights the limitations of traditional, technically focused design instruction in cultivating reflective, innovative thinkers (Findeli, 2001; Oxman, 2001; Boyarski, 1998). While stylized exercises serve an important role in skill-building, they may inadvertently reinforce closed-task mindsets, risk aversion, and superficial understandings of design's socio-contextual implications. As Brosens et al. (2023) argue, design curricula must now shift toward future-proofing students, emphasizing the integration of technical, epistemic, and reflective competencies. The strong statistical differences observed in this study provide quantitative support for such curricular reforms, demonstrating how even a single, well-designed contextual task can shift students' orientations toward design knowledge, problem-solving, and motivation.

By embedding ambiguity and real-world relevance into design tasks, the present study operationalized design education as a process of knowledge construction rather than knowledge reproduction (Oxman, 2004). Students were not merely executing commands or replicating forms; they were making judgments, reasoning through uncertainty, and iteratively redefining problems—practices central to AE and essential to contemporary design practice (McKenna, 2006; Mylopoulos et al., 2018). Moreover, these tasks provided cognitive training opportunities, encouraging students to externalize their reasoning, test assumptions, and engage in reflective self-assessment—all core elements in the development of metacognition. This directly reflects the observed improvement in the metacognitive dimension ($d = 1.35$), confirming the value of reflective iteration and reasoning as instructional goals in design education. Such outcomes reflect Vygotskian sociocultural learning theories, where knowledge emerges through guided interaction with tools, peers, and contextual affordances (Jaramillo, 1996).

One of the key theoretical contributions of this study lies in its confirmation that efficiency and innovation are not mutually exclusive but must be deliberately balanced within instructional design. As Pusic et al. (2022) and Opre (2015) note, AE flourishes when learners fluctuate between fluency in known procedures and challenges of experimentation with novel strategies. The intervention developed here embraced this principle by allowing students to apply learned design principles while extending their application into unfamiliar and personally relevant domains. In doing so, this study also responds to a major challenge identified in the literature: the difficulty of designing learning environments that nur-

ture both innovation and recognition of the limits. These results demonstrate that even in time-constrained undergraduate contexts, it is possible to design tasks that are structured enough to offer guidance, yet open-ended enough to support adaptive thinking. The magnitude of observed effects across all dimensions reinforces this point; AE can occur when tasks are well-scaffolded yet open-ended, prompting learners to transfer and transform their knowledge.

Finally, the study speaks to a broader shift in the goals of design education. As the field struggles with ecological crises, technological disruption, and shifting labor markets, educators are called to cultivate not only technically competent graduates but also adaptive, ethically grounded, and socially responsive professionals (Findeli, 2001; Brosens et al., 2023). Developing AE may offer a pathway to meet these demands, enabling students to become lifelong learners capable of critically engaging with dynamic design contexts. The empirical evidence presented in this study offers strong support for this pedagogical shift. Contextual design tasks, when purposefully outlined, can serve as transformative mechanisms for promoting the core habits of AE. By demonstrating the impact of contextual design exercises on AE development, this study lays groundwork for future curricula that foreground reflective practice, user empathy, and real-world relevance—an evolution that aligns design education with contemporary challenges and future needs.

Conclusion

This study provides empirical support for the integration of contextual, learner-centered exercises in undergraduate design education as a pathway for fostering AE. By situating students in open-ended, personally relevant tasks that required interpretation, reflection, and strategic thinking, the intervention promoted meaningful gains across all AE dimensions. These results underscore the potential of instructional models that balance structure and openness -allowing learners to build fluency while also adapting their knowledge to novel, ambiguous challenges. In doing so, this research contributes to ongoing efforts to reimagine design education for a rapidly evolving professional landscape. As the demands placed on designers grow in complexity, so too must the educational environments that prepare them. Contextual exercises, as demonstrated in this study, not only support the development of cognitive and metacognitive flexibility but also encourage deeper engagement with the socio-cultural and ethical dimensions of design practice. Moving forward, embedding such practices into foundational design curricula offers a compelling strategy for preparing adaptive, innovative, and reflective design professionals.

Limitations

While this study provides compelling evidence for the effectiveness of contextual exercises in enhancing AE among undergraduate design students, certain limitations should be acknowledged. The research was conducted within a single design course at one institution, which may limit the generalizability of the findings. Institutional culture, student demographics, and curricular structures could influence how contextual learning strategies are received and implemented in other settings. Furthermore, the quasi-experimental design,

while practical in an educational context, did not include random assignment, leaving the possibility of pre-existing differences between groups despite efforts to ensure equivalency.

Additionally, the duration of the intervention was relatively short, covering a couple weeks in a single semester. Although statistically significant improvements in AE dimensions were observed, the study does not capture whether these gains are sustained over time or transferred to other design contexts and courses. The reliance on a self-report survey instrument, though validated, also presents a limitation, as it does not fully capture the complexity of AE development as manifested in practice, design behavior, or iterative processes.

Implications

Despite these limitations, the study offers important implications for design education and design curriculum development. The significant improvements in metacognition, personal epistemology, and perspective-taking suggest that contextual learning tasks, particularly those grounded in personal or social relevance, can foster deeper and more flexible forms of expertise in design students. These outcomes challenge traditional pedagogical models that prioritize technical proficiency and product-focused output, emphasizing instead the value of learning environments that promote reflective decision-making, adaptability, and engagement with uncertainty.

Incorporating contextual exercises into foundational design education may better prepare students for the cognitive and ethical demands of contemporary practice, where problems are often ill-structured, wicked, interdisciplinary, and socially embedded. Such pedagogical strategies align with broader calls to develop curricula that support future-proof competencies, such as innovation, critical thinking, and adaptive reasoning. For instructors, this requires a shift toward designing learning experiences that are open-ended yet scaffolded where students are encouraged to explore, interpret, and take intellectual risks in ways that mirror the complexities of real-world design problems.

Future research directions

Building on the results of this study, future research should examine how AE develops longitudinally across multiple courses or throughout an entire design program. Long-term investigations could illuminate whether early exposure to contextual learning exercises leads to more sustained cognitive flexibility and innovation in advanced studio settings or in professional practice. In addition, qualitative approaches such as student interviews, portfolio analysis, and observational studies could complement survey-based data and provide richer insight into how AE manifests in the design process. Future studies might also explore how different types of contextual tasks, such as collaborative versus individual projects, or digital versus physical prototyping, affect specific AE dimensions. Cross-cultural studies would be especially valuable in understanding how educational traditions, cultural values, or institutional norms influence the development of AE. Finally, integrating findings from cognitive science, educational psychology, and design theory could support the creation of more nuanced models of AE development, helping educators design interventions that are both theoretically grounded and pedagogically effective.

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