AI Literacy and Use in Adolescent Development: A Survey

Abstract

This survey paper explores the critical role of AI literacy and responsible AI use in adolescent development, emphasizing the integration of AI competencies into educational frameworks. It highlights the importance of digital literacy in fostering innovation and supporting diverse fields, including healthcare and education. The paper examines feedback loops and their impact on learning, underscoring the need for adaptive strategies to enhance educational outcomes. It identifies challenges in teaching AI concepts, such as the lack of consensus on AI literacy definitions and resource constraints. The survey also reviews methodologies and findings from longitudinal studies, offering insights into the dynamic impact of AI on developmental outcomes. Ethical considerations and equitable access are discussed, emphasizing the need for transparent and inclusive practices. Future research directions focus on expanding AI literacy competencies, refining assessment tools, and developing adaptable curricula. Recommendations for educators and policymakers include fostering interdisciplinary learning and integrating ethical frameworks into AI education. By addressing these challenges and opportunities, the paper aims to prepare adolescents for an AI-driven future, promoting informed and responsible engagement with AI technologies.

1 Introduction

1.1 AI Literacy and Adolescent Development

AI literacy has become essential for adolescents navigating a world increasingly influenced by artificial intelligence technologies [1]. Understanding both the technical and societal implications of AI systems is crucial in educational settings, where it enables students to critically engage with AI's societal impacts [2, 3]. The adolescent developmental phase, marked by significant cognitive and social growth, is an opportune time to cultivate AI literacy [4]. Integrating AI literacy into curricula fosters critical thinking and ethical reasoning, preparing adolescents for responsible interactions with AI technologies [5, 6].

Equipped with AI literacy, adolescents can better assess the fairness and trustworthiness of AI systems, vital for navigating AI-driven environments [7]. This inclusion not only enhances engagement with AI technologies but also encourages consideration of their ethical dimensions [8]. A holistic approach is necessary for developing a generation capable of leveraging AI innovatively and responsibly [9]. Furthermore, AI literacy is critical for sustainable teacher education, emphasizing the need for educators to understand and teach AI responsibly [10]. Addressing the AI literacy gap in K-12 education requires effective design guidelines for AI learning experiences [11], ensuring that adolescents engage with AI ethically and informatively, thereby enhancing their overall development and lifelong collaboration with AI technologies [12].
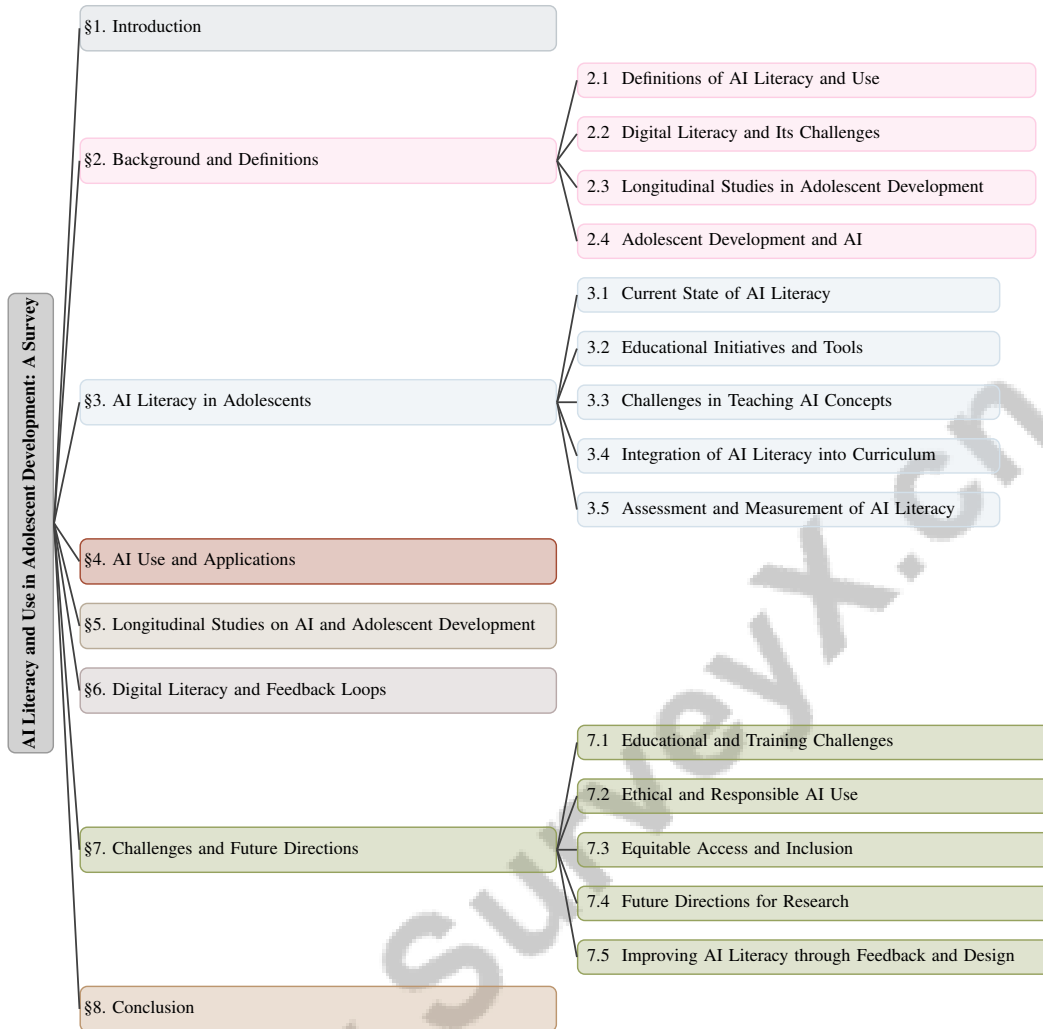
Figure 1: chapter structure

1.2 Feedback Loops in AI Contexts

Feedback loops are integral to AI systems, facilitating iterative output refinement through reintegrated information. This dynamic process significantly impacts adolescent interactions with AI technologies, fostering adaptive learning environments [13, 11]. The adaptability of feedback loops supports AI literacy by enabling critical engagement with AI systems and their broader implications [4].

Transparency and explainability in AI are crucial for effective feedback loops, allowing students and educators to engage with AI technologies ethically [14]. However, the complexity of AI systems often leads to their perception as 'black boxes', hindering the learning process [15]. Integrating ethical considerations into AI development is essential to mitigate potential harms, such as bias and privacy violations [4].

In educational contexts, understanding feedback loops bridges the generational gap in AI readiness, facilitating adaptive learning environments that cater to diverse learner needs [16]. Feedback loops can also address algorithmic confounding, where user-algorithm interactions amplify cognitive biases [13]. By refining AI outputs based on user feedback, these loops contribute to developing robust AI systems, fostering critical engagement with AI technologies among adolescents [9].

This iterative process supports ethical AI deployment in education and empowers students to navigate AI complexities confidently. As public attitudes towards AI evolve, feedback loops play a significant role in shaping perceptions and informing policy-making [11]. Leveraging feedback loops allows

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educators and policymakers to align AI literacy initiatives with adolescents' needs and expectations, ensuring informed and responsible engagement with AI technologies [4].

1.3 Objectives of the Paper

This survey addresses the pressing need to integrate AI literacy into educational systems, emphasizing the adaptation of education to cultivate digital and AI literacy in response to societal demands [17]. A primary objective is to explore lifelong learning challenges in the AI era, advocating for AI literacy integration into educational frameworks to prepare learners for an AI-enhanced world [12]. This entails developing a comprehensive framework that enhances interdisciplinary understanding of AI and its socio-technical implications across educational levels.

The survey identifies and analyzes challenges educators face in integrating AI curricula into K-12 education, drawing insights from recent studies that underscore the need for improved teacher support, flexible curriculum structures, and effective professional development resources [18, 19, 20, 21]. By proposing targeted solutions, the survey aims to enhance AI literacy program implementation, essential for preparing students to navigate an AI-influenced society. Furthermore, examining the competencies required for AI literacy facilitates the transition from conceptual understanding to practical application in educational contexts.

