A Survey of Large Language Models in Industrial Design and Innovation Methods

www.surveyx.cn

Abstract

This survey paper presents a comprehensive examination of the transformative role of Large Language Models (LLMs) and generative AI in advancing industrial design and innovation methods. LLMs enhance creativity, decision-making, and efficiency across various domains by generating human-like content and augmenting design processes. Key applications include improving recommendation systems, fostering independent thinking in educational settings, and optimizing energy usage in AI deployment. The integration of LLMs in design processes generates content that parallels human creativity, as exemplified by the LLM-REC model. Educational contexts benefit from LLM-powered conversational agents that stimulate questioning and foster independent thinking. Sustainable practices in generative AI, such as the SPROUT framework, highlight advancements toward environmentally responsible AI deployment. However, challenges remain, including ethical concerns, computational costs, and the potential degradation of model quality due to the interplay with the Internet. The survey underscores the need for culturally aware and sustainable AI models, multilingual advancements, and robust policy frameworks to manage risks and ensure ethical standards. Future research should focus on optimizing training processes and exploring AI integration in diverse creative and educational contexts. The insights from agent-based models and the adaptation of LLMs to user expectations demonstrate the potential of these technologies to serve as collaborative partners, enhancing user engagement and satisfaction across various tasks.

1 Introduction

1.1 Relevance of LLMs in Industrial Design and Innovation

Large Language Models (LLMs) are revolutionizing industrial design and innovation by enhancing creativity, decision-making, and efficiency across various sectors. Their advanced linguistic capabilities facilitate the processing and generation of human-like language, crucial for addressing complex queries and improving knowledge dissemination in manufacturing environments, thus bridging theoretical frameworks with practical applications [1]. Additionally, LLMs play a significant role in integrating Generative AI and Evolutionary Algorithms for large-scale multi-objective optimization, which aids informed decision-making in industrial contexts [2].

By refining analytical narrative structures, LLMs enable designers to extract deeper insights from complex datasets, thereby advancing industrial design methodologies [3]. In technology acceptance, LLMs enhance the generation of human-like responses, essential for understanding user interactions and preferences in design processes [4]. This capability is particularly advantageous in online marketing, where LLMs assist in constructing Marketing-oriented Knowledge Graphs (MoKGs) to optimize campaigns and improve customer engagement.

The diffusion of Generative AI across scientific disciplines illustrates its impact on collaboration patterns and research methodologies [5]. LLMs support co-creativity in design, allowing writers and

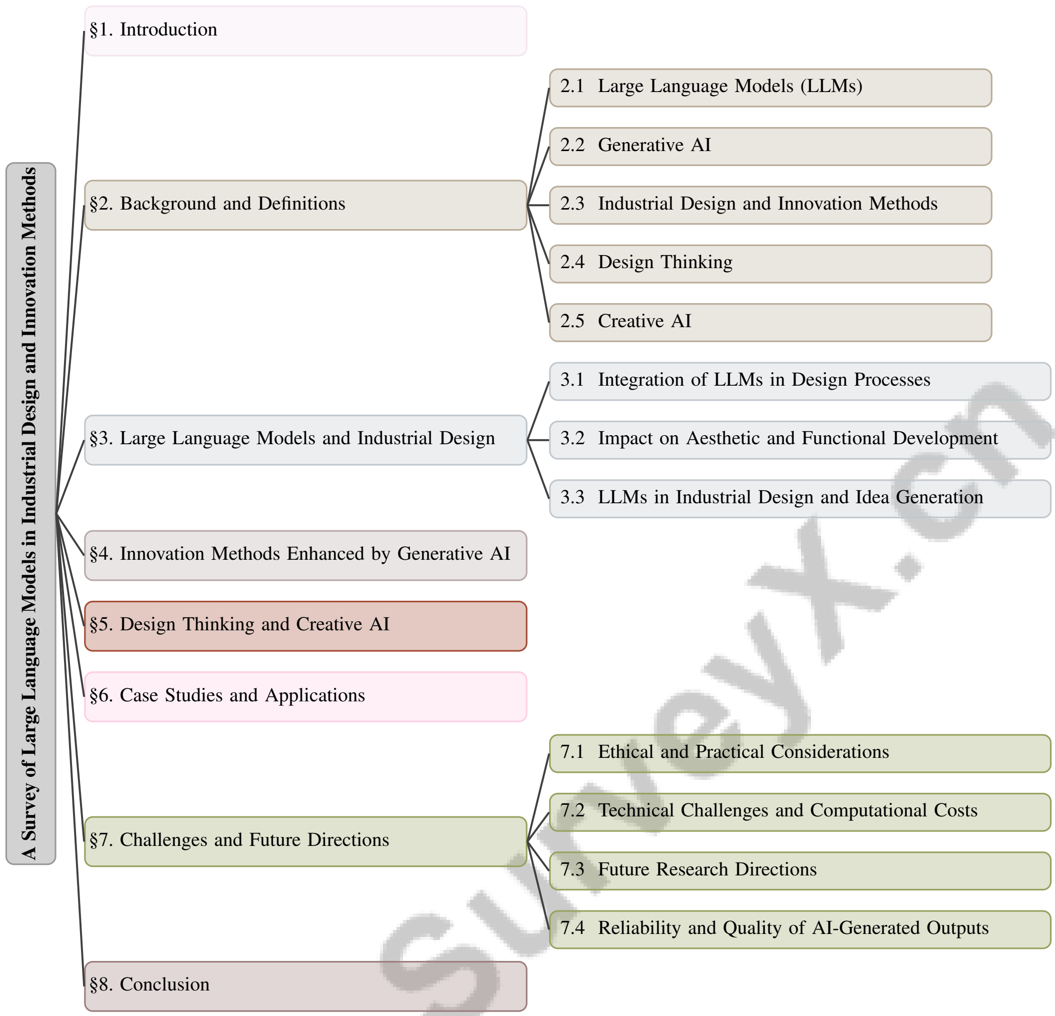

Figure 1: chapter structure

designers to explore new possibilities in story generation and creative content development. Their transformative potential extends to educational contexts, enhancing educator efficiency and enriching learning experiences through Generative AI integration [6].

In social robotics, LLMs present unique ethical challenges and opportunities for improving human-robot interaction, relevant to advancing industrial design and innovation methods. Their capacity to generate complex robot behavior underscores their importance in automation within industrial design, paving the way for future developments. Nonetheless, concerns regarding the trustworthiness of generative AI outputs persist, as LLMs produce results that are plausible but not necessarily accurate [7].

In healthcare, LLMs assist patients in navigating significant information challenges related to complex illnesses, showcasing their versatility in addressing diverse needs [8]. As LLMs evolve, their integration into various tasks has yielded mixed success in accurately modeling human behavior, highlighting the need for ongoing research and development [9]. The development and operation of LLM-based applications require automated workflows to ensure quality and efficiency throughout the application lifecycle, addressing inherent deployment challenges [10]. Understanding the societal impacts of generative AI is vital for advancing industrial design and innovation methods, as these technologies continue to shape social and economic landscapes [11].

The rapid development of LLMs has raised concerns about potential misuse, including misinformation, fraud, and academic dishonesty [12]. Effective moderation of online communities using advanced AI techniques, including LLMs, is essential to mitigate these issues [13]. Moreover, recent

AI-generated, for reference only.

surveys highlight the architectural innovations and training strategies of LLMs, underscoring their growing significance across various applications [14]. Their potential to enhance personalized interventions, such as in behavioral health, further illustrates their importance in advancing industrial design and innovation methods [15]. Understanding user perceptions, as explored in studies like the LLM-based conversational assistant Mango Mango used in cooking tasks, is vital for improving real-world interactions with such systems [16]. Additionally, distinct human-generative AI collaboration types, including student interactions with generative AI for problem-solving, illuminate the evolving dynamics of human-AI collaborations [17]. Investigating children's mental models of AI, as demonstrated with generative AI models like ChatGPT and DALL-E, addresses a critical knowledge gap regarding younger users' understanding and use of AI technologies [18]. Finally, addressing the challenges and risks associated with LLMs for knowledge extraction, particularly in climate action, highlights the limitations and potential societal dangers of relying on generative AI outputs [19].

1.2 Structure of the Survey

This survey is systematically organized to comprehensively explore the role of Large Language Models (LLMs) in industrial design and innovation methods. The introduction discusses the relevance of LLMs in transforming industrial design and innovation through the integration of generative AI, design thinking, and creative AI, highlighting their transformative potential across sectors such as manufacturing, marketing, and education.

Subsequent sections provide a foundational understanding of key concepts, including LLMs, industrial design, innovation methods, generative AI, design thinking, and creative AI, tracing their evolution and contextualizing their application in industrial design.

The third section examines the integration of LLMs into industrial design processes, focusing on their impact on product aesthetic and functional development, as well as their role in idea generation, emphasizing how LLMs enhance creativity and efficiency in design processes.

The fourth section explores innovation methods enhanced by generative AI, emphasizing LLMs' contributions to ideation, production, human-AI collaboration, and educational innovation, underscoring collaborative efforts between humans and AI in creating innovative solutions.

The fifth section analyzes the intersection of design thinking and creative AI, discussing how LLMs support user-centered approaches to problem-solving and innovation while examining implications for creative processes across various fields.

The sixth section presents case studies and real-world applications of LLMs in industrial design and innovation, showcasing successful implementations and lessons learned.

The penultimate section identifies challenges and future directions for integrating LLMs with industrial design and innovation methods, including ethical considerations, technical challenges, and potential research directions.

