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Differential Learning Gains in Design Education with Generative AI Tools and Pedagogical Responses

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Abstract: While design production has become more efficient and design results seem to be stronger, this does not prove learning from the use of Generative AI tools. The key question for generative AI's entry into design education is whether students can internalize and integrate external intelligence to make it their own. This study analyzes learning gains in three aspects: cognitive deepening, knowledge internalization and transfer and application, by using literature analysis and theoretical synthesis. It defines three parallel states – performance enhancement, process transformation, and transfer development. Pedagogical responses are suggested in the study that will maintain cognitive engagement, reconstruct knowledge, enable transfer and offer adaptive support. The educational value should not be measured by the speed of generation or by completed artefacts but by the extent to which learners acquire professional capabilities that they can internalise and transfer. Hence, the emphasis of design education is no longer on AI-enhanced performance, but on capability of learners.

Keywords: Keywords: generative artificial intelligence; design education; learning gains

1. Introduction

As China's national strategy for educational digitalization advances, the Opinions on Accelerating the Digitalization of Education, jointly issued by the Ministry of Education and eight other departments, calls for artificial intelligence to be integrated into all elements and processes of education and teaching. It also encourages the exploration of human-AI co-teaching and AI-assisted large-scale personalized instruction, while stressing higher-order thinking, judgment, and practical skills [1]. In this policy context, generative AI in design education is not simply a question of technology adoption. A crucial question to ask when it comes to AI-assisted teaching is whether these tools can lead to genuine and sustainable learning outcomes.

Generative AI is transforming the way learners ideate, explore options, and make design decisions. Beyond the implications of altering production tools, Fleischmann also thinks the impact of AI on design education can be seen in cognitive and pedagogical changes as AI gets more involved in learners' ideation and decision making processes [2]. The use of tools is not a guarantee of learning gains, though. Hwang and Hwang conducted a study with design students and discovered that the use of generative AI significantly enhanced the scores of students' creative works as rated by experts, and students indicated that they had less confidence in their own critical thinking skills [3]. This means that a good artefact does not equate with the development of learning outcomes in learners' cognition.

Cognitive engagement, thinking skills, and knowledge co-creation are shown to mediate the effectiveness of learning in human-AI co-creation research [4]. The use of some AI tools in learning may also be poorly structured, which can foster cognitive offloading, decrease metacognitive involvement, and diminish epistemic agency [5–6]. This means that even students who have access to the same tools can have vastly different outcomes. Some may only improve in efficiency and artifact quality; others may grow in their understanding of design problems and reorganizing their professional knowledge; and still others may be able to develop capabilities that can be transferred across tasks and contexts. So it is important for design education to determine where improvement is found and if it will be integrated in the learner's development.

This study does not focus on difference in tool use, it focuses on differences in learning gains. It explores design learning with generative AI from three perspectives, namely, cognitive deepening, knowledge internalization, and transfer and application. It then identifies typical gain states and suggests pedagogical responses. A key issue with AI-assisted design education is how to differentiate between enhanced outputs and true learning, and how to transform the ease of relying on an external intelligence into sustainable and transferable professional skills that the learner can continue to build.

2. Literature Review

Once generative AI tools become part of design tasks, artifact completion, generation efficiency, and technical fluency alone cannot show what learners have gained. Design learning is an open-ended problem-solving activity, a process of knowledge integration and an iterative development, and meaningful learning should show itself in the own cognitive structures and professional actions of the learners. The empirical study conducted by Pramod indicates that human-AI co-creation has an impact on learning effectiveness that is mediated by cognitive engagement, thinking skills and knowledge co-creation [4]. Vendrell and Johnston also claim that AI's educational potential relies on its capacity to amplify learners' reasoning, evaluation and metacognition [5]. Based on this, this study defines design learning gains as positive changes in learners' understanding, knowledge reconstruction and transfer of learning after the AI intervention, and analyzes it based on three dimensions.