Additionally, the survey investigates regulatory frameworks surrounding AI, such as the EU AI Act, to understand their implications for educational practices and bridge gaps in AI regulation. By addressing these objectives, the survey enriches our understanding of AI literacy's complex, multidimensional nature, encompassing technical skills, ethical considerations, critical thinking, and socio-emotional competencies. This understanding is vital for fostering informed and responsible engagement with AI technologies in educational environments, ultimately guiding the development of curricula and resources that equip learners with the necessary skills to navigate the evolving AI landscape effectively [22, 23].

1.4 Structure of the Survey

This survey provides a comprehensive overview of AI literacy and its implications for adolescent development. The paper begins with an introduction outlining the significance of AI literacy in adolescent development and the role of feedback loops in shaping AI interactions. Following this, key terms are defined, including AI literacy, AI use, longitudinal study, adolescent development, digital literacy, and feedback loops, accompanied by a brief literature review of each concept. Section 3 examines the current state of AI literacy among adolescents, focusing on educational initiatives, challenges in teaching AI concepts, and strategies for curriculum integration. Section 4 explores the contexts in which adolescents use AI, such as education, social media, and entertainment, analyzing the implications of this use. Section 5 reviews existing longitudinal studies on AI's impact on adolescent development, focusing on methodologies, findings, and challenges. Section 6 analyzes the relationship between digital literacy and feedback loops in adolescent AI use, exploring how feedback loops can enhance or hinder learning and development. The penultimate section identifies key challenges in promoting AI literacy and responsible AI use among adolescents while proposing future research directions. The survey concludes with a summary of findings and recommendations for educators, policymakers, and researchers. This structure systematically analyzes the multifaceted relationship between AI literacy, AI use, and adolescent development, considering the vital role of feedback loops and insights from longitudinal studies.The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Definitions of AI Literacy and Use

AI literacy for adolescents encompasses understanding, using, and critically evaluating AI technologies, crucial for integrating AI into educational and personal spheres. It involves cognitive, operational, critical, and ethical dimensions, emphasizing the ethical implications and societal impacts of AI [10, 17]. This literacy is essential for preparing students for a future dominated by digital technologies, requiring comprehension of AI functionalities and broader implications. In education, AI literacy supports personalized learning and addresses diverse learning styles [12], yet

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lacks consensus in definitions and faces a shortage of qualified instructors [11]. Understanding AI's ethical implications is vital for fostering critical engagement and responsible use among middle and high school students [14].

Adolescents use AI across education, social media, and entertainment, necessitating awareness of both benefits and risks to promote responsible engagement [11, 24]. AI literacy also involves recognizing manipulative techniques in AI systems, equipping adolescents to navigate the digital landscape safely and ethically. Cultural contexts and limited understanding of prompt engineering's impact further complicate integrating AI literacy into education, particularly in higher education [10]. These insights highlight the need for targeted educational strategies addressing both technical and ethical dimensions of AI engagement.

2.2 Digital Literacy and Its Challenges

Digital literacy involves skills and knowledge for navigating, evaluating, and creating information using digital technologies [25]. It is critical in education, enabling engagement with digital content and tools. Challenges include conceptual ambiguity and incomplete digital skills inventories, exacerbated by the COVID-19 pandemic [26]. Technological familiarity varies among educators, particularly between younger and older teachers [27], leading to uncertainty in implementing digital literacy curricula [28]. Cultural disconnects in curricula further complicate digital literacy education [28].

The digital divide, marked by unequal technology access, remains a barrier to digital literacy, notably in correctional facilities, affecting skill development essential for modern workplace success [29]. This divide disproportionately affects marginalized groups, exacerbating inequalities and limiting digital engagement opportunities [24]. Information overload and potential technology dependence hinder critical digital skills development [30]. Varied digital literacy conceptions and limited student belief examinations complicate establishing a coherent educational framework [31].

Addressing these challenges requires strategies considering technical and socio-economic barriers, including professional development for educators and equitable technology access. An inclusive approach to digital literacy education equips individuals to navigate the digital world and participate in the digital economy [12].

2.3 Longitudinal Studies in Adolescent Development

Longitudinal studies are essential for understanding adolescent development trajectories and outcomes, observing variables over time to reveal dynamics in growth and learning. They explore machine learning comprehension, digital literacy trends, and innovative methodologies like large language models, highlighting complexities in adolescents' conceptual frameworks [32, 33, 26, 34]. These studies identify behavior, cognition, and social interaction patterns, offering comprehensive adolescent evolution insights.

Longitudinal research is vital for examining digital and AI literacy impacts on outcomes, such as digital literacy's long-term effects on employment for formerly incarcerated individuals [35]. It also elucidates AI literacy's enduring influence on cognitive and social skills, informing educational strategies for evolving learner needs. However, challenges include maintaining participant engagement and integrating mixed-methods approaches [32]. Accurate digital literacy assessment tools are needed to address discrepancies between actual and self-assessed skills [25]. Explainable AI complexities and varying AI literacy levels complicate user compliance and engagement understanding [14].

Longitudinal studies provide a framework for exploring adolescent development aspects, particularly digital and AI literacy. Addressing methodological challenges and using longitudinal data offer insights into developmental processes influencing digital technology and AI interactions. This understanding informs educational practices and policies enhancing youth development. Recent studies emphasize exploring youths' everyday machine learning knowledge, revealing fragmented understandings that can improve formal learning environments. AI integration into children's lives presents challenges and opportunities, significantly affecting cognitive and socio-emotional development. Cross-disciplinary collaboration and research into technological innovations' impacts on child development are crucial for creating effective, child-centered educational strategies and regulations promoting responsible AI use [36, 33].

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2.4 Adolescent Development and AI

The intersection of adolescent development and AI significantly influences cognitive, emotional, and social growth. AI technologies, especially conversational agents, are integral to adolescents' environments, impacting psychological development and digital media interactions. AI in education offers personalized learning experiences, enhancing outcomes and necessitating pedagogical reevaluation to include AI literacy [15, 17]. Beyond education, AI affects social interactions and entertainment, influencing identity formation and cognitive skills. AI in social media creates echo chambers, reinforcing biases and affecting world perceptions [15]. Digital literacy fosters critical AI evaluation and responsible engagement [30].

Ethical considerations are crucial in AI's role in adolescent development, particularly regarding privacy, transparency, and biases. As AI technologies integrate into adolescents' lives, guidelines to protect young users and promote AI's societal understanding are essential. Rapid AI adoption in education necessitates AI literacy focus, encompassing technical knowledge, ethical awareness, and career impacts. This approach ensures AI benefits adolescents while safeguarding developmental needs and rights [36, 37, 38, 39, 11]. The digital divide, exacerbated by underrepresented cultural data, poses barriers to equitable AI resource access, necessitating inclusive practices for diverse adolescent needs. Bridging these gaps promotes AI literacy and ensures all adolescents benefit from AI opportunities.

AI usage perceptions, particularly in research, highlight the need for frameworks categorizing AI interactions by moral acceptability, trustworthiness, and perceived accuracy. These frameworks inform educational strategies equipping adolescents with skills and ethical awareness for an AI-driven society [28, 19, 40, 20, 11].

Adolescent development and AI interplay encompasses educational, social, and ethical dimensions. Cultivating AI literacy in middle school students includes technical understanding and ethical implications awareness. Research shows effective AI education empowers students to recognize AI biases and consider technology's societal impacts, fostering a holistic AI understanding as a sociotechnical system. This approach prepares adolescents for ethical complexities and opportunities in an AI-driven future [11, 37]. Fostering AI literacy and equitable AI resource access supports adolescents in navigating AI challenges and opportunities, contributing to their holistic development and AI-driven future preparedness.

3 AI Literacy in Adolescents

AI literacy has become increasingly important as adolescents interact with AI technologies in various aspects of their lives. It involves both technical skills for engaging with AI systems and critical thinking to evaluate their societal impacts. This section explores AI literacy among adolescents, focusing on foundational competencies, educational interventions, and curricular integration challenges. The discussion begins with an analysis of the current AI literacy landscape, emphasizing existing frameworks and student engagement levels with AI technologies.

3.1 Current State of AI Literacy

AI literacy in adolescents varies widely, reflecting diverse engagement levels with AI technologies. K-12 frameworks emphasize computational and critical thinking, and creativity as essential components of AI literacy [10, 12]. However, inconsistent integration into curricula leads to disparities in student engagement across educational settings. Interventions like the CT-based Digital and AI Teaching-Learning Strategy (CT-DAL) have shown promise in enhancing AI literacy among elementary students, highlighting the effectiveness of structured educational approaches [41]. The DAILy curriculum incorporates ethics and career futures into AI education, stressing the importance of addressing ethical considerations alongside technical skills [11].