The conclusion synthesizes primary findings regarding the influence of LLMs on industrial design and innovation methodologies, emphasizing their transformative potential in enhancing feedback mechanisms and personalized recommendations. It also stresses the need for rigorous empirical evaluation and theoretical grounding in future research, offering actionable recommendations for practitioners to effectively integrate LLMs into their design processes and innovation strategies [20, 21, 22].The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Large Language Models (LLMs)

Large Language Models (LLMs) are a pivotal class of AI systems that excel in generating human-like text, utilizing advanced neural architectures such as the Transformer model [14]. With parameters often exceeding 10 billion, LLMs have revolutionized human-computer interaction by producing coherent and contextually relevant text, impacting sectors like education, healthcare, and design. Their development involves extensive pre-training on diverse text corpora to capture linguistic nuances, followed by fine-tuning for specific tasks to enhance applicability across sectors [14].

LLMs facilitate the creation of complex environments, crucial for co-evolutionary algorithms requiring diverse scenarios [17]. They automate coding workflows, enabling parametric model generation without deep programming expertise, although challenges in manual, trial-and-error processes of LLM-based application development remain, affecting scalability and quality [14].

In educational contexts, LLMs provide personalized feedback and interactive content, enriching learning experiences, though their performance on standardized tests like the GMAT remains under scrutiny [15]. They play a key role in moderating online interactions, ensuring safe digital communication [14]. However, the reliability of LLM outputs is often questioned due to challenges in complex reasoning and world dynamics understanding, which can lead to unreliable outputs [19].

The ethical implications of LLMs, especially when integrated with social robotics, raise concerns about misinformation, emotional disruption, and biases, exacerbated by the physical embodiment of these technologies [18]. Addressing these ethical challenges is crucial for responsibly leveraging LLMs across applications [14]. Additionally, prompt literacy has emerged as a vital skill for effective interaction with generative AI systems, underscoring the need for user competency development in this area [14].

2.2 Generative AI

Generative AI comprises technologies that autonomously produce new content, challenging traditional creativity and aesthetics. Key models include Generative Adversarial Networks (GANs), Transformers, Variational Autoencoders, and Diffusion Models, enhancing AI's creative capabilities [11]. These advancements expand user engagement in content creation, reshaping human-AI collaboration dynamics [18]. However, generative AI often synthesizes outputs from existing data, limiting its capacity for genuine novelty [19].

In design, generative AI broadens the design space and refines evaluation processes, particularly in interactive systems. It optimizes product design phases, facilitating innovative solutions in architectural design through text and image generation [12]. Its impact extends to construction, where it is applied across design, planning, procurement, and maintenance stages. In education, generative AI automates creativity and enhances feedback on human-written texts, fostering students' writing skills and enabling personalized learning experiences [23, 24, 25, 26, 27]. However, developing critical competencies regarding generative AI remains a challenge.

In marketing, generative AI transforms storytelling, influencing consumer experiences and strategies. It impacts training datasets for AI models, raising considerations about AI-generated data implications. The diverse generative AI technologies introduce complex copyright issues related to authorship and fair use, alongside AI safety concerns, including bias, toxicity, and misinformation, necessitating a predictive framework to understand these implications [11].

As generative AI technology advances, its applications in design and innovation are expected to broaden significantly, unlocking new avenues for creativity and problem-solving across fields. This expansion is driven by generative AI's ability to generate contextually relevant ideas and solutions, enhancing the creative process while addressing challenges such as bias and accuracy. Generative AI's role across disciplines—from language generation and image translation to scientific research—demonstrates its potential to facilitate collaboration and innovation. By integrating user preferences and domain-specific insights, generative AI can produce content that balances novelty and usefulness, redefining our approach to creativity and knowledge development in an interconnected world [28, 5, 29, 30, 31]. The nuanced dynamics of human-AI interactions in tasks like academic and creative writing highlight the need for ongoing research to fully understand and harness these technologies.

2.3 Industrial Design and Innovation Methods

Industrial design is an interdisciplinary practice focusing on the aesthetic and functional development of products to enhance user experience, usability, and marketability. It integrates form and function, necessitating a deep understanding of materials, manufacturing processes, and consumer behavior to drive effective innovation. Central to industrial design are feedback mechanisms, classified into expert-created models leveraging established design principles, data-driven models utilizing empirical data for design decisions, and LLM-based approaches harnessing Large Language Models for personalized,

AI-generated, for reference only.

context-aware feedback, thus enhancing the design process through adaptive interactions and enriched recommendations [32, 21, 22]. These mechanisms ensure products meet aesthetic and functional standards while aligning with user needs.

Innovation methods in industrial design often involve iterative processes incorporating user feedback, prototyping, and testing. The emergence of LLMs and generative AI has transformed natural language processing, significantly enhancing creativity and efficiency across domains by leveraging advanced algorithms and vast datasets to produce human-like text and multimodal content. These technologies enhance applications in content generation, translation, and summarization while presenting challenges that necessitate responsible integration and ongoing research to address ethical concerns and improve detection methods for generated content [14, 33, 12, 34, 35]. Generative AI tools influence thinking processes and agency, distinguishing between human-led and AI-led interactions, essential for understanding how AI can augment human creativity and problem-solving.

The integration of LLMs in industrial design addresses traditional automation systems' limitations, which often exhibit rigidity and inability to adapt to unforeseen changes. By incorporating LLMs, dynamic decision-making processes can be established, allowing for flexible and adaptive design strategies. However, challenges remain in optimizing LLMs for industrial applications, including substantial computational resources required for training and complexities in resource management to ensure effective model performance [14].

Generative AI's role in product design is marked by the challenge of balancing inspiration with efficiency. Its integration into creative processes enhances innovative expression potential while optimizing workflow efficiency, allowing writers and creators to explore diverse ideas and receive constructive feedback, enriching creative output while reducing revision time [36, 37, 3, 30, 38]. However, generative AI's application in augmented reality has been limited by the lack of comprehensive design frameworks, restricting its full potential exploration. Additionally, generative AI's use in fields like ship hull design addresses inefficiencies and the time-consuming nature of traditional methods, showcasing its potential to revolutionize design practices through computational algorithms.

The complexity of decision-making policies and environments in industrial design is compounded by high-dimensional state spaces and continuous interactions, complicating critical scenario predictions. These challenges underscore the need for advanced AI systems capable of navigating complex design landscapes. The integration of LLMs in robot action planning highlights the significant design costs associated with generating accurate robot instructions, as these models often require detailed inputs to mitigate ambiguity and information gaps. Innovative methods such as interactive planning, enabling LLMs to seek clarification from humans, have been proposed to reduce these costs, demonstrating the need for cost-effective solutions in leveraging LLMs for precise robotic instruction generation while navigating human-robot interaction complexities [39, 40, 41, 42].

2.4 Design Thinking

Design thinking is a user-centered methodology emphasizing empathy, ideation, and experimentation to address complex problems and foster innovation. This approach integrates user needs into the design process, creating solutions that are both functional and aesthetically pleasing. The iterative nature of design thinking involves continuous prototyping and testing, allowing designers to refine ideas based on user feedback and evolving requirements, which is crucial for adapting to dynamic user demands and ensuring solution relevance [43].

Incorporating LLMs and generative AI into design thinking processes significantly enhances the ability to generate and evaluate creative solutions. By leveraging LLM capabilities, designers can engage in reflective dialogues that foster user engagement and commitment, as demonstrated by platforms like Gradschool.chat, which highlight the importance of reflective dialogue in research contexts [44]. This approach aids in developing innovative solutions and enhancing user experience personalization by reducing cognitive load and improving task management [45].

Interface design plays a critical role in generative AI tools, impacting user prompting behavior and creativity. Different interface designs can either facilitate or hinder the creative process, underscoring the importance of designing interfaces that support effective user interaction and creativity in design thinking applications [46]. Additionally, using virtual agents powered by LLMs to simulate systems models of creativity allows for exploring creativity in social contexts, offering insights into collaborative creative processes [47].

In educational settings, applying design thinking principles through generative AI tools enhances personalized learning experiences. Frameworks categorizing generative AI applications into learning strategies, paths, teaching materials, and environments interact with personalized learning to offer tailored educational experiences [48]. This underscores design thinking's potential to transform educational practices by integrating user-centered design principles with advanced AI technologies.

Design thinking remains pivotal in fostering innovation and creativity across fields. Integrating LLMs and generative AI into these processes enhances the ability to generate novel solutions while ensuring alignment with user needs. As these technologies evolve, they are expected to enrich the design thinking paradigm further, offering new opportunities for innovation and user-centered design. The development of prompt literacy, as explored in recent studies, emphasizes its role in enhancing communication and cognitive development, further supporting generative AI integration in design thinking [49].

2.5 Creative AI

Creative AI represents a transformative frontier in artificial intelligence, where machines are not merely tools but active participants in the creative process, significantly impacting innovation across various domains. Integrating AI into creative workflows challenges traditional notions of authorship and creativity by introducing co-creativity dynamics between humans and machines [50]. This shift is particularly evident in screenwriting, where frameworks proposing LLM roles of Writer, Editor, and Actors collaboratively enhance creative output, demonstrating AI's potential to elevate creativity and content quality [37].

AI's role in creativity varies with task complexity and the type of human capital involved, highlighting the nuanced interplay between AI capabilities and human expertise [51]. In construction, generative AI significantly enhances productivity, quality, and safety, illustrating its potential to revolutionize traditional processes through innovative applications [52]. Such advancements emphasize balancing AI assistance benefits in creative tasks with associated risks concerning productivity, creativity, and accountability [53].

AI's ability to generate high-quality content and augment datasets is crucial in scenarios with scarce real data, offering solutions that drive innovation and overcome data limitations [54]. However, detecting machine-generated content is essential for maintaining innovation integrity, as highlighted by benchmarks focusing on distinguishing between human and AI-generated outputs [55]. These benchmarks introduce novel loss terms to enhance model performance on numerical survey questions, a feature often overlooked in existing benchmarks [9].

Despite its transformative potential, Creative AI presents challenges, such as the risk of dependency on AI systems, which could stifle human creativity if not managed carefully. This concern is compounded by AI's potential to provide culturally inappropriate or generic advice, impacting its role in creative processes [56]. Ethical considerations, including the emotional and mental health impacts of interactions with LLM-based systems, complicate AI integration into creative domains [57]. Key challenges include ethical concerns regarding narrative manipulation, the quality and accuracy of data used in AI models, and the need for skilled professionals to implement these technologies effectively [58].