(1) Cognitive Deepening: From Obtaining Results to Understanding Problems

Design learning starts with understanding the problem, users, context and constraints. While generative AI can swiftly deliver information, concepts, and potential solutions, quick generation is not necessarily indicative of deep learning. The cognitive deepening aspect relates to whether learners think more deeply about the problem after AI intervention, resulting in more complete explanations of the problem, deeper understanding of relationships, and more well-founded design reasoning. In this study, Hwang and Hwang identified better creative products and lower self-perception of critical thinking, suggesting that this external generative capacity can enhance the immediate task without an improvement in cognitive involvement of learners [3]. It is therefore important to consider cognitive gains, and assess whether interaction with AI leads to learners being able to identify new problems, revise their understanding of previous problems, and be able to explain their design choices more clearly, rather than the amount or richness of what is produced.

The need to retain some "cognitive friction" in design education also exists. If information searching, problem interpretation and option selection are all substituted by immediate generation, work may appear more efficient but leave less space for comparison, questioning and verification that is essential for the development of thinking. For related research, it is suggested that AI should be used as a temporary thinking partner and that important learning activities like conceptual interpretation, reasoning and evaluation should be maintained [5]. The

first criterion for distinguishing between performance enhancement and learning gains is cognitive deepening.

(2) Knowledge Internalization: From External Support to Professional Understanding

The information and suggestions provided by AI tools are vast and can be provided instantaneously, however, learners need to reorganize, interpret, and validate this information before it becomes a stable professional understanding. The cognitive offloading literature indicates that some cognitive processes are regularly turned over to other tools, and that the effects of doing so depend on what is offloaded, and how offloading interacts with the internal cognitive processes [6]. AI can streamline material search and formal exploration in design learning. However, with design principles, evaluative criteria and solution logic in the system, learners can create quality products without cultivating a structure of professional knowledge.

The knowledge internalization dimension focuses on the extent to which information, methods, and feedback from the human-AI interaction can be translated to design knowledge that can be explained and reproduced independently by learners. The learner should be able to describe why a design solution works, identify and understand the relationship between the generated design content, professional design standards, user needs, and design goals, and reorder the relationships using the language and actions of the learner. Pramod's study shows that learning effectiveness depends upon the cognitive engagement as well as thinking skills in order to co-create the knowledge [4]. This implies that the educational potential of AI lies in the ability to allow the learner to actively build up knowledge from information from outside.

(3) Transfer and Application: From Single Tasks to Cross-context Use

Transfer is also a crucial aspect of the sustainability of learning gains. Transfer is the capacity of a learner to transfer the knowledge, strategies or principles of judgment that he or she has learned to new problems and contexts. Barnett and Ceci's taxonomy of transfer reveals that transfer is multifaceted along content and context dimensions, and transfer is more challenging as the gap between learning and transfer widens [7]. With respect to the design field, good work which relies on a specific tool, prompting regime or a task that has been known and familiar is not necessarily good work that relies on stable professional development, but rather on context dependent task enhancement.

The transfer and application dimension refers to whether students can apply methods of problem analysis, evaluative criteria, and design strategies when the design topic, user context, medium, or AI tool changes. Learners should utilize the effective method/s from a successful workflow and be able to adjust to different constraints, instead of just reproducing it for different situations. In design education, studies have also demonstrated the potential of generative AI to enhance design performance by fostering greater creative exploration and the critical evaluation and refinement of AI-generated content, highlighting ongoing roles for learners in evaluating and developing AI-generated design ideas [2,8]. Transfer is used to assess developmental learning gains as well as improvements for a specific task as a result of using AI.