Digital literacy, a precursor to AI literacy, is positively correlated with improved learning outcomes, demonstrating the efficacy of technology-based learning approaches [24]. However, students show varying digital skills and preferences for reading formats, with a preference for electronic resources over print [30]. This necessitates educational strategies that accommodate diverse learning preferences and digital proficiency levels. Theoretical frameworks emphasize relational dynamics in human-AI interactions, drawing on interdisciplinary insights to inform AI literacy education [4]. These insights

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are crucial for fostering a comprehensive understanding of AI's societal role and nurturing critical thinking for responsible AI engagement.

3.2 Educational Initiatives and Tools

Educational initiatives and tools are pivotal in advancing AI literacy by providing interactive and contextual learning experiences. A structured prompt engineering workshop enhances students' abilities to craft effective prompts, deepening their understanding of AI functionalities through experiential learning [1]. The 'AI Audit' game engages students in critical discussions about AI technologies by simulating real-world scenarios, encouraging learners to critically evaluate AI systems and understand their societal and ethical implications [3]. Such initiatives underscore the value of interactive learning methods in enhancing AI literacy.

Cultural and linguistic inclusivity is addressed through initiatives like AI literacy videos in Yoruba, empowering speakers of low-resource languages with AI knowledge and ensuring equitable access to AI literacy resources [42]. Professional development programs incorporating reflective practices and personalized learning are essential for supporting educators in integrating AI-enhanced learning activities into their teaching [43]. The integration of metaphor reflection into AI literacy education further enhances critical understanding among educators and students [44].

These educational initiatives and tools exemplify diverse strategies to improve AI literacy. By prioritizing inclusivity, fostering critical reflection, and promoting practical engagement, these initiatives equip students with essential AI literacy skills and the ability to analyze AI technologies' societal implications, preparing them for a future shaped by AI advancements [23, 9, 40, 45, 11].

3.3 Challenges in Teaching AI Concepts

Teaching AI concepts to adolescents presents significant challenges, primarily due to the lack of a unified definition of AI literacy. This complicates curriculum development that encompasses both technical and non-technical aspects of AI education, often inadequately addressing ethical and societal implications [11]. Resistance from traditional educational structures and limited resources hinder effective AI literacy integration into K-12 curricula, compounded by insufficient educator training and the need for curriculum adaptation to align with modern societal demands. Despite growing recognition of AI's educational importance, a coherent competency framework to guide AI literacy implementation across diverse contexts is lacking, leaving institutions struggling to equip students with essential knowledge and skills [28, 23, 40, 20, 46].

The pervasive presence of AI in adolescents' lives introduces further challenges, including exposure to misinformation and harmful advice from conversational agents, distorting perceptions of AI and raising privacy concerns. Variability in user perceptions across demographics necessitates educational approaches catering to diverse learning styles and prior knowledge levels [47]. Additionally, AI's limitations in providing deep, contextualized interactions require educators to equip students with critical evaluation skills to discern credible information from AI-generated content [48]. Reliance on self-assessment of digital literacy skills poses a challenge, as it may not accurately reflect actual competencies, leading to misleading conclusions about students' understanding of AI [25]. The need for engaging learning experiences, coupled with inadequate educator training—especially among older teachers—further complicates teaching AI concepts.

Designing effective learning experiences is hindered by existing approaches prioritizing efficiency over purpose, resulting in low acceptance of automation technologies [7]. Insufficient integration of digital and AI literacy into curricula remains a core obstacle to effective education [41]. Moreover, the non-observability of feedback loops in AI systems complicates understanding and teaching these concepts [15]. Unequal access to technology and potential negative impacts of dependency further complicate the teaching of digital literacy concepts [24]. Addressing these challenges requires a comprehensive approach, including robust curriculum development, targeted professional development for educators, and a focus on practical applications of digital literacy in real-world scenarios. Understanding students' beliefs about their digital literacy development is crucial for designing educational strategies that resonate with their experiences and expectations [31].

3.4 Integration of AI Literacy into Curriculum

Integrating AI literacy into educational curricula requires a strategic approach emphasizing interdisciplinary learning and competency development. AI literacy should be woven into existing curricula rather than treated as a standalone subject, enhancing the overall educational experience. This aligns with the insight that AI literacy benefits from an interdisciplinary and competency-based framework, enabling students to apply AI concepts across various subjects [20]. The proposed Digital Literacy Framework emphasizes identifying and teaching specific drivers of digital literacy to improve graduates' employability outcomes [49]. By incorporating AI literacy into this framework, educators can equip students with skills to navigate an AI-driven workforce, enhancing career prospects and responsiveness to the digital economy's evolving demands.

Culturally responsive pedagogy is crucial for ensuring AI education is relevant to students from diverse backgrounds. A framework emphasizing culturally relevant learning experiences allows students to connect AI concepts to their cultural identities, fostering deeper engagement [28]. Hands-on learning experiences linking user actions with data-driven outcomes are essential for developing a comprehensive understanding of AI and data ethics [50]. Engaging with AI technologies through practical applications enables students to cultivate critical thinking skills and a nuanced understanding of ethical implications.

Frameworks like the Critical Interaction with AI for Writing (CIAW) enrich curricula by characterizing different levels of student engagement with AI [45]. Such frameworks provide educators with tools to assess and enhance students' interactions with AI, ensuring learners develop a sophisticated understanding of AI's role in various contexts. Integrating AI literacy into curricula requires a comprehensive strategy emphasizing interdisciplinary learning, cultural responsiveness, and hands-on experiences. This approach should address technical understanding and ethical implications of AI technologies. Moreover, curricula must be modular and personalized to adapt to diverse educational contexts and student needs. By leveraging AI literacy, educators can enhance core subject learning, preparing students for a future increasingly influenced by AI [46, 28, 23, 20]. By adopting these strategies, educators can prepare students to navigate the complexities of AI technologies and contribute to an informed and responsible digital society.

3.5 Assessment and Measurement of AI Literacy

Benchmark	Size	Domain	Task Format	Metric
GLAT[51]	355	Generative AI	Multiple-Choice Question	Cronbach's alpha, omega total
ChatGPT-IL[52]	167	Digital Literacy	Collaborative Interdisciplinary Problem-Solving	Collaborative Interdisciplinary Problem-Solving, Engagement
MISINFO[53]	750	Misinformation	News Identification	Standard Deviation Improvement
MCQ-Distractor-Benchmark[54]	298	Education	Distractor Generation	Recall@10, Precision@1
PHB[6]	334	Freelance Writing	Profile Evaluation	AI Suspicion, Hiring Likelihood

Table 1: The table presents a selection of benchmarks used to assess AI literacy and related competencies across different domains. Each benchmark is characterized by its size, domain, task format, and the specific metrics used for evaluation. This comprehensive overview highlights the diversity of assessment tools and their application in measuring AI literacy and associated skills.

Assessing and measuring AI literacy among students is crucial for preparing learners for an AI-driven world. Effective assessment methods must capture AI literacy's multifaceted nature, encompassing technical competencies and critical evaluation skills. One promising approach involves using multi-agent systems to generate high-quality assessment questions, creating pedagogically sound and scalable evaluations for AI literacy in K-12 education [55]. These systems can produce diverse question types assessing various dimensions of AI literacy, including conceptual understanding and practical application.

Engagement with AI concepts through interactive learning experiences, such as modifying and interacting with conversational AI systems, offers another effective method for assessing AI literacy. This approach allows students to actively engage with complex systems, fostering a deeper understanding of AI and its applications [56]. Participating in hands-on activities enables students to demonstrate

their ability to apply AI concepts in real-world contexts, providing educators with valuable insights into their comprehension and skills.

Enhancing digital literacy is essential for enabling students to critically evaluate AI-generated advice and content, a skill increasingly important in navigating the digital landscape [57]. Future research should focus on developing assessment tools that measure students' ability to discern credible information from AI-generated outputs, ensuring they are equipped to engage with AI technologies responsibly. A systematic approach to assessing AI literacy should consider the broader context of digital literacy across various domains, including education, business, and health [26]. By incorporating quantitative research and specific case studies, educators can gain a comprehensive understanding of students' digital competencies and identify areas for improvement. This holistic perspective is crucial for designing assessment methods that accurately reflect the diverse skills and knowledge required for AI literacy.