As Creative AI evolves, it offers new opportunities for innovation while presenting significant challenges that must be addressed to ensure ethical and effective integration into creative processes. The development of frameworks like PAIR, emphasizing adaptive filtering and progressive prompting, illustrates efforts to enhance controlled and relevant knowledge extraction, supporting nuanced and effective creative applications [59]. A primary challenge identified is the potential overreliance on ChatGPT, which may hinder students' development of critical thinking and decision-making skills [17].

In recent years, the role of Large Language Models (LLMs) in various fields has garnered significant attention, particularly in industrial design. This integration not only influences creativity and efficiency but also enhances both aesthetic and functional development. As illustrated in Figure 2, the figure highlights the impact of LLMs on idea generation, showcasing a hierarchical structure that categorizes key methods and frameworks. These frameworks are essential for optimizing design processes, facilitating automation, and fostering innovative ideas through the synergy of human and

AI collaboration. Such an approach underscores the transformative potential of LLMs in enhancing the design landscape.

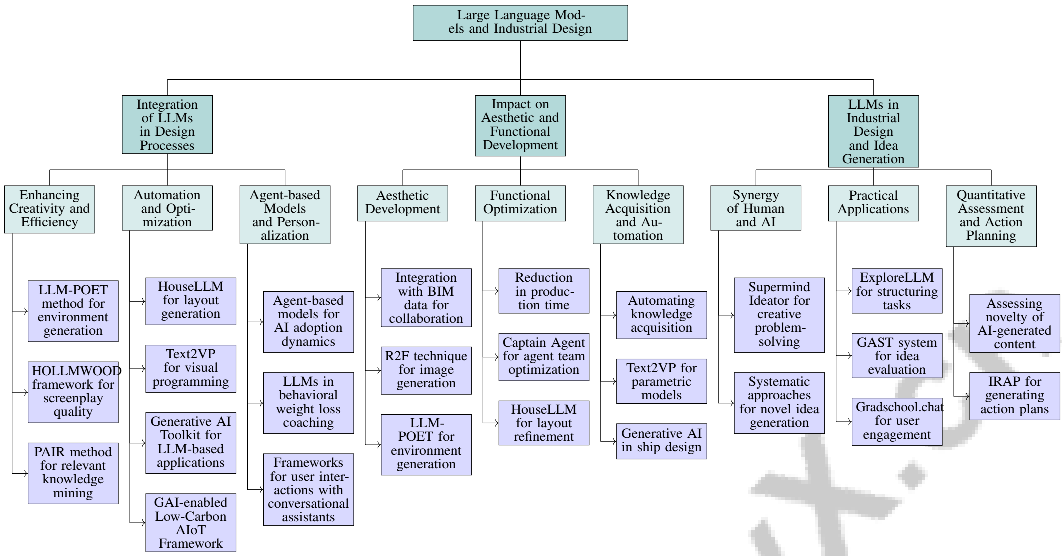

Figure 2: This figure illustrates the integration of Large Language Models (LLMs) in industrial design, highlighting their impact on creativity, efficiency, aesthetic and functional development, and idea generation. The hierarchical structure categorizes key methods and frameworks that enhance design processes, optimize automation, and foster innovative idea generation through the synergy of human and AI collaboration.

3 Large Language Models and Industrial Design

3.1 Integration of LLMs in Design Processes

Integrating Large Language Models (LLMs) into design processes is transforming industrial design by enhancing creativity and operational efficiency. LLMs facilitate design stages from ideation to execution by generating contextually relevant outputs, thereby improving the precision and relevance of design elements. The LLM-POET method exemplifies this transformation through environment generation and mutation, significantly enhancing creativity and efficiency in design workflows [60]. Frameworks like HOLLMWOOD simulate human screenwriting processes to improve screenplay quality [37], while the PAIR method ensures the relevance and accuracy of mined knowledge, crucial for informed design decision-making [59].

In interactive design, HouseLLM generates initial layouts from natural language specifications, enhancing creativity and efficiency [61]. Text2VP automates visual programming workflow generation by interpreting user intentions and coding them into C# scripts, illustrating LLMs' role in automating complex design tasks [62]. The Generative AI Toolkit streamlines the development, testing, monitoring, and optimization of LLM-based applications, showcasing LLMs' ability to enhance creativity and operational efficiency through automation [10]. Furthermore, the GAI-enabled Low-Carbon AIoT Framework integrates Generative AI techniques to optimize energy usage and minimize carbon emissions, highlighting the environmental benefits of LLMs in design frameworks [63]. Benchmarks evaluating generative models' influence on user prompting behavior and task performance further underscore LLMs' role in enhancing design processes [64].

As illustrated in Figure 3, the integration of LLMs in design processes is categorized into key themes: enhancing creativity, improving operational efficiency, and providing environmental benefits. This figure highlights various methods and frameworks that showcase the transformative potential of LLMs across diverse design applications. Agent-based models simulating generative AI adoption dynamics enhance creativity and efficiency in design by predicting interactions within socio-economic systems [11]. Studies examining LLMs like ChatGPT in behavioral weight loss coaching demonstrate their potential to enhance personalization and effectiveness in messaging [15]. Additionally, frameworks categorizing user interactions with LLM-based conversational assistants provide insights into refining design processes [16].

The continuous evolution of LLMs in design processes highlights their transformative potential in driving innovation and improving outcomes across industries. As generative AI models develop, their integration into design processes is expected to broaden, creating innovative avenues for enhancing creativity and operational efficiency. Automated systems that translate academic research into accessible design cards can inspire designers more effectively than traditional papers. By balancing novelty and usefulness in AI-generated content, these models can facilitate a more adaptive approach to creativity, reshaping workplace dynamics and the valuation of skills in creative tasks. This integration streamlines workflows and democratizes access to creative tools while presenting challenges related to cognitive inequalities and expertise in the AI era [65, 37, 51, 26, 31].

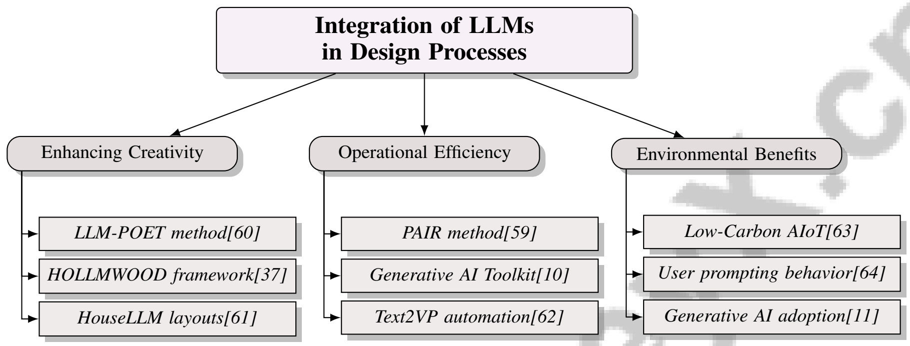

Figure 3: This figure illustrates the integration of Large Language Models (LLMs) in design processes, highlighting their role in enhancing creativity, operational efficiency, and providing environmental benefits. Key methods and frameworks are categorized under these themes, showcasing the transformative potential of LLMs across various design applications.

3.2 Impact on Aesthetic and Functional Development

The incorporation of Large Language Models (LLMs) into product design processes significantly influences both aesthetic and functional aspects, fostering new paradigms for creativity and efficiency. LLMs automate complex design tasks, allowing designers to concentrate on innovation. For instance, the seamless integration of Building Information Modeling (BIM) data with AI insights enhances real-time collaboration and improves design workflows compared to traditional methods [66].

Aesthetic development benefits from LLMs' capability to generate designs with compositional accuracy. Techniques such as R2F, which maps rare concepts to frequent alternatives, improve image generation, ensuring alignment and coherence in product design [67]. Benchmarks addressing the generation of 3D shapes with strict parametric controls further highlight LLMs' role in maintaining aesthetic integrity in industrial applications [68]. The LLM-POET method enhances aesthetic and functional development by generating environments through natural language descriptions, improving co-evolutionary processes [60].

Functionally, LLMs optimize design processes by reducing production time and enhancing problem-solving efficiency. Systems integrating LLMs have demonstrated significant reductions in production time, outperforming human developers with average production times of 119.10 minutes compared to 528.64 minutes for humans [69]. Adaptive systems like Captain Agent optimize agent teams for specific tasks, improving problem-solving efficiency in design [70]. The HouseLLM method refines generated layouts using a conditional diffusion model, ensuring final designs closely align with user specifications [61].

Moreover, LLMs automate knowledge acquisition and content-centric design processes, systematically learning multiword expressions through formal ontological representations [71]. This capability ensures design elements are contextually relevant and aligned with user needs. The Text2VP innovation exemplifies this by generating parametric models interactively through AI-generated scripts, significantly enhancing workflow automation [62].

The effectiveness of generative AI in ship design, integrating multidisciplinary optimization objectives and exploring broader design spaces, underscores LLMs' transformative impact on aesthetic and functional development [72]. A nuanced critique of generative AI outputs and their influence on aesthetic judgment further illustrates the complex interplay between AI-generated content and human perception [50].

3.3 LLMs in Industrial Design and Idea Generation

Large Language Models (LLMs) are pivotal in generating new design ideas and concepts, blending human creativity with AI capabilities. The Supermind Ideator exemplifies this synergy by enhancing creative problem-solving across domains, demonstrating LLMs' ability to facilitate innovative idea generation through human and AI collaboration [73]. Systematic approaches analyzing qualitative data enable LLMs to contribute significantly to novel design idea generation, providing designers with robust frameworks for conceptual exploration [26].