Groups	Core Focus	Key Indicators	Criterion for Differential Gain
Cognitive Deepening	Whether AI use deepens understanding of the design problem	Problem explanation; relational analysis; design reasoning; formation of rationale	From directly obtaining results to developing new problem understanding and design reasoning
Knowledge Internalization	Whether external information becomes the learner' s own professional understanding	Conceptual reorganization; explanation of reasons; professional verification; method summarization	From dependence on external prompts to independent explanation and reconstruction of knowledge
Transfer and Application	Whether learning can be applied to new design tasks and contexts	Cross-task application; adaptation across tools; strategy transfer; independent completion	From task-specific enhancement to stable capabilities transferable across contexts

2.

There are links between the three dimensions. Through the process of cognitive deepening, it can be ascertained whether meaningful learning has occurred or not. Knowledge internalization indicates whether the external support was internalized by the learner. Transfer and application are evidence that these changes are not confined to the task at hand. The aspects are arranged together as a continuum to determine immediate performance to sustained development and to identify differences in the learning gains that generative AI generates.

3 Research subjects

Cognitive deepening, knowledge internalization, and transfer and application are not necessarily concurrent, but can be mixed in various ways in design tasks. This study summarizes these differences as three typical states of learning gain, keeping technical proficiency separate from learning capability. The states refer to the nature and depth of learning outcomes and not fixed learner groups. Student performance may vary from course to course, task to task and condition to condition.

3.1 Performance Enhancement: Improved Task Performance with Limited Learning Consolidation

The most immediate impact of AI in the performance enhancement state is to accelerate the acquisition of information, formal production, and presentation of solutions, enabling students to create visually complete or content-rich artefacts more rapidly. The output improvement is largely dependent on the immediate capability of the tool, and learners' understanding of the problem, reorganization of the professional knowledge, and application in contexts remains limited. It is plausible that better outputs do not necessarily imply more learning. The results are comparable for design education, where generative AI can enhance expert assessments of creative outputs while not necessarily improving students' self-assessment of critical thinking skills [3]. Performance enhancement is a real but limited outcome, and its main risk is that visible quality can mask insufficient internal learning.

3.2 Process Transformation: Cognitive Deepening with Partial Internalization

In the process transformation state, AI starts to influence the process of problem clarification, solution comparison and knowledge reorganization, not just the time to completion of tasks. The iterative interaction helps learners to refine their own understanding of the design problem, to apply professional judgment to the content they produce, and to

transform some of the feedback they receive into their own design rationale. Learning gains are now from output to cognition and knowledge. However, the transformations might still be related to a specific task or tool setting. If the task type, media specifications or technological environment differs significantly, learners' approach may not be transferred reliably. Teaching at this stage should be used to organize and consolidate cognitive changes already made.

3.3 Transfer Development: Learning Sustained Across Tasks

AI-assisted learning gains carry over to the next task in the transfer development state. Specific interactions provide learners with opportunities to extract methods of problem analysis, design principles, and criteria for assessing alternatives, which are then applied in new design situations. They are able to hold the level of professional performance reasonably steady when the tools are changed or AI support is lessened. Learners can still use AI; what matters is that they have transformed external intelligence into professional capabilities that they can use independent of the AI. Transfer development is a good approximation of the long-term education value targeted by design education and is an indicator of the capability growth facilitated by AI-supported teaching [4,7].

Understanding the use of AI does not explain the differences in design learning gains. The key is what the learner retains after using the tool. Performance enhancement involves performance improvement of the ongoing task, process transformation involves change in cognition and knowledge, and transfer development involves more enduring capability formation. These states collectively represent a continuum of moves from outward evidence of performance to internal growth, and inform educators' decisions about more personalized interventions.

4. Pedagogical Responses to Differential Learning Gains

Generative AI tools are straightforward to use, offer quick turnaround, and frequently generate seemingly finished outputs. Learners, on the other hand, vary in terms of their prior knowledge, their own cognitive regulation and their engagement in the task. The same technological settings thus can result in significantly different learning gains. Task, process and assessment design should take these differences into consideration and aim to go beyond mere performance enhancement and foster cognitive deepening, knowledge internalization, transfer and application.