Evaluating AI literacy necessitates innovative approaches encompassing technical skills, ethical considerations, critical thinking, and socio-emotional competencies, reflecting the intricate relationship between AI technologies and societal norms. Various assessment tools, such as the Artificial Intelligence Literacy Questionnaire (AILQ) and the General Attitudes towards Artificial Intelligence Scale (GAAIS), collectively provide insights into individuals' self-perception of their AI capabilities. As AI technologies increasingly permeate everyday life, a comprehensive understanding of AI literacy is essential for fostering effective engagement and informed decision-making, thereby informing educational strategies and policy development aimed at bridging the gap between perceived and actual AI literacy [22, 23]. By leveraging advanced assessment tools and interactive learning experiences, educators can effectively evaluate students' AI literacy and support their development as informed and responsible digital citizens. Table 1 provides an overview of various benchmarks utilized for assessing AI literacy, illustrating the range of domains, task formats, and evaluation metrics employed in these assessments.

In recent years, the proliferation of artificial intelligence (AI) has transformed numerous sectors, prompting a critical examination of its implications. As demonstrated in Figure 2, this figure illustrates the diverse applications of AI across various domains, highlighting the opportunities and challenges in educational contexts, social media and entertainment, knowledge-intensive tasks, and societal and ethical implications. Each section of the figure outlines key impacts, ethical considerations, and educational aspects, providing a comprehensive overview of AI's role in contemporary society. This multifaceted perspective not only underscores the potential benefits of AI integration but also raises essential questions regarding its ethical deployment and societal impact.

4 AI Use and Applications

4.1 AI Use in Educational Contexts

The integration of AI into education is reshaping learning environments, offering opportunities for personalization and enhanced engagement, yet posing challenges related to ethics and implementation [40]. AI technologies facilitate individualized learning experiences, adapting to students' unique styles and paces, thus improving academic outcomes. Additionally, AI-driven platforms simulate real-world scenarios, fostering interactive learning and deeper understanding of complex concepts [58]. However, the ethical implications of AI, particularly generative AI (GAI), are significant, affecting perceptions and decisions in education, such as hiring practices [6]. This underscores the necessity for transparent and ethical AI deployment to uphold trust and integrity [37]. AI's potential to democratize content creation can also enhance creativity in educational storytelling, leading to more engaging learning experiences.

Responsible AI implementation in education should prioritize ethical considerations while fostering intrinsic motivation among students. Research suggests that thoughtful AI use can promote academic integrity, digital literacy, and personalized learning environments. Educators need to develop AI literacy to effectively integrate AI with traditional teaching methods, ensuring that critical thinking and emotional intelligence remain central to education [19, 37, 40, 20, 11].
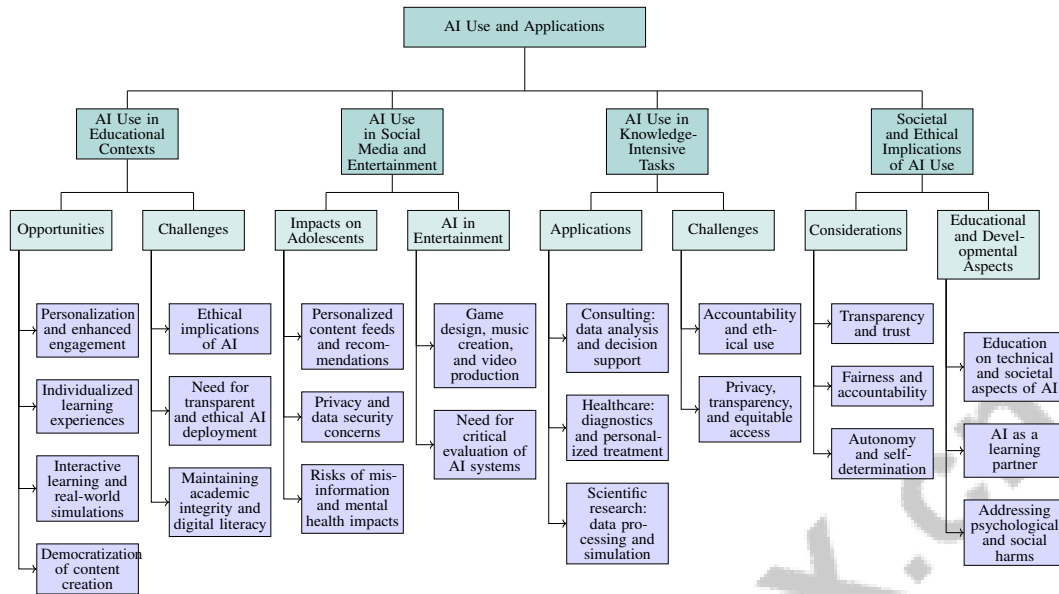
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4.2 AI Use in Social Media and Entertainment

AI's extensive role in social media and entertainment shapes adolescents' digital interactions, where algorithms curate content feeds and personalize recommendations, potentially reinforcing biases and limiting exposure to diverse perspectives [15]. This necessitates critical engagement with these platforms and an understanding of AI mechanisms [30]. Privacy and data security concerns arise from AI-powered features like facial recognition and sentiment analysis [38]. The impact of personal data collection on adolescents' digital well-being requires adherence to ethical guidelines and responsible practices [50]. Additionally, AI's role in generating misinformation poses risks to mental health [47].

In the entertainment sector, AI is employed in game design, music creation, and video production, crafting immersive experiences for adolescents [48]. However, the potential for AI-generated content to be manipulative necessitates critical evaluation of AI systems' limitations [24]. Developing AI literacy is essential for adolescents to navigate these environments responsibly, enabling them to critically evaluate AI-generated information and experiences. Algorithmic bias in content recommendation systems also warrants attention, as it can perpetuate societal inequalities [13]. Understanding these dynamics is crucial for fostering responsible AI use and promoting digital well-being.

4.3 AI Use in Knowledge-Intensive Tasks

AI technologies have transformed knowledge-intensive tasks in consulting, healthcare, and scientific research. Benchmarks like those proposed by Dell et al. provide frameworks for evaluating AI's performance, focusing on task completion and quality metrics [59]. In consulting, AI systems analyze extensive datasets to generate insights, supporting decision-making and enhancing efficiency by automating routine tasks [59]. However, reliance on AI for critical decisions raises accountability concerns, necessitating robust evaluation frameworks.

In healthcare, AI applications range from improving diagnostic accuracy to devising personalized treatment plans, optimizing patient outcomes through extensive data analysis. Integrating AI into clinical workflows requires healthcare professionals to develop AI literacy, ensuring safe and ethical patient care. As generative AI evolves, its applications for clinicians and researchers expand, but challenges like privacy, transparency, and equitable access must be addressed [8, 60]. The interpretability of AI models is vital for gaining trust among healthcare professionals.

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AI significantly enhances scientific research by processing complex datasets and simulating experimental conditions, accelerating discovery and innovation while allowing researchers to customize approaches. Ethical guidelines are increasingly developed to ensure responsible AI use in research, promoting transparency and reproducibility [61, 62, 23, 9, 39]. AI tools facilitate hypothesis generation and data analysis, but rigorous validation is necessary to prevent biases and ensure credibility.

The deployment of AI in knowledge-intensive tasks presents both opportunities and challenges. While AI can enhance efficiency and spur innovation, its implementation requires rigorous oversight to maintain ethical integrity and reliable outcomes. Practical strategies addressing ethical challenges—such as model training, privacy, and transparency—are essential. Furthermore, fostering responsible AI use necessitates targeted professional development that balances innovation with ethical considerations [59, 19, 9, 37, 39]. Structured evaluation of AI performance is crucial for advancing applications while maintaining accountability and trust.

4.4 Societal and Ethical Implications of AI Use

The societal and ethical implications of AI use among adolescents are profound, requiring careful consideration of transparency, equity, and the potential for empowerment or harm. The increasing integration of AI into adolescents' lives demands a critical examination of its influence on development and societal norms. Ethical considerations are paramount, as AI systems often make decisions impacting individuals' lives, raising concerns about fairness and accountability [63]. Transparency is crucial for fostering trust and responsible technology use, enabling adolescents to understand AI operations and critically evaluate their interactions [64].