In practical applications, LLMs like ExploreLLM assist users in structuring complex tasks and personalizing interactions, leading to more satisfying experiences than traditional chatbots [45]. This capability is crucial in design contexts where personalized interactions yield more effective design solutions. The Generate And Search Test (GAST) system illustrates how LLMs enable individuals to efficiently generate and evaluate solutions, democratizing the ideation process and enhancing creative tool accessibility [30].

The integration of LLMs in interactive systems, such as Gradschool.chat, emphasizes their potential to engage users in discussions about their research interests, fostering greater satisfaction and engagement [44]. This engagement reflects LLMs' broader potential to support collaborative ideation processes, merging user input with AI-generated suggestions for innovative outcomes.

Moreover, LLMs' ability to quantitatively assess the novelty of AI-generated content enhances understanding of its creative potential, as demonstrated by proposed approaches in assessing true innovation [74]. This quantitative assessment is vital for validating the originality of design concepts and ensuring AI-generated ideas contribute meaningfully to the design process.

In action planning, methods like Interactively Robot Action Planning (IRAP) highlight LLMs' role in generating action plans that clarify ambiguous instructions through active questioning [39]. This capability is particularly valuable in industrial design, where precise communication of design intentions is essential for successful implementation.

Large Language Models significantly enhance the generation of innovative design ideas and concepts by providing systematic analytical frameworks that leverage advanced reasoning capabilities, facilitating personalized interactions through tailored prompts, and offering efficient tools for ideation and evaluation. This integration fosters a comprehensive understanding of user preferences and diverse perspectives in design processes [75, 41, 21, 22]. As these models evolve, their integration into design processes promises to expand the horizons of creativity and innovation in industrial design.

4 Innovation Methods Enhanced by Generative AI

4.1 Generative AI in Ideation and Production

Generative AI, particularly through Large Language Models (LLMs), is revolutionizing ideation and production by enhancing creativity and operational efficiency across various domains. Systems like Text2VP democratize design tools by automating visual programming workflows, enabling users to create parametric models without deep programming skills [62]. In healthcare, generative AI personalizes coaching messages, boosting engagement in interventions like weight loss programs [15], while in culinary arts, LLMs assist in crafting new recipes through personalized guidance [16].

Integrating explicit knowledge and reasoning capabilities in generative AI enhances explainability and auditability, crucial for trustworthiness in production environments [7]. However, challenges remain, such as addressing common LLM errors like incomplete answers and hallucinations, which a structured framework can help assess [19].

Generative AI-driven storytelling enhances marketing by crafting personalized narratives that resonate with audiences, showcasing innovative marketing potential [58]. Agent-based models predicting

AI-generated, for reference only.

generative AI's societal impact further elucidate its broader implications on education, skills, and employment [11].

4.2 Human-AI Collaboration in Innovation

The integration of LLMs and generative AI into creative processes has significantly advanced human-AI collaboration in innovation. In software development, AI-powered code reviews enhance quality and efficiency by offering automated insights [76]. A framework categorizes generative AI tools into interaction levels: Digital Pen, AI Task Specialist, AI Assistant, and AI Co-Creator, illustrating AI's evolving roles from basic tools to sophisticated collaborators [77]. The Prompt Sapper system exemplifies this by enabling non-technical users to develop AI services via natural language prompts, fostering inclusivity [78].

In education, AI enhances writing productivity and confidence in structured tasks, like argumentative essays, supporting creativity through structured guidance [53]. A survey categorizes human-generative AI collaboration into three types— even contribution, human leads, and AI leads—offering insights into student interactions with AI in problem-solving [17].

To illustrate the hierarchical structure of Human-AI collaboration in innovation, Figure 4 highlights key areas such as software development, education, and innovation potential. Each category showcases specific examples of AI's integration and impact, emphasizing the transformative and synergistic roles of AI in enhancing creativity and problem-solving.

Human-AI collaboration in developing innovative products underscores AI's transformative potential, enhancing creativity and problem-solving while generating diverse ideas and contextual solutions. As AI systems evolve, their roles in innovation are expected to expand, offering new opportunities for creativity and efficiency across domains [77, 30, 79, 17].

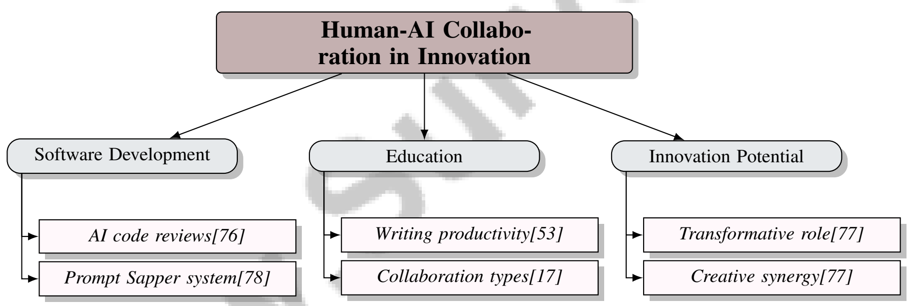

Figure 4: This figure illustrates the hierarchical structure of Human-AI collaboration in innovation, highlighting key areas such as software development, education, and innovation potential. Each category showcases specific examples of AI's integration and impact, emphasizing the transformative and synergistic roles of AI in enhancing creativity and problem-solving.

4.3 Educational Innovation through Generative AI

Generative AI, particularly via LLMs, is revolutionizing educational innovation, significantly impacting student engagement, motivation, and learning outcomes. Tools like TheTeacher.AI, an AI chatbot for teacher support, exemplify AI's role in enhancing professional development in low-resource settings, democratizing quality education access [80].

Generative AI's educational application is further illustrated by tools like Feedback Copilot, which enhances student feedback quality, thereby improving learning outcomes and engagement [6]. This personalization of educational experiences is a key transformative aspect of AI in education [48].

Hybrid models combining human and AI feedback highlight pedagogical implications across diverse contexts, suggesting future exploration avenues [25]. Such models are vital for understanding AI's role in complementing traditional teaching methods and enhancing educational frameworks.

The Ryelands AI Lab curriculum demonstrates how generative AI technologies cultivate critical competencies in students, preparing them for careers in an evolving technological landscape [81]. This underscores the importance of integrating AI literacy into educational programs.

Generative AI's impact on educational practices offers new avenues for innovation and personalization in learning. As research continues to explore AI's capabilities and implications in education, these technologies' potential to transform traditional models and enhance student experiences becomes increasingly evident [23].

5 Design Thinking and Creative AI

The integration of design thinking and creative AI marks a significant evolution in innovation methodologies. As design paradigms advance through AI, particularly with Large Language Models (LLMs), it is crucial to assess their role within user-centered design frameworks. This integration not only enhances creativity but also aligns design outcomes with user needs, fostering inclusivity. The following subsection examines LLMs in user-centered design, highlighting their ability to generate innovative solutions and facilitate meaningful interactions.

5.1 LLMs in User-Centered Design

LLMs significantly enhance user-centered design by generating novel ideas and solutions, expanding creative possibilities for designers. These models offer diverse insights that stimulate exploration, helping designers overcome cognitive barriers [6]. The Feedback Copilot method exemplifies how LLMs assist educators in delivering personalized feedback, aligning design processes with user preferences [6].

LLMs also enhance user-centered moderation through advanced language comprehension, ensuring effective interactions that meet user expectations [13]. This capability is crucial for maintaining a user-centric focus in communication-reliant environments. In educational contexts, LLM-facilitated interactions promote engaging, mentor-like conversations, enhancing active learning and personalizing educational experiences [17]. Positive interactions correlate with a sense of agency, while negative agency impacts collaborative problem-solving [17].

By employing innovative tools, LLMs foster creativity, personalization, and engagement in user-centered design. Techniques like text enrichment for tailored recommendations and role-playing enhance questioning skills among novice designers. Leveraging LLMs' commonsense knowledge and reasoning enables design teams to create feedback and solutions that resonate with users, leading to more effective and empathetic outcomes [32, 21, 22]. As LLMs evolve, their integration into user-centered design frameworks is poised to transform problem-solving and innovation approaches.

5.2 Collaborative Creativity with AI

Integrating AI into collaborative creativity enhances synergies between human creativity and machine intelligence. Generative AI systems actively participate in creative processes, from digital tools assisting human creativity to AI co-creators with autonomous capabilities. AI democratizes access to creative tools, reshapes human capital dynamics, and emphasizes a shift from specialized expertise to broader cognitive adaptability. AI enriches the creative process by generating diverse solutions, while human oversight ensures contextual understanding [77, 30, 51].

In fields like screenwriting, AI systems such as HOLLMWOOD integrate LLMs to simulate human creative processes, enhancing output quality and originality [37]. AI complements human creativity, offering new opportunities for storytelling and content production. AI-powered tools like the Prompt Sapper enable non-technical users to engage in creative processes via natural language interactions, democratizing AI-driven innovation and fostering inclusivity [78]. This democratization expands the creative potential of individuals and teams, allowing them to leverage AI capabilities without specialized technical skills.

In educational contexts, AI enhances collaborative creativity by improving learning experiences and student engagement. Tools offering structured guidance and feedback help students develop creative skills, promoting a collaborative learning environment where AI acts as both mentor and partner [53]. This model aligns with pedagogical principles emphasizing active learning and personalized education, highlighting AI's potential to transform traditional educational practices.

The classification of human-generative AI collaboration into categories such as even contribution, human-led, and AI-led provides a framework for understanding diverse ways AI augments human creativity [17]. Balancing human and machine inputs ensures AI complements rather than replaces human creativity. AI's role in collaborative creativity is transformative, offering new avenues for innovation across various fields. As AI systems advance, their integration into creative workflows revolutionizes collaboration between human ingenuity and machine intelligence, enhancing creativity across interaction levels—from AI as a task specialist to a co-creator—and driving innovative solutions and creative content. Generative AI actively contributes to creativity, producing novel outcomes while augmenting human cognitive abilities, though it raises concerns about cognitive inequalities, shifting creative advantage from specialized expertise to broader skill sets. Combining AI's generative capabilities with traceable information fosters a more effective knowledge development environment, enhancing human-AI collaboration and yielding richer and more diverse creative outputs [77, 30, 51].