(1) Preserve Essential Cognitive Engagement to Prevent Performance Enhancement from Replacing Learning

AI can provide a quick output from task requirement and make it visible. It is important to develop a deeper understanding of the problem that students are attempting to solve before having them produce artefacts, as artefacts that are better developed may reflect what the technology has provided rather than what the students have learned. Cognitive activities should be kept for the key design stages to be completed by learners. They may describe their interpretation of the problem and initial hypothesis prior to generation, outline their criteria for comparing alternatives, and document their reasoning after major decisions. These activities should provide a basis for information acquisition and content production that would be rooted in the problem understanding and the design reasoning, without causing unnecessary burden. Vendrell and Johnston claim that maintaining a cognitive friction and using a mixture of AI mediated and AI free phases can help maintain critical thinking and epistemic agency in AI-rich learning environments [5].

(2) Strengthen Knowledge Reconstruction to Transform External Information into Professional Understanding

Teachers need to check if students understand the answers, examples, and revision suggestions that are continuously provided by AI. Learners can rephrase a solution, justifying evidence, reasoning backwards, revising outputs produced and comparing analogous cases. They can explain "why this was adopted," "why this was changed," and "what would change if the conditions were different." These activities ask the learners to structure the information they have just received in context of a professional knowledge structure. For those students with less conceptual understanding, instructors should provide more explicit explanations of key design principles and criteria. Process prompts can also be decreased for learners who already demonstrate stable judgment and will begin to organize information independently and be responsible for explaining why they make the design decisions. Then, the teaching can be changed from providing more answers to helping students reconstruct knowledge.

(3) Adjust Instructional Support and Assessment According to Learning-Gain States

Learning gains are not static over time. If a student is able to make it from performance enhancement to process transformation, the next time the student is asked to perform a more complex task, the student may revert to relying on an outside source to assist them. Instruction should focus on recording these changing states through process records, design discussions, transfer tasks and interim outcomes rather than assigning learners to fixed categories. If learning is primarily at the performance enhancement level, the teacher should probe deeper for explanations of the problem and rationale for the design. Once knowledge reconstruction starts, they can add new context constraints, which are useful for abstraction and transfer. Tasks may be open and professionally more complex for learners with relatively stable transfer. Assessment should monitor current performance of output, change in process, and transfer performance, as opposed to making inferences about learning based on the quality of the end product.

Pedagogical responses to differences in learning gains can be used to maintain cognitive engagement, facilitate knowledge internalization and ensure transfer and application over time. They can support flexible use of AI tools and transform the convenience of immediate technology into professional capabilities for learners to keep, explain, and transfer. AI intervention can be regarded as truly educational if it leaves the learner with relevant design understanding and action, even after the tool is removed, the task changes, or the context shifts.

5. Conclusions

The use of generative AI tools can streamline the design process and make it more efficient, and while these tools can produce impressive results, the use of AI does not necessarily create learning gains. Tool use and human-AI collaboration are not ends in themselves, but are the context for this study, which focuses on changes in learners' own development. It measures design learning gains with regard to three dimensions: cognitive deepening, knowledge internalization, and transfer and application. It also differentiates between three common states: performance enhancement, process transformation and transfer development. These differences provide an explanation for the fact that students with similar technological conditions are able to create artifacts of similar qualities and make learning gains of various natures and extents.

Once AI has been implemented, design education should take into account not just the manner in which students use a tool, but the content that students gain from using a tool. Essential cognitive engagement should be maintained in task design, the learning activities should enable the external information to become professional knowledge, and assessment should apply cross-context tasks to observe whether the learning lasts. The educational value of generative AI depends on the quality of current artifacts and on whether learners develop design

understanding and professional capabilities they can explain, retain, and transfer. These dimensions and pedagogical responses can be tested in the future in concrete design courses, via longitudinal tasks, process data, and transfer assessments.

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