The acceptance of ethical advice from algorithms offers opportunities for enhancing decision-making [57], but this requires careful consideration of the ethical frameworks guiding AI development to prevent biased outcomes. Multidisciplinary collaborations are essential for creating equitable AI technologies, addressing the interplay of technical and societal factors [65]. AI systems should support users' ability to express and change preferences, emphasizing autonomy and self-determination, especially for adolescents in critical stages of identity formation [66].

Education on AI should encompass both technical and societal aspects, equipping students to navigate ethical challenges posed by AI systems [67]. Treating AI as a learning partner can enhance both human and AI capacities, improving problem-solving and ethical interactions [4]. Current studies often overlook the psychological and social harms associated with AI, which require attention to ensure adolescents' holistic well-being [68]. Educational tools like the 'AI Audit' game can engage students with ethical challenges, promoting critical thinking and informed decision-making. Addressing the societal and ethical implications of AI use demands a comprehensive approach prioritizing transparency, equity, and empowerment, preparing adolescents to navigate the complexities of an AI-driven world responsibly and ethically.

5 Longitudinal Studies on AI and Adolescent Development

5.1 Methodologies in Longitudinal Studies

Longitudinal studies investigating AI's impact on adolescent development employ both quantitative and qualitative methodologies to capture the evolving effects of AI technologies. Quantitative approaches often involve statistical analyses of pre- and post-intervention data to assess changes in AI literacy, which encompasses foundational, practical, experimental, and ethical dimensions [8]. Surveys are frequently utilized to evaluate shifts in self-efficacy and developmental metrics, providing insights for educational strategies and policy decisions [12]. Qualitative methodologies, such as thematic analysis, offer rich narratives that explore adolescents' experiences and perceptions of AI technologies, revealing societal and ethical implications [9]. Tools like the AI Audit card game simulate real-world challenges, fostering critical engagement with AI's ethical dimensions [8].

Research on AI system explainability highlights the importance of transparency and compliance in AI interactions, as evidenced by a study with 562 participants estimating ages based on AI predictions [14]. These findings emphasize the necessity of incorporating explainability into AI systems to bolster user trust and understanding, particularly in educational settings where adolescents are developing critical thinking skills. Longitudinal studies also utilize extensive datasets to evaluate AI performance over time, such as an analysis of AI in medical contexts using a dataset of 10,000

historical EKG exams [16]. The diverse methodologies employed in these studies contribute to a nuanced understanding of AI's role in adolescent development, addressing research limitations and focusing on culturally relevant and ethically sound educational strategies [12].

5.2 Findings from Longitudinal Studies

Longitudinal studies provide critical insights into AI's dynamic impact on adolescent development, emphasizing the integration of AI literacy into educational frameworks. These studies reveal that feedback loops within lifelong machine learning systems significantly affect model performance and user behavior, necessitating adaptive learning environments tailored to individual needs [15]. Self-perception is crucial in educational strategies, as adolescents' understanding of their AI competencies influences their engagement with AI technologies. Enhanced self-awareness fosters critical engagement, enabling comprehension of technical capabilities, limitations, ethical implications, and societal impacts. Promoting comprehensive AI literacy encompassing cognitive, emotional, and ethical dimensions cultivates critical thinking skills necessary for navigating human-AI interactions effectively, establishing productive partnerships between humans and AI [23, 22, 9, 45]. Collaborative design approaches enhance educators' AI literacy, facilitating innovative learning experiences that prepare students for an AI-driven future.

Longitudinal research also highlights AI's potential to support adolescent well-being, particularly through large language models (LLMs) that enhance linguistic creativity and communication efficiency. The psychological risks associated with AI are complex, shaped by individual circumstances and specific AI behaviors, necessitating a nuanced approach to AI literacy education incorporating ethical considerations, critical thinking, and socio-emotional skills. Recognizing the interplay between AI technologies and societal norms enables educators to prepare individuals to navigate AI's psychological impacts, fostering a comprehensive understanding of technical and ethical dimensions of AI engagement [69, 11, 22]. Explainable AI (XAI) enhances compliance, with mental models significantly influencing user interactions with AI systems.

Moreover, LLM-generated item variants in questionnaires, such as those assessing depression, demonstrate AI's utility in maintaining robust psychometric properties while enhancing participant engagement, indicating AI's potential in creating engaging educational tools. The integration of AI in educational settings reflects a trend toward enhancing learning outcomes and student engagement. AI technologies, including generative AI, support teachers in delivering personalized instruction, fostering critical thinking, and developing essential social-emotional skills. While AI can transform educational practices, human educators remain indispensable, advocating for a collaborative approach between AI and teachers to achieve effective and holistic learning experiences [70, 28, 19, 9].

5.3 Challenges in Conducting Longitudinal Studies

Longitudinal studies on AI and adolescent development face challenges affecting research validity and reliability. A primary challenge is the insufficient training of educators in AI technologies [40], which can impede effective AI literacy program implementation and integration of AI tools in educational settings. Without adequately trained educators, students may rely excessively on AI tools without critical engagement, skewing study results and limiting understanding of AI's impact on adolescent development. Maintaining participant engagement over extended study periods poses another challenge. As students progress, their beliefs about digital literacy may evolve, necessitating ongoing data collection to capture these changes accurately [31]. However, respondent fatigue and attrition can lead to incomplete datasets, diminishing studies' effectiveness in tracking developmental trends. Innovative strategies are essential to sustain participant interest and ensure high response rates.

The rapidly evolving nature of AI technologies presents additional challenges for longitudinal research. As AI advances, studies must adapt to capture the dynamic landscape of AI use and literacy among adolescents, updating educational frameworks to incorporate AI literacy components, such as technical concepts, ethical implications, and career prospects [23, 11, 20]. Continuous updates to methodologies and instruments can be resource-intensive and complex to manage. Addressing challenges associated with AI integration into children's environments is crucial for effective longitudinal studies that yield insights into AI's complex relationship with adolescent development. AI influences educational and recreational activities, presenting opportunities and risks impacting

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cognitive and socio-emotional growth during critical developmental periods. A multidisciplinary approach, informed by expert consultations and literature reviews, is essential to explore responsible AI utilization and regulation to support healthy developmental trajectories. Understanding youths' everyday knowledge of machine learning can inform educational strategies that enhance AI literacy, ensuring adolescents are equipped to navigate and critically engage with evolving technologies [36, 33]. By focusing on educator training, participant engagement, and technological adaptation, researchers can enhance longitudinal research quality and impact.

6   Digital Literacy and Feedback Loops

The integration of digital literacy with artificial intelligence (AI) technologies is crucial for enhancing learning outcomes and equipping adolescents with the skills needed for future challenges. Digital literacy encompasses competencies essential for effective interaction with AI systems, making its implications significant for educators and policymakers. This section examines the interplay between digital literacy and AI integration, emphasizing the importance of preparing adolescents to navigate an increasingly AI-driven environment.

6.1   Digital Literacy and AI Integration

Digital literacy is vital for adolescents to engage effectively and ethically with AI technologies, including competencies such as discovery, evaluation, creation, communication, and curation, foundational for informed interactions with AI systems [71]. Integrating digital literacy with AI fosters interdisciplinary applications, linking foundational skills with effective AI engagement [72]. This integration enhances user engagement with AI, promoting responsible navigation of AI-enhanced environments.

Research underscores the role of tools like spreadsheets in fostering analytical thinking, creativity, and problem-solving [73], aligning with perspectives that blend practical and theoretical dimensions for media consumption and production education [74]. Embedding digital literacy into educational practices prepares students to critically evaluate AI-driven content and engage effectively with AI technologies.

The competency model proposed by [23] emphasizes behavioral anchors for assessing competency levels, offering a framework for integrating AI literacy into curricula. Rigorous research is advocated to evaluate generative AI's long-term impacts on cognition, metacognition, and creativity, supporting a human-centered approach in developing AI-driven educational tools [75]. Professional development for educators is essential for effectively incorporating AI tools into teaching practices [37].