5.3 LLMs in Creative Problem-Solving and User Interaction

LLMs are powerful tools for creative problem-solving and enhancing user interaction, leveraging advanced linguistic capabilities. In creative domains, LLMs generate novel ideas and solutions by providing diverse, contextually relevant suggestions that help overcome cognitive barriers and expand the creative potential of designers and problem solvers [37]. Their ability to simulate human-like dialogue and produce creative content enhances their role as co-creators across various fields, fostering more dynamic and interactive creative processes [17].

As illustrated in Figure 5, the role of LLMs in enhancing creative problem-solving and user interaction encompasses key aspects such as novel idea generation, personalized user experiences, and educational applications. This visual representation underscores the multifaceted contributions of LLMs in these areas.

In user interaction, LLMs significantly improve the quality and personalization of experiences. By interpreting and responding to natural language inputs, LLMs facilitate intuitive and engaging interactions, crucial in applications ranging from customer service to educational platforms [16]. Integrating LLMs into interactive systems allows for personalized content and interactions, ensuring user needs are met with precision and relevance [53].

Furthermore, LLMs enhance problem-solving efficiency by automating complex tasks and providing real-time feedback, essential in environments requiring rapid decision-making [62]. This capability is particularly valuable in educational settings, where LLMs support personalized learning by offering tailored guidance and feedback, fostering a more engaging and effective learning environment [6].

The integration of LLMs in creative problem-solving and user interaction highlights their transformative potential in enhancing creativity, efficiency, and personalization across various domains. As generative AI models like ChatGPT advance, their applications in addressing complex challenges and improving user engagement are expected to expand significantly. This evolution presents new opportunities for innovation while necessitating careful consideration of implications in various fields, especially in higher education, where they can assist students and reshape institutional policies. By leveraging natural language processing techniques, these models can analyze student work, identify key themes, and support educators in refining curricula and evaluation methods, ultimately transforming the educational landscape [26, 30, 82].

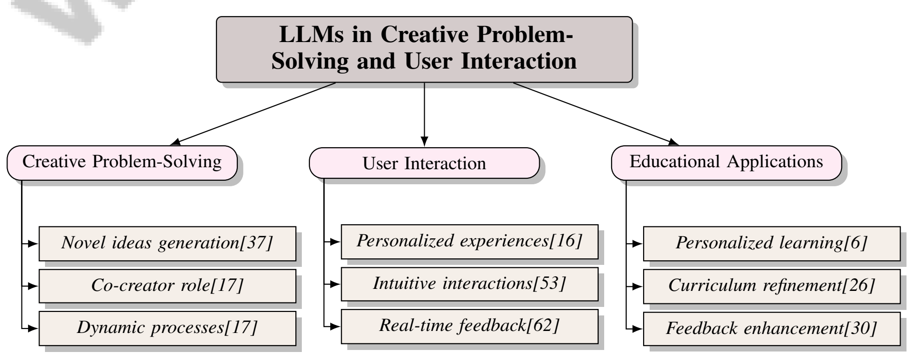

Figure 5: This figure illustrates the role of LLMs in enhancing creative problem-solving and user interaction, highlighting key aspects such as novel idea generation, personalized user experiences, and educational applications.

6 Case Studies and Applications

The examination of generative AI's application across sectors like education, design, manufacturing, and software development reveals its transformative potential. In education, it personalizes learning and reshapes traditional models, while in design and manufacturing, it boosts productivity and fosters innovation [83, 30, 24, 25]. These sectors illustrate the diverse application of generative AI, especially in optimizing production processes and nurturing creativity in design and manufacturing.

6.1 Generative AI in Design and Manufacturing

Generative AI is revolutionizing design and manufacturing by offering innovative solutions and optimizing workflows. It has been instrumental in developing marketing strategies for brands like Starbucks and iPhone, demonstrating frameworks such as PRR that enhance creativity and efficiency beyond traditional methods [28]. The integration of text and image generation tools in design emphasizes prompt specificity and acknowledges the limitations of generative models [84], enhancing both aesthetic and functional design aspects.

The rise of multi-modal generative AI systems highlights the need for unified frameworks to fully exploit these technologies [85]. Future developments in multi-modal systems promise to integrate text, image, and sound, offering comprehensive solutions in design and manufacturing contexts.

Generative AI's application in these fields is paving the way for creative, efficient, and adaptable practices. Its transformative capabilities are reshaping paradigms in sectors like healthcare, education, and scientific research, as evidenced by advancements in language generation and personalized learning. The expanding literature on generative AI underscores its growing influence across disciplines, highlighting its role in collaborative efforts and educational outcomes [5, 29, 24].

6.2 LLMs in Educational and Creative Applications

Large Language Models (LLMs) significantly enhance educational and creative domains by providing innovative solutions for learning and creative outputs. Automated feedback systems efficiently manage feedback volumes but highlight the need for context-specific AI applications [86]. Benchmarks like MUGC demonstrate LLMs' ability to generate high-quality creative content [55], showcasing their versatility in educational and creative pursuits.

The integration of LLMs in augmented reality (AR), explored through the AIGC+AR prototype, opens new design spaces for creative expression, allowing qualitative comparisons of AI-generated content in AR settings [87]. Synthetic data generated by LLMs addresses data scarcity and sensitivity issues, particularly beneficial in educational contexts requiring diverse datasets [88].

In business education, LLMs like GPT-4 Turbo excel in standardized tests, indicating their potential to revolutionize educational assessment [89]. Experiences from LLM-focused courses show enhanced student engagement, suggesting that LLM integration fosters dynamic learning environments [90].

The application of LLMs in educational and creative settings underscores their potential to transform traditional practices, offering scalable, personalized, and innovative solutions. As Generative Artificial Intelligence (GAI) models like ChatGPT gain traction, their influence on education and creativity is expected to grow, presenting new opportunities for innovation and engagement in higher education while necessitating robust policy development and curriculum adaptation [82, 24].

6.3 Generative AI in Software Development and Programming

Generative AI is significantly impacting software development and programming by enhancing productivity, creativity, and efficiency. AI models like LLMs automate code generation and refactoring, accelerating development cycles and reducing errors [76]. Frameworks like Prompt Sapper democratize software creation by enabling non-technical users to engage with AI-driven services via natural language prompts [78].

AI-powered code review systems use LLMs to provide automated insights and suggestions, improving software production efficacy [77]. These systems enhance collaboration through real-time feedback, crucial for maintaining high code quality standards.

Generative AI also enhances Integrated Development Environments (IDEs) by offering intelligent code completion and debugging assistance, streamlining the development process [53]. The integration of generative AI in software development reshapes traditional methodologies, introducing tools that boost productivity, foster creativity, and improve developer collaboration. Research indicates these AI-driven tools streamline processes and influence cognitive approaches in programming, leading to efficient workflows and enriched creative outputs. The convergence of generative AI with existing technologies underscores its transformative role, encouraging new collaborative thinking in software development [83, 91, 30, 92, 93]. As these technologies advance, their integration into development processes promises further field revolution, offering new opportunities for innovation and efficiency.

7 Challenges and Future Directions

The integration of Large Language Models (LLMs) and Artificial Intelligence (AI) across various domains presents numerous ethical and practical challenges that merit careful consideration. These challenges not only shape the operational frameworks of LLMs but also influence their broader implications, particularly in creative and educational contexts. The following subsections will explore specific ethical dilemmas and practical challenges arising from these technologies, underscoring the need for innovative strategies to navigate this evolving landscape.

7.1 Ethical and Practical Considerations

The deployment of LLMs and AI in design processes introduces significant ethical and practical challenges. A primary concern is the potential for AI-generated content to perpetuate biases present in training data, leading to skewed narratives and undermining the authenticity of creative outputs [58]. Ensuring data quality and accountability in AI outputs is crucial, necessitating robust evaluation frameworks to assess their reliability [11].

Ethical considerations also extend to online community moderation, where AI systems must address biases from training datasets. Developing ethical moderation practices that emphasize fairness and transparency is essential to prevent the reinforcement of existing biases [13]. Moreover, the reliance on specific models and datasets in benchmarks for detecting AI-generated content limits the generalizability of these tools across different LLMs and languages [12].

Practically, integrating LLMs into educational settings poses challenges related to student engagement and effective AI tool utilization. Research indicates low engagement with AI chatbots in non-LLM-related courses, highlighting barriers to their integration and the need for improved design strategies [90]. Additionally, the personalization required in automated messaging systems, such as coaching applications, emphasizes the necessity of tailoring AI interactions to individual user needs [15].

Managing information overload and facilitating meaningful dialogues with AI assistants further illustrate practical difficulties in ensuring effective user interactions [16]. Furthermore, understanding how children conceptualize AI is vital for designing effective tools for younger users, necessitating further research to bridge existing knowledge gaps [18].

Addressing these ethical and practical challenges necessitates the establishment of clear guidelines prioritizing user control, authorship rights, and ethical AI use. Current studies highlight inherent inaccuracies in LLM outputs, including hallucinations and the lack of verifiable references, which undermine trust in AI-generated information [19]. Future research should focus on enhancing students' understanding of generative AI, mitigating overreliance, and refining AI tool design to support learning and agency. Strategies to address hallucinations and biased outputs in LLMs are essential for ensuring the reliability of AI-generated solutions [14].

7.2 Technical Challenges and Computational Costs

The deployment of LLMs is accompanied by significant technical challenges and computational costs critical for their effective application. A primary challenge is the vast computational resources required for training these models, often comprising billions of parameters and necessitating extensive hardware capabilities [14]. This requirement poses scalability barriers, as the necessary infrastructure is not universally accessible, limiting LLM adoption.

Fine-tuning LLMs, essential for task-specific adaptations, further exacerbates computational demands. This process requires substantial computational power and sophisticated techniques to maintain model performance [14]. Such complexity presents hurdles for researchers and practitioners aiming to leverage LLMs in specialized applications.

The environmental impact of training and deploying LLMs is increasingly concerning, as energy consumption contributes to a substantial carbon footprint. The urgency for sustainable AI practices is prompting calls for energy-efficient training methods and alternative approaches to minimize environmental impacts [14].

Real-time performance and latency issues also pose challenges, particularly in applications requiring immediate responses. Latency in processing large models can hinder effectiveness in dynamic environments, necessitating ongoing research into optimization techniques to enhance LLM speed and responsiveness [14].

7.3 Future Research Directions

Future research in LLM integration within design and innovation should prioritize several key areas to enhance their effectiveness across diverse domains. Developing culturally aware LLMs that incorporate therapeutic principles can inform innovation methods and support personalized user interactions [56]. Exploring AI's integration in various creative domains and developing solutions that accommodate writers' needs for agency and control is crucial for expanding AI applicability [36].

Investigating synthetic data applications remains a promising avenue, with future studies focusing on effective strategies for ensuring data quality, addressing ethical concerns, and exploring emerging trends in synthetic data [88]. Enhancing the entity expansion process to be more controllable and explainable, potentially through metapath-oriented techniques, is another important research area [59].

Optimizing training processes for Generative AI models and exploring carbon trading mechanisms are vital for reducing AI's environmental impact [63]. Additionally, research should examine Generative AI's evolving role in scientific methodologies, its influence on team dynamics, and ethical challenges in its application [5].

Developing robust frameworks for Multimodal LLM (MLLM) integration and exploring their implications across disciplines, while ensuring ethical considerations are prioritized, is critical for future research [94]. Refining LLM fine-tuning processes to improve output accuracy is also proposed for future exploration [60].

Investigating the evolution of prompting strategies with new generative models can yield valuable insights into LLM integration in design and innovation processes [64]. Exploring the implementation of LLM-based social robots in diverse real-world settings and conducting longitudinal studies to understand ethical implications is essential for advancing responsible AI use [57].

Enhancing models' learning capabilities from user interactions and refining methods to reduce errors in complex scenarios are critical for improving LLM applicability in real-world contexts [62]. Future research should also explore additional pedagogical frameworks to enhance educational tools like Feedback Copilot across various contexts [6]. Integrating LLMs with traditional teaching methods and exploring their applications in broader educational contexts present further research opportunities [89].

Moreover, developing robust fairness metrics, enhancing human-AI collaboration in storytelling, and exploring cultural nuances in AI applications are essential future research areas [58]. Investigating GigaCheck's application across different languages and LLMs, along with improvements in handling longer texts and enhancing detection method robustness, is another area for exploration [12]. Furthermore, retraining models with datasets from various metaverse experiences is crucial for validating the generalizability of findings [13].

Future research should also focus on developing tailored LLM experiences, exploring integration with IDEs, and assessing LLM impacts on student learning and engagement [90]. Efficient training methods, ethical implications of LLMs, and enhancing generalization across diverse tasks are vital areas for future exploration [14]. Optimizing AI prompts and evaluating the long-term effectiveness of AI-generated coaching messages through randomized controlled trials are also important directions [15].

Finally, future research should investigate LLMs' generalization to unseen behavioral scenarios and improve individual-level predictions [9]. Enhancing LLMs' understanding of colloquial language, improving user guidance on system capabilities, and exploring the potential for LLMs to act as proactive partners in task completion are critical exploration areas [16]. Additionally, focusing on larger, more diverse samples and examining how children's perceptions of AI evolve over time is vital for advancing responsible AI technologies [18].

Exploring these research directions will significantly enhance our understanding of LLM capabilities and their transformative potential across various fields. By integrating insights from Artificial Intelligence in Education (AIED) and personalized recommendation systems, we can develop more effective, theory-driven approaches to LLM applications. This will ensure responsible and effective integration of AI technologies into design and innovation, ultimately improving learning outcomes and the quality of personalized recommendations. Careful application of empirical evidence and theoretical frameworks will refine feedback mechanisms in educational settings and optimize recommendation systems, maximizing the impact of LLMs across multiple domains [21, 22].

7.4 Reliability and Quality of AI-Generated Outputs

Benchmark	Size	Domain	Task Format	Metric
AES-GER[95]	20	Education	Essay Evaluation	Spearman's r, ICC
LLM-ED[96]	116	Engineering Design	Prototyping	Distance Fired, Rank
LLM-EVAL[97]	100	Education	Text Evaluation	Grammaticality, Fluency
3D-PreMise[68]	57	Industrial Design	3D Shape Generation	Chamfer Distance, Similarity Distance
MEGA[98]	1,000	Natural Language Processing	Classification	Accuracy, F1-score
VSD-AI[99]	685	Augmentative And Alternative Communication	Communication Option Generation	Quality, Relevance
LLM-MB[1]	20	Manufacturing	Question Answering	Factuality, Completeness
MUGC[55]	53,440	Literature	Text Classification	Accuracy, F1-Score

Table 1: Table summarizing various benchmarks used to evaluate AI-generated outputs across different domains, including their respective sizes, task formats, and evaluation metrics. The table provides a comprehensive overview of the diversity in AI evaluation methods, highlighting the importance of domain-specific approaches to ensure reliability and quality in AI applications.

The reliability and quality of AI-generated outputs remain critical concerns influencing the adoption of AI technologies across various domains. A primary challenge is the consistency of AI outputs, which, while generally reliable, often lack the personalized and context-aware nuances characteristic of human-generated content [25]. This limitation underscores the need for improved guidance in selecting and integrating AI tools to enhance output quality [93]. Table 1 presents a detailed summary of benchmarks utilized in assessing the reliability and quality of AI-generated outputs, emphasizing the need for diverse evaluation methods across different domains.

The interplay between fair use and AI copyrightability introduces complexities affecting AI technology development and the economic dynamics of creator income and consumer welfare [100]. Regulatory environments can yield varying outcomes, impacting the consistency and applicability of AI-generated content in creative fields.

In higher education, while institutions actively incorporate Generative AI (GAI) into their frameworks, significant gaps remain in policy development and communication strategies. A structured approach to stakeholder engagement is necessary to ensure that AI-generated outputs meet the quality and reliability standards required by educational institutions [101].

Addressing these concerns involves establishing robust frameworks and guidelines prioritizing accuracy, consistency, and personalization of AI outputs. As AI technologies advance, sustained research and development initiatives are crucial for enhancing the reliability and quality of AI-generated content. This enhancement is vital for the effective and responsible integration of these technologies into a wide range of applications, including education, creative writing, and problem-solving. Generative AI, particularly through large language models, shows promise in generating contextually relevant outputs and providing scalable feedback, yet it raises important ethical considerations regarding accountability, inclusivity, and the preservation of human creativity. Ongoing efforts must focus on

AI-generated, for reference only.

combining the innovative potential of generative AI with robust mechanisms for traceability and human oversight to ensure these systems meet diverse user needs while maintaining high quality and ethical standards [79, 86, 53, 29, 30].

8 Conclusion

Large Language Models (LLMs) and generative AI are pivotal in reshaping industrial design and innovation by enhancing creativity, efficiency, and decision-making across diverse domains. The LLM-REC model exemplifies this potential by advancing recommendation systems with precise and relevant text generation, thus refining design processes. In educational contexts, LLM-driven conversational agents have proven effective in fostering inquiry and promoting independent thinking, signaling the need for further exploration to fully harness their capabilities. Additionally, sustainable AI practices, such as the SPROUT framework, demonstrate significant reductions in carbon emissions while maintaining high-quality outputs, marking progress towards environmentally responsible AI deployment.

The integration of generative AI into traditional systems, as evidenced by the LB-KBQA system, has notably improved the accuracy and efficiency of knowledge-based question-answering in both academic and industrial settings. However, challenges remain, particularly concerning the interaction between generative AI and the Internet, which can affect model quality and diversity, highlighting the need for careful management of training data. Ethical considerations are paramount; educators must critically assess AI outputs and cultivate environments that promote responsible technology use. Moreover, the performance gap between generative models for high-resource and low-resource languages underscores the urgency for advancements in multilingual AI.

While the survey expresses optimism about the benefits of generative AI, it also acknowledges concerns about potential misuse and emphasizes the importance of robust policy frameworks. The recognition of Multilingual Large Language Models (MLLMs) as valuable tools for enhancing engagement and providing adaptive support in science education further illustrates the transformative impact of these technologies.

AI-generated, for reference only.

References

[1] Samuel Kernan Freire, Chaofan Wang, Mina Foosherian, Stefan Wellsandt, Santiago Ruiz-Arenas, and Evangelos Niforatos. Knowledge sharing in manufacturing using large language models: User evaluation and model benchmarking, 2024.

[2] Gaurav Singh and Kavitesh Kumar Bali. Enhancing decision-making in optimization through llm-assisted inference: A neural networks perspective, 2024.

[3] Vidya Setlur and Larry Birnbaum. Can nuanced language lead to more actionable insights? exploring the role of generative ai in analytical narrative structure, 2024.

[4] Hitesh Mohapatra and Soumya Ranjan Mishra. Exploring ai tool's versatile responses: An in-depth analysis across different industries and its performance evaluation, 2023.

[5] Liangping Ding, Cornelia Lawson, and Philip Shapira. Rise of generative artificial intelligence in science, 2024.

[6] Stanislav Pozdniakov, Jonathan Brazil, Solmaz Abdi, Aneesha Bakharia, Shazia Sadiq, Dragan Gasevic, Paul Denny, and Hassan Khosravi. Large language models meet user interfaces: The case of provisioning feedback, 2024.

[7] Doug Lenat and Gary Marcus. Getting from generative ai to trustworthy ai: What llms might learn from cyc, 2023.