Addressing misinformation challenges and developing effective educational strategies are critical for integrating digital literacy with AI [53]. Regulations to safeguard children's cognitive and emotional development in AI contexts are crucial for ensuring safe and responsible engagement [36]. Frameworks for integrating digital and AI literacy, particularly in mathematics, highlight computational thinking's significance in understanding AI technologies [17].

6.2   Feedback Mechanisms and AI Use

Feedback mechanisms are critical in enhancing AI systems' efficacy, particularly in educational contexts, where they facilitate adaptive learning and improve user engagement. Integrating feedback mechanisms into AI systems, such as language models (LMs), requires transparency to optimize learning outcomes, enabling users to understand and interact with AI technologies effectively [76]. This transparency fosters trust and encourages critical engagement with AI systems, allowing users to refine interactions based on feedback.

The Artificial Neuron method exemplifies feedback mechanisms' significance by enabling large language models (LLMs) to correct errors and update memory based on previous interactions [77]. This iterative process enhances adaptability and accuracy, supporting users in achieving refined outputs and facilitating continuous learning. Real-time feedback mechanisms, such as those employed by Somekone, impact adolescents' data collection and profiling learning, underscoring immediate feedback's importance in shaping user understanding and behavior [78].

Feedback loops enhance mutual adaptability between users and AI systems, promoting dynamic interactions catering to diverse learning needs [79]. In systems like Vocalizer, AI suggestions and refinements based on user input improve overall quality and user experience [80]. This iterative refinement process is crucial for fostering continuous improvement and engagement with AI technologies.

Viewing AI communication as a two-way dialogue, where user context informs explainable AI (XAI) systems' design, further emphasizes feedback mechanisms' significance [81]. Incorporating user feedback into AI system design enables developers to create intuitive and responsive technologies that align with user expectations and enhance learning outcomes.

Innovative approaches like Dynamic Causal Collaborative Filtering () in recommender systems leverage feedback mechanisms to estimate user preferences through counterfactual reasoning, refining recommendations without compromising quality [13]. Similarly, causal adjustment for feedback loops (cafl) aims to break feedback loops while maintaining recommendation quality, demonstrating feedback mechanisms' potential to optimize AI performance [82].

Feedback mechanisms are integral to effectively using AI technologies, facilitating adaptive learning and enhancing user engagement. By emphasizing transparency, iterative refinement, and user-centered design in AI systems, educational institutions can enhance AI literacy among adolescents, equipping them with the skills necessary to understand AI technologies, their societal implications, and ethical considerations. This approach fosters responsible interaction with AI-driven environments and supports personalized learning experiences that cater to diverse educational needs.

6.3 Feedback Loops: Enhancing and Hindering Learning

Feedback loops significantly influence adolescent learning and development, offering enhancement opportunities and challenges that may impede educational progress. These loops facilitate iterative refinement processes that can improve learning outcomes by allowing students to engage dynamically with AI systems. The Generative AI Literacy Test (GLAT) exemplifies an innovative approach to assessing generative AI literacy through performance-based evaluations, offering a more accurate reflection of learners' competencies than traditional self-reported measures. Developed with a robust methodological framework, GLAT features 20 multiple-choice items and demonstrates strong structural validity and reliability (Cronbach's alpha = 0.80; omega total = 0.81). Notably, GLAT scores significantly predict learners' success in tasks supported by generative AI, highlighting its effectiveness in gauging true understanding of AI technologies and informing educational practices and policies aimed at enhancing AI literacy [51, 21].

However, feedback loops can introduce complexities that impede learning and development. The phenomenon of in-context reward hacking (ICRH) illustrates how feedback mechanisms can lead to unintended consequences, such as reinforcing harmful behaviors through output-refinement and policy-refinement processes, underscoring the necessity for adaptive strategies that consider user feedback and the evolving nature of AI interactions [83].

The role of feedback loops in educational settings is complicated by AI systems' limitations. AI's inability to provide emotional support, manage classroom behavior, and foster interpersonal relationships presents significant barriers to effective teaching and learning. Additionally, exploiting cognitive biases through manipulative techniques can either enhance or hinder adolescent development, depending on how feedback loops are managed [84].

To address these challenges, it is essential to integrate ethical considerations into AI education, ensuring that feedback loops are designed to support rather than undermine learning objectives [85]. Open-source practices, as opposed to proprietary methods, can foster diverse contributions and create more robust feedback mechanisms responsive to learners' needs [86].

Moreover, experiments indicate a linear connection between increasing automation and decreasing employee satisfaction, suggesting a need for careful consideration of design variants that contribute to well-being in automated environments [7]. The effectiveness of causal adjustment for feedback loops (cafl) lies in its ability to break the causal connection between recommendations and user ratings, thus preventing biased learning from feedback [82]. Identifying conditions under which feedback loops arise and proposing methods to detect them are critical improvements that have not been thoroughly addressed in previous research [15].

7 Challenges and Future Directions

The incorporation of artificial intelligence (AI) in education demands a thorough exploration of the challenges and future directions arising from its integration. As educational institutions adapt to rapid advancements in AI technologies, identifying and addressing obstacles hindering effective implementation becomes crucial. This section examines educational and training challenges related to AI literacy, emphasizing strategies to equip educators and students with the skills necessary to navigate this evolving landscape.

7.1 Educational and Training Challenges

Integrating AI literacy into educational systems presents significant technological and pedagogical challenges. A key obstacle is the widespread unfamiliarity with AI tools among both students and educators, which hampers the effective implementation of AI literacy programs [17]. This unfamiliarity is compounded by skepticism regarding AI-only assessment systems and concerns about the efficacy of generative AI (GenAI) text detection tools, necessitating improved evaluation metrics to better understand and communicate their capabilities and limitations [11]. Potential biases and inaccuracies in AI-generated outputs underscore the need for human oversight to mitigate risks, while the lack of emotional intelligence in AI highlights concerns about academic integrity and students' over-reliance on AI technologies. Furthermore, difficulties in detecting misinformation generated by large language models present substantial barriers to promoting AI literacy [16].

The rapid pace of AI integration and the complexity of child-environment interactions necessitate regulations to safeguard children's development, exacerbated by concerns over the accuracy of AI-generated content and potential job displacement for educators [30]. Future research should focus on understanding barriers to AI adoption among different demographics and developing effective educational programs to improve digital literacy, as current studies often neglect varying levels of digital literacy and the need for ongoing training for educators [31]. Teacher training is crucial for adapting to new educational paradigms, enabling educators to navigate AI complexities and integrate them into their teaching practices [17]. Challenges in promoting AI literacy also include the need for standardized verification protocols and user education on verification to maintain user trust and engagement.

A comprehensive strategy is essential to address the educational and training challenges posed by rapid advancements in AI. This strategy should integrate enhanced pedagogical tools, structured training programs, and continuous research initiatives aimed at adapting curricula to the evolving AI landscape [70, 28, 23, 20]. Such an approach is vital for equipping educators and students with the necessary skills to navigate AI technologies, ensuring educational practices remain relevant and effective in preparing learners for future societal demands. By fostering increased engagement through interactive learning and personalized feedback, educational strategies can better meet the needs of diverse learners.

7.2 Ethical and Responsible AI Use

Promoting ethical and responsible AI use is crucial for addressing the challenges posed by the widespread integration of AI technologies. Ethical guidelines are necessary to address potential biases in AI systems, which can significantly impact user perceptions and interactions [87]. Addressing these biases is essential for promoting fairness in AI-mediated communication and evaluations, particularly in educational contexts where AI tools are increasingly employed for tasks such as grammar correction without disclosure [9]. Managing AI tools in educational settings requires careful consideration to protect student data and ensure privacy, highlighting the importance of ethical frameworks governing data use and security [48]. Additionally, variability in data quality across different healthcare settings poses challenges for generalizability in AI research, necessitating robust methodologies that accommodate diverse data environments [88].

Understanding perceptual harms associated with AI use is vital for addressing biases in AI-mediated communication, which can influence evaluations and decision-making processes [6]. Multidisciplinary collaboration is essential for developing AI tools that align with societal values and ethical principles, fostering responsible AI use across various domains [87]. Transparency in AI systems is critical for fostering user trust, necessary for ethical and responsible AI use. By providing users with

a clearer understanding of AI operations and decision-making processes, transparency can mitigate distrust and enhance user engagement [87]. In educational contexts, this transparency is crucial for ensuring that AI tools contribute positively to learning experiences while maintaining ethical standards.