[8] Shreya Rajagopal, Jae Ho Sohn, Hari Subramonyam, and Shiwali Mohan. Can generative ai support patients' caregivers' informational needs? towards task-centric evaluation of ai systems, 2025.

[9] Keiichi Namikoshi, Alex Filipowicz, David A. Shamma, Rumen Iliev, Candice L. Hogan, and Nikos Arechiga. Using llms to model the beliefs and preferences of targeted populations, 2024.

[10] Jens Kohl, Luisa Gloger, Rui Costa, Otto Kruse, Manuel P. Luitz, David Katz, Gonzalo Barbeito, Markus Schweier, Ryan French, Jonas Schroeder, Thomas Riedl, Raphael Perri, and Youssef Mostafa. Generative ai toolkit – a framework for increasing the quality of llm-based applications over their whole life cycle, 2024.

[11] Joao Tiago Aparicio, Manuela Aparicio, Sofia Aparicio, and Carlos J. Costa. Predicting the impact of generative ai using an agent-based model, 2024.

[12] Irina Tolstykh, Aleksandra Tsybina, Sergey Yakubson, Aleksandr Gordeev, Vladimir Dokholyan, and Maksim Kuprashevich. Gigacheck: Detecting llm-generated content, 2024.

[13] Henrik Axelsen, Johannes Rude Jensen, Sebastian Axelsen, Valdemar Licht, and Omri Ross. Can ai moderate online communities?, 2023.

[14] Humza Naveed, Asad Ullah Khan, Shi Qiu, Muhammad Saqib, Saeed Anwar, Muhammad Usman, Naveed Akhtar, Nick Barnes, and Ajmal Mian. A comprehensive overview of large language models. *arXiv preprint arXiv:2307.06435*, 2023.

[15] Zhuoran Huang, Michael P. Berry, Christina Chwyl, Gary Hsieh, Jing Wei, and Evan M. Forman. Comparing large language model ai and human-generated coaching messages for behavioral weight loss, 2025.

[16] Szeyi Chan, Jiachen Li, Bingsheng Yao, Amama Mahmood, Chien-Ming Huang, Holly Jimison, Elizabeth D Mynatt, and Dakuo Wang. "mango mango, how to let the lettuce dry without a spinner?": Exploring user perceptions of using an llm-based conversational assistant toward cooking partner, 2023.

[17] Gaoxia Zhu, Vidya Sudarshan, Jason Fok Kow, and Yew Soon Ong. Human-generative ai collaborative problem solving who leads and how students perceive the interactions, 2024.

[18] Eliza Kosoy, Soojin Jeong, Anoop Sinha, Alison Gopnik, and Tanya Kraljic. Children's mental models of generative visual and text based ai models, 2024.

[19] Denis Havlik and Marcelo Pias. Common errors in generative ai systems used for knowledge extraction in the climate action domain, 2024.

[20] Adrian de Wynter. Awes, laws, and flaws from today's llm research, 2024.

[21] John Stamper, Ruiwei Xiao, and Xinying Hou. Enhancing llm-based feedback: Insights from intelligent tutoring systems and the learning sciences, 2024.

[22] Hanjia Lyu, Song Jiang, Hanqing Zeng, Yinglong Xia, Qifan Wang, Si Zhang, Ren Chen, Christopher Leung, Jiajie Tang, and Jiebo Luo. Llm-rec: Personalized recommendation via prompting large language models. *arXiv preprint arXiv:2307.15780*, 2023.

[23] Rania Abdelghani, Hélène Sauzéon, and Pierre-Yves Oudeyer. Generative ai in the classroom: Can students remain active learners?, 2023.

[24] Stephen Elbourn. The impact of generative ai on student churn and the future of formal education, 2024.

[25] Anastasia Olga, Tzirides, Akash Saini, Gabriela Zapata, Duane Searsmith, Bill Cope, Mary Kalantzis, Vania Castro, Theodora Kourkoulou, John Jones, Rodrigo Abrantes da Silva, Jen Whiting, and Nikoleta Polyxeni Kastania. Generative ai: Implications and applications for education, 2023.

[26] Andrew Katz, Umair Shakir, and Ben Chambers. The utility of large language models and generative ai for education research, 2023.

[27] Maria J. Molina, Amy McGovern, Jhayron S. Perez-Carrasquilla, and Robin L. Tanamachi. Using generative artificial intelligence creatively in the classroom: Examples and lessons learned, 2024.

[28] Ming-Hui Huang and Roland T. Rust. Automating creativity, 2024.

[29] Sandeep Singh Sengar, Affan Bin Hasan, Sanjay Kumar, and Fiona Carroll. Generative artificial intelligence: A systematic review and applications, 2024.

[30] Ted Selker. Ai for the generation and testing of ideas towards an ai supported knowledge development environment, 2023.

[31] Anirban Mukherjee and Hannah Chang. The creative frontier of generative ai: Managing the novelty-usefulness tradeoff, 2023.

[32] Hyunseung Lim, Dasom Choi, and Hwajung Hong. Identify design problems through questioning: Exploring role-playing interactions with large language models to foster design questioning skills, 2024.

[33] Chunhe Ni, Jiang Wu, Hongbo Wang, Wenran Lu, and Chenwei Zhang. Enhancing cloud-based large language model processing with elasticsearch and transformer models, 2024.

[34] Desta Haileselassie Hagos, Rick Battle, and Danda B. Rawat. Recent advances in generative ai and large language models: Current status, challenges, and perspectives, 2024.

[35] Yingqing He, Zhaoyang Liu, Jingye Chen, Zeyue Tian, Hongyu Liu, Xiaowei Chi, Runtao Liu, Ruibin Yuan, Yazhou Xing, Wenhai Wang, Jifeng Dai, Yong Zhang, Wei Xue, Qifeng Liu, Yike Guo, and Qifeng Chen. Llms meet multimodal generation and editing: A survey, 2024.

[36] Morteza Behrooz, Yuandong Tian, William Ngan, Yael Yungster, Justin Wong, and David Zax. Holding the line: A study of writers' attitudes on co-creativity with ai, 2024.

[37] Jing Chen, Xinyu Zhu, Cheng Yang, Chufan Shi, Yadong Xi, Yuxiang Zhang, Junjie Wang, Jiashu Pu, Rongsheng Zhang, Yujiu Yang, and Tian Feng. Hollmwood: Unleashing the creativity of large language models in screenwriting via role playing, 2024.

[38] Gionnieve Lim and Simon T. Perrault. Rapid aideation: Generating ideas with the self and in collaboration with large language models, 2024.

[39] Kazuki Hori, Kanata Suzuki, and Tetsuya Ogata. Interactively robot action planning with uncertainty analysis and active questioning by large language model, 2023.

[40] Artem Lykov and Dzmitry Tsetserukou. Llm-brain: Ai-driven fast generation of robot behaviour tree based on large language model, 2023.

[41] Bhashithe Abeysinghe and Ruhan Circi. The challenges of evaluating llm applications: An analysis of automated, human, and llm-based approaches, 2024.

[42] Callie Y. Kim, Christine P. Lee, and Bilge Mutlu. Understanding large-language model (llm)-powered human-robot interaction, 2024.

[43] Hari Subramonyam, Divy Thakkar, Jürgen Dieber, and Anoop Sinha. Content-centric prototyping of generative ai applications: Emerging approaches and challenges in collaborative software teams, 2024.

[44] Soya Park, Hari Subramonyam, and Chinmay Kulkarni. Thinking assistants: Llm-based conversational assistants that help users think by asking rather than answering, 2024.

[45] Xiao Ma, Swaroop Mishra, Ariel Liu, Sophie Su, Jilin Chen, Chinmay Kulkarni, Heng-Tze Cheng, Quoc Le, and Ed Chi. Beyond chatbots: Explorellm for structured thoughts and personalized model responses, 2023.

[46] Maddalena Torricelli, Mauro Martino, Andrea Baronchelli, and Luca Maria Aiello. The role of interface design on prompt-mediated creativity in generative ai, 2024.

[47] Naomi Imasato, Kazuki Miyazawa, Takayuki Nagai, and Takato Horii. Creative agents: Simulating the systems model of creativity with generative agents, 2024.

[48] Yuang Wei, Yuan-Hao Jiang, Jiayi Liu, Changyong Qi, Linzhao Jia, and Rui Jia. The advancement of personalized learning potentially accelerated by generative ai, 2025.

[49] Yohan Hwang, Jang Ho Lee, and Dongkwang Shin. What is prompt literacy? an exploratory study of language learners' development of new literacy skill using generative ai, 2023.

[50] Jessica Hullman, Ari Holtzman, and Andrew Gelman. Artificial intelligence and aesthetic judgment, 2023.

[51] Meiling Huang, Ming Jin, and Ning Li. Augmenting minds or automating skills: The differential role of human capital in generative ai's impact on creative tasks, 2024.

[52] Ridwan Taiwo, Idris Temitope Bello, Sulemana Fatoama Abdulai, Abdul-Mugis Yussif, Babatunde Abiodun Salami, Abdullahi Saka, and Tarek Zayed. Generative ai in the construction industry: A state-of-the-art analysis, 2024.

[53] Zhuoyan Li, Chen Liang, Jing Peng, and Ming Yin. The value, benefits, and concerns of generative ai-powered assistance in writing, 2024.

[54] Paulius Jurcys and Mark Fenwick. Originality and the future of copyright in an age of generative ai, 2023.

[55] Yaqi Xie, Anjali Rawal, Yujing Cen, Dixuan Zhao, Sunil K Narang, and Shanu Sushmita. Mugc: Machine generated versus user generated content detection, 2024.

[56] Inhwa Song, Sachin R. Pendse, Neha Kumar, and Munmun De Choudhury. The typing cure: Experiences with large language model chatbots for mental health support, 2024.

[57] Alva Markelius. An empirical design justice approach to identifying ethical considerations in the intersection of large language models and social robotics, 2024.