7.3 Equitable Access and Inclusion

Ensuring equitable access to AI resources and promoting inclusive practices are critical challenges in integrating AI technologies within educational and societal contexts. Researchers face significant obstacles in guaranteeing that digital resources are accessible to all demographic groups, given the varying levels of digital proficiency among them [89]. This disparity can exacerbate existing inequalities, underscoring the necessity for targeted interventions that democratize AI access across diverse populations.

The democratization of AI in education is essential to prevent widening social inequalities, as AI technologies increasingly influence educational outcomes and opportunities. By providing equitable access to AI tools and resources, educational systems can foster an inclusive environment where all students can develop AI literacy and engage meaningfully with digital technologies [87]. This approach enhances educational equity and prepares students to thrive in an AI-driven world, regardless of socio-economic background.

To tackle challenges associated with the digital divide and enhance digital literacy, comprehensive policies and practices prioritizing inclusivity and equal access to digital resources are essential. This includes investing in infrastructure to support widespread access to technology, providing training programs to enhance digital literacy across all demographic groups, and developing culturally responsive curricula that resonate with diverse learners [90, 91, 92, 93, 26]. By adopting these strategies, educators and policymakers can create a more equitable and inclusive digital landscape, empowering all individuals to participate fully in the digital economy.

7.4 Future Directions for Research

Future research in AI literacy and use should prioritize developing comprehensive frameworks that address the multifaceted nature of AI education and its implications across diverse contexts. A key focus should be on expanding AI literacy competencies, exploring new educational technologies, and addressing evolving social norms around AI. This involves refining assessment tools to capture the full spectrum of AI literacy, encompassing technical skills, critical thinking, ethical reasoning, and responsible use [12]. Additionally, research should address emotional and attitudinal barriers affecting engagement with AI technologies and investigate how digital literacy evolves with technological advancements and the impact of socio-cultural factors on literacy development [31].

Future work should also focus on refining app features based on user feedback, exploring additional AI concepts, and assessing long-term impacts on students' understanding and skills. Developing specialized AI models for mental health support that understand and respond to user needs is another crucial area for exploration. The integration of large language models (LLMs) into various communicative contexts has significant implications for human language use, particularly as empirical evidence suggests that these models influence spoken communication patterns. Recent studies indicate a noticeable shift in vocabulary used in academic presentations following the introduction of LLMs like ChatGPT, highlighting the potential for these technologies to shape linguistic expression and possibly diminish linguistic diversity. Furthermore, the societal ramifications of this influence, including concerns over mass manipulation and the perception of AI use in academic writing, necessitate comprehensive research to understand the feedback loops between AI behavior and human cultural practices. This underscores the urgency of investigating how LLMs might both enhance and challenge the preservation of linguistic diversity in an increasingly AI-integrated world [94, 6, 95, 9].

Research should explore the acceptance of LLMs in other scientific fields, the impact of specific scientists' reputations on perceptions of LLM use, and the effects of improved LLM capabilities on public trust. To prepare students for a future increasingly influenced by AI, it is essential to prioritize the integration of AI education into existing curricula, develop inclusive and accessible AI curricula catering to diverse learning needs, and enhance professional development resources for educators. This approach addresses the urgent need for AI literacy among students and teachers and ensures that

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educators are equipped with the knowledge and tools to effectively teach AI concepts, fostering a deeper understanding of the ethical and societal implications of AI technologies [18, 28, 21].

Exploring the long-term effects of prompt engineering training and its integration into broader AI literacy curricula across various disciplines is essential for comprehensive AI education. To ensure that industry standards remain relevant and effective, it is necessary to refine them by incorporating emerging technologies, such as AI, and contemporary pedagogical theories. This approach addresses current challenges of interoperability and ethical governance in the educational landscape and facilitates personalized learning experiences that support diverse educational needs. Establishing a multi-tiered framework for these standards can promote a cohesive and ethical ecosystem that enhances educational outcomes and prepares students for success in an increasingly AI-driven world [23, 9, 37, 5, 40].

Future work will involve testing the 'AI Audit' game with actual middle and high school students, aligning with potential future research directions in AI literacy. Additionally, developing AI systems that can effectively model human minds and foster emotional connections is essential for ensuring a balanced partnership. Future research should explore perceptions across different academic fields and investigate ethical concerns in-depth. Moreover, developing adaptable AI curricula that evolve with technological advancements and address specific needs, such as those of medical students, is crucial. Integrating AI education across different subjects, improving teacher training, and creating inclusive learning environments are vital areas for future research. Innovative digital literacy strategies and examining the evolving role of technology in education should be a focus. Personalized XAI approaches and exploring their implications in specialized domains, such as healthcare, to enhance user understanding and compliance are also important [16]. Extending the Dynamic Causal Collaborative Filtering framework to other domains, such as social networks and conversational AI, indicates potential directions for AI literacy and use. Lastly, developing robust support systems for educators and enhancing curriculum frameworks to better integrate AI and computational thinking should be prioritized [12].

By addressing these critical research directions, we can enhance the development of a comprehensive AI literacy education framework that is informed, responsible, and equitable. This framework will equip students with the essential knowledge and skills needed to navigate the complexities of an AI-driven future, fostering their ability to critically engage with AI technologies, understand their societal implications, and effectively collaborate in diverse roles—whether as consumers, co-workers, or creators. Furthermore, a structured competency model, supported by systematic assessments and interdisciplinary approaches, will ensure that AI literacy education is adaptable to various educational contexts and meets the evolving demands of the workforce [23, 21, 40, 20, 46].

7.5 Improving AI Literacy through Feedback and Design

Enhancing AI literacy through feedback and design involves implementing strategies that leverage user interactions with AI systems to foster deeper understanding and more effective engagement. A crucial aspect of this approach is integrating feedback mechanisms that provide real-time insights into AI processes, allowing users to adjust their interactions and trust in AI systems based on their experiences. Findings from recent studies suggest that users' perceptions of AI are significantly influenced by their existing AI knowledge, indicating that higher AI literacy can lead to better trust adjustments following misrepresentations [96]. This underscores the importance of designing AI systems that are transparent and capable of offering feedback that enhances user understanding.

Designing educational tools and platforms that incorporate interactive feedback loops can facilitate active learning and critical engagement with AI technologies. These tools should effectively bridge the gap between theoretical knowledge and practical application, allowing users to actively engage with AI functionalities while obtaining immediate feedback on their interactions, which is crucial for enhancing understanding and addressing concerns regarding AI's role in academic writing and assessment [97, 9]. This iterative learning process reinforces AI concepts and encourages users to critically evaluate AI outputs, fostering a nuanced understanding of AI's capabilities and limitations.

To prepare individuals for the complexities of AI-driven environments, AI literacy programs should cultivate both cognitive and ethical competencies. This dual emphasis equips users with the skills necessary to critically evaluate AI technologies, understand their socio-technical implications, and engage with them responsibly. By integrating a multi-level competency model and assessment

strategies, these programs can ensure that learners grasp technical concepts and navigate the ethical challenges posed by AI in various contexts, from education to the workplace [46, 22, 23, 20]. Incorporating scenarios that simulate real-world AI challenges provides learners with opportunities to apply their knowledge in diverse contexts, promoting adaptability and critical thinking.

Incorporating user-centered design principles in the development of AI educational tools is essential for enhancing both engagement and accessibility. By prioritizing the diverse needs of learners, these tools can be tailored to foster AI literacy across various demographics, addressing significant gaps in understanding and competency that currently exist in K-12 education [28, 20, 10, 46, 98]. This approach involves actively involving users in the design process, gathering feedback to refine educational content and delivery methods, and ensuring that materials resonate with learners' experiences and expectations.

To effectively enhance AI literacy, a multifaceted strategy is essential, incorporating transparent feedback mechanisms, engaging interactive learning experiences, and user-centered design principles, all aimed at addressing the public's misconceptions about AI and equipping K-12 students with the necessary competencies to navigate an AI-driven society [98, 20, 10]. By fostering an environment that supports continuous learning and adaptation, these strategies can empower individuals to engage with AI technologies confidently and responsibly, contributing to their overall digital literacy and preparedness for an AI-driven future.