[58] Marko Vidrih and Shiva Mayahi. Generative ai-driven storytelling: A new era for marketing, 2023.

[59] Chunjing Gan, Dan Yang, Binbin Hu, Ziqi Liu, Yue Shen, Zhiqiang Zhang, Jinjie Gu, Jun Zhou, and Guannan Zhang. Making large language models better knowledge miners for online marketing with progressive prompting augmentation, 2023.

[60] Fuma Aki, Riku Ikeda, Takumi Saito, Ciaran Regan, and Mizuki Oka. Llm-poet: Evolving complex environments using large language models, 2024.

[61] Ziyang Zong, Zhaohuan Zhan, and Guang Tan. Housellm: Llm-assisted two-phase text-to-floorplan generation, 2024.

[62] Guangxi Feng and Wei Yan. Text2vp: Generative ai for visual programming and parametric modeling, 2024.

[63] Jinbo Wen, Ruichen Zhang, Dusit Niyato, Jiawen Kang, Hongyang Du, Yang Zhang, and Zhu Han. Generative ai for low-carbon artificial intelligence of things with large language models, 2024.

[64] Eaman Jahani, Benjamin S. Manning, Joe Zhang, Hong-Yi TuYe, Mohammed Alsobay, Christos Nicolaides, Siddharth Suri, and David Holtz. As generative models improve, we must adapt our prompts, 2024.

[65] Donghoon Shin, Lucy Lu Wang, and Gary Hsieh. From paper to card: Transforming design implications with generative ai, 2024.

[66] Suhyung Jang and Ghang Lee. Interactive design by integrating a large pre-trained language model and building information modeling, 2023.

[67] Dongmin Park, Sebin Kim, Taehong Moon, Minkyu Kim, Kangwook Lee, and Jaewoong Cho. Rare-to-frequent: Unlocking compositional generation power of diffusion models on rare concepts with llm guidance, 2025.

[68] Zeqing Yuan, Haoxuan Lan, Qiang Zou, and Junbo Zhao. 3d-premise: Can large language models generate 3d shapes with sharp features and parametric control?, 2024.

[69] Artem Lykov, Miguel Altamirano Cabrera, Mikhail Konenkov, Valerii Serpiva, Koffivi Fid'ele Gbagbe, Ali Alabbas, Aleksey Fedoseev, Luis Moreno, Muhammad Haris Khan, Ziang Guo, and Dzmitry Tsetserukou. Industry 6.0: New generation of industry driven by generative ai and swarm of heterogeneous robots, 2024.

[70] Linxin Song, Jiale Liu, Jieyu Zhang, Shaokun Zhang, Ao Luo, Shijian Wang, Qingyun Wu, and Chi Wang. Adaptive in-conversation team building for language model agents, 2024.

[71] Sanjay Oruganti, Sergei Nirenburg, Jesse English, and Marjorie McShane. Automating knowledge acquisition for content-centric cognitive agents using llms, 2023.

[72] Sahil Thakur, Navneet V Saxena, and Prof Sitikantha Roy. Generative ai in ship design, 2024.

[73] Steven R. Rick, Gianni Giacomelli, Haoran Wen, Robert J. Laubacher, Nancy Taubenslag, Jennifer L. Heyman, Max Sina Knicker, Younes Jeddi, Hendrik Maier, Stephen Dwyer, Pranav Ragupathy, and Thomas W. Malone. Supermind ideator: Exploring generative ai to support creative problem-solving, 2023.

[74] Anirban Mukherjee. Psittacines of innovation? assessing the true novelty of ai creations, 2024.

[75] Toru Ishida, Tongxi Liu, Hailong Wang, and William K. Cheunga. Facilitating holistic evaluations with llms: Insights from scenario-based experiments, 2024.

[76] Zeeshan Rasheed, Malik Abdul Sami, Muhammad Waseem, Kai-Kristian Kemell, Xiaofeng Wang, Anh Nguyen, Kari Systä, and Pekka Abrahamsson. Ai-powered code review with llms: Early results, 2024.

[77] Jennifer Haase and Sebastian Pokutta. Human-ai co-creativity: Exploring synergies across levels of creative collaboration, 2024.

[78] Zhenchang Xing, Qing Huang, Yu Cheng, Liming Zhu, Qinghua Lu, and Xiwei Xu. Prompt sapper: Llm-empowered software engineering infrastructure for ai-native services, 2023.

[79] Yueqi Xie, Tao Qi, Jingwei Yi, Xiyuan Yang, Ryan Whalen, Junming Huang, Qian Ding, Yu Xie, Xing Xie, and Fangzhao Wu. Measuring human contribution in ai-assisted content generation, 2025.

[80] Jun Ho Choi, Oliver Garrod, Paul Atherton, Andrew Joyce-Gibbons, Miriam Mason-Sesay, and Daniel Björkegren. Are llms useful in the poorest schools? theteacher.ai in sierra leone, 2024.

[81] Jesse Josua Benjamin, Joseph Lindley, Elizabeth Edwards, Elisa Rubegni, Tim Korjakow, David Grist, and Rhiannon Sharkey. Responding to generative ai technologies with research-through-design: The ryelands ai lab as an exploratory study, 2024.

[82] Stefanie Krause, Bhumi Hitesh Panchal, and Nikhil Ubhe. The evolution of learning: Assessing the transformative impact of generative ai on higher education, 2024.

[83] Mariana Coutinho, Lorena Marques, Anderson Santos, Marcio Dahia, Cesar Franca, and Ronnie de Souza Santos. The role of generative ai in software development productivity: A pilot case study, 2024.

[84] Joern Ploennigs and Markus Berger. Generative ai and the history of architecture, 2023.

[85] Hong Chen, Xin Wang, Yuwei Zhou, Bin Huang, Yipeng Zhang, Wei Feng, Houlun Chen, Zeyang Zhang, Siao Tang, and Wenwu Zhu. Multi-modal generative ai: Multi-modal llm, diffusion and beyond, 2024.

[86] Euan D Lindsay, Mike Zhang, Aditya Johri, and Johannes Bjerva. The responsible development of automated student feedback with generative ai, 2025.

[87] Yongquan Hu, Dawen Zhang, Mingyue Yuan, Kaiqi Xian, Don Samitha Elvitigala, June Kim, Gelareh Mohammadi, Zhenchang Xing, Xiwei Xu, and Aaron Quigley. Investigating the design considerations for integrating text-to-image generative ai within augmented reality environments, 2024.

[88] Xu Guo and Yiqiang Chen. Generative ai for synthetic data generation: Methods, challenges and the future, 2024.

[89] Vahid Ashrafimoghari, Necdet Gürkan, and Jordan W. Suchow. Evaluating large language models on the gmat: Implications for the future of business education, 2024.

[90] Arto Hellas, Juho Leinonen, and Leo Leppänen. Experiences from integrating large language model chatbots into the classroom, 2024.

[91] Victoria Jackson, Bogdan Vasilescu, Daniel Russo, Paul Ralph, Maliheh Izadi, Rafael Prikladnicki, Sarah D'Angelo, Sarah Inman, Anielle Lisboa, and Andre van der Hoek. Creativity, generative ai, and software development: A research agenda, 2024.

[92] Tianlong Zhong, Gaoxia Zhu, Kang You Lim, and Yew Soon Ong. Generative ai as a tool or leader? exploring ai-augmented thinking in student programming tasks, 2024.

[93] Ryan Yen, Nicole Sultanum, and Jian Zhao. To search or to gen? exploring the synergy between generative ai and web search in programming, 2024.

[94] Arne Bewersdorff, Christian Hartmann, Marie Hornberger, Kathrin Seßler, Maria Bannert, Enkelejda Kasneci, Gjergji Kasneci, Xiaoming Zhai, and Claudia Nerdel. Taking the next step with generative artificial intelligence: The transformative role of multimodal large language models in science education, 2024.

[95] Kathrin Seßler, Maurice Fürstenberg, Babette Bühler, and Enkelejda Kasneci. Can ai grade your essays? a comparative analysis of large language models and teacher ratings in multidimensional essay scoring, 2024.

[96] Daniel Nygård Ege, Henrik H. Øvrebø, Vegar Stubberud, Martin Francis Berg, Christer Elverum, Martin Steinert, and Håvard Vestad. Chatgpt as an inventor: Eliciting the strengths and weaknesses of current large language models against humans in engineering design, 2024.

[97] Seungyoon Kim and Seungone Kim. Can language models evaluate human written text? case study on korean student writing for education, 2024.

[98] Kabir Ahuja, Harshita Diddee, Rishav Hada, Millicent Ochieng, Krithika Ramesh, Prachi Jain, Akshay Nambi, Tanuja Ganu, Sameer Segal, Maxamed Axmed, Kalika Bali, and Sunayana Sitaram. Mega: Multilingual evaluation of generative ai, 2023.

[99] Cynthia Zastudil, Christine Holyfield, Christine Kapp, Xandria Crosland, Elizabeth Lorah, Tara Zimmerman, and Stephen MacNeil. Exploring the use of generative ai to support automated just-in-time programming for visual scene displays, 2024.

[100] S. Alex Yang and Angela Huyue Zhang. Generative ai and copyright: A dynamic perspective, 2024.

[101] Yueqiao Jin, Lixiang Yan, Vanessa Echeverria, Dragan Gašević, and Roberto Martinez-Maldonado. Generative ai in higher education: A global perspective of institutional adoption policies and guidelines, 2024.

AI-generated, for reference only.

Disclaimer:

SurveyX is an AI-powered system designed to automate the generation of surveys. While it aims to produce high-quality, coherent, and comprehensive surveys with accurate citations, the final output is derived from the AI's synthesis of pre-processed materials, which may contain limitations or inaccuracies. As such, the generated content should not be used for academic publication or formal submissions and must be independently reviewed and verified. The developers of SurveyX do not assume responsibility for any errors or consequences arising from the use of the generated surveys.

AI-generated, for reference only.