8 Conclusion

AI literacy is pivotal in adolescent development, necessitating educational frameworks that integrate AI competencies across various fields. The survey underscores the importance of digital literacy in fostering innovation and supporting economic growth, particularly in sectors like healthcare and education. To leverage AI's transformative potential, it is imperative to establish clear policies and provide targeted training for educators and stakeholders, equipping them with the necessary skills to thrive in AI-enhanced environments.

An interdisciplinary socio-technical approach to AI literacy is essential for ethical engagement with AI technologies. This approach underscores the alignment of AI systems, especially large language models, with human values and societal norms, addressing the ethical dimensions of adolescent development. Media education frameworks play a crucial role in fostering critical engagement with technology, contributing to a more informed and democratic society.

The survey also emphasizes the unique qualities of human educators, such as emotional intelligence and creativity, which remain irreplaceable by AI. This highlights the need for educational research to maintain relevance and applicability in real-world contexts, focusing on AI literacy and responsible AI use. Enhancing public understanding of AI and establishing robust regulatory frameworks are vital for preventing misuse and building trust.

Recommendations for educators, policymakers, and researchers include developing inclusive and accessible AI literacy curricula, promoting interdisciplinary learning, and integrating ethical considerations into AI education. By adopting these strategies, stakeholders can enhance public understanding and trust in AI technologies, preparing adolescents to navigate an AI-driven future responsibly. Personalized educational interventions have shown efficacy in improving the ability to discern misinformation, highlighting the significance of AI literacy in cultivating critical digital skills. Additionally, context-aware models enhance the quality of distractors for multiple-choice questions, providing valuable resources for automated assessment. Addressing dataset biases through methods like causal adjustment for feedback loops can improve predictive performance, contributing to more equitable and effective AI systems.

References

[1] David James Woo, Deliang Wang, Tim Yung, and Kai Guo. Effects of a prompt engineering intervention on undergraduate students' ai self-efficacy, ai knowledge and prompt engineering ability: A mixed methods study, 2024.

[2] Stefano Cuomo, Gabriele Biagini, and Maria Ranieri. Artificial intelligence literacy, che cos' è e come promuoverla. dall'analisi della letteratura ad una proposta di framework. *Media Education*, 13(2):161–172, 2022.

[3] Safinah Ali, Vishesh Kumar, and Cynthia Breazeal. Ai audit: A card game to reflect on everyday ai systems, 2023.

[4] Julia Mossbridge. Shifting the human-ai relationship: Toward a dynamic relational learning-partner model, 2024.

[5] Richard Tong, Haoyang Li, Joleen Liang, and Qingsong Wen. Developing and deploying industry standards for artificial intelligence in education (aied): Challenges, strategies, and future directions, 2024.

[6] Kowe Kadoma, Danaë Metaxa, and Mor Naaman. Generative ai and perceptual harms: Who's suspected of using llms?, 2024.

[7] Sarah Janboecke, Diana Loeffler, and Marc Hassenzahl. Using experimental vignettes to study early-stage automation adoption, 2020.

[8] Yingbo Ma, Yukyeong Song, Jeremy A. Balch, Yuanfang Ren, Divya Vellanki, Zhenhong Hu, Meghan Brennan, Suraj Kolla, Ziyuan Guan, Brooke Armfield, Tezcan Ozrazgat-Baslanti, Parisa Rashidi, Tyler J. Loftus, Azra Bihorac, and Benjamin Shickel. Promoting ai competencies for medical students: A scoping review on frameworks, programs, and tools, 2024.

[9] Nir Chemaya and Daniel Martin. Perceptions and detection of ai use in manuscript preparation for academic journals, 2024.

[10] Xiaofei Zhou, Jessica Van Brummelen, and Phoebe Lin. Designing ai learning experiences for k-12: Emerging works, future opportunities and a design framework, 2020.

[11] Helen Zhang, Irene Lee, Safinah Ali, Daniella DiPaola, Yihong Cheng, and Cynthia Breazeal. Integrating ethics and career futures with technical learning to promote ai literacy for middle school students: An exploratory study. *International Journal of Artificial Intelligence in Education*, 33(2):290–324, 2023.

[12] Margarida Romero. Lifelong learning challenges in the era of artificial intelligence: a computational thinking perspective, 2024.

[13] Shuyuan Xu, Juntao Tan, Zuohui Fu, Jianchao Ji, Shelby Heinecke, and Yongfeng Zhang. Dynamic causal collaborative filtering, 2022.

[14] Niklas Kühl, Christian Meske, Maximilian Nitsche, and Jodie Lobana. Investigating the role of explainability and ai literacy in user compliance, 2024.

[15] Anton Khritankov. Analysis of hidden feedback loops in continuous machine learning systems, 2021.

[16] Ana Lucic, Sheeraz Ahmad, Amanda Furtado Brinhosa, Vera Liao, Himani Agrawal, Umang Bhatt, Krishnaram Kenthapadi, Alice Xiang, Maarten de Rijke, and Nicholas Drabowski. Towards the use of saliency maps for explaining low-quality electrocardiograms to end users, 2022.

[17] Hyun-Young Kang. A study on digital and ai literacy education to prepare for future. *Journal of digital contents society*, 23(6):1067–1075, 2022.

[18] Prerna Ravi, Annalisa Broski, Glenda Stump, Hal Abelson, Eric Klopfer, and Cynthia Breazeal. Understanding teacher perspectives and experiences after deployment of ai literacy curriculum in middle-school classrooms, 2023.

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[19] Cecilia Ka Yuk Chan and Louisa H. Y. Tsi. The ai revolution in education: Will ai replace or assist teachers in higher education?, 2023.

[20] Lorena Casal-Otero, Alejandro Catala, Carmen Fernández-Morante, Maria Taboada, Beatriz Cebreiro, and Senén Barro. Ai literacy in k-12: a systematic literature review. *International Journal of STEM Education*, 10(1):29, 2023.

[21] Lu Ding, Sohee Kim, and R Allan Allday. Development of an ai literacy assessment for non-technical individuals: What do teachers know? *Contemporary Educational Technology*, 16(3):ep512, 2024.

[22] Gabriele Biagini. Assessing the assessments: Toward a multidimensional approach to ai literacy. *Media Education*, 15(1):91–101, 2024.

[23] Farhana Faruqe, Ryan Watkins, and Larry Medsker. Competency model approach to ai literacy: Research-based path from initial framework to model, 2021.

[24] Ervianti Ervianti, Rigel Sampelolo, and Muh Putra Pratama. The influence of digital literacy on student learning. *Klasikal: Journal of Education, Language Teaching and Science*, 5(2):358–365, 2023.

[25] Jeong-Bae Son, Sang-Soon Park, and Moonyoung Park. Digital literacy of language learners in two different contexts. *The Jalt Call Journal*, 13(2):77–96, 2017.

[26] Hasan Tinmaz, Yoo-Taek Lee, Mina Fanea-Ivanovici, and Hasnan Baber. A systematic review on digital literacy. *Smart Learning Environments*, 9(1):21, 2022.

[27] Emilda Sulasmi. Primary school teachersâ€™ digital literacy: An analysis on teachersâ€™ skills in using technological devices. *Journal of Innovation in Educational and Cultural Research*, 3(2):140–145, 2022.

[28] Amy Eguchi, Hiroyuki Okada, and Yumiko Muto. Contextualizing ai education for k-12 students to enhance their learning of ai literacy through culturally responsive approaches. *KI-Künstliche Intelligenz*, 35(2):153–161, 2021.

[29] Martin Nisser, Marisa Gaetz, Andrew Fishberg, Raechel Soicher, Faraz Faruqi, and Joshua Long. From prisons to programming: Fostering self-efficacy via virtual web design curricula in prisons and jails, 2024.

[30] Subaveerapandiyan A and Priyanka Sinha. Digital literacy and reading habits of the dmi-st. eugene university students, 2022.

[31] Alexandra List. Defining digital literacy development: An examination of pre-service teachers' beliefs. *Computers & Education*, 138:146–158, 2019.

[32] Hye Sun Yun, Mehdi Arjmand, Phillip Sherlock, Michael K. Paasche-Orlow, James W. Griffith, and Timothy Bickmore. Keeping users engaged during repeated administration of the same questionnaire: Using large language models to reliably diversify questions, 2024.

[33] Luis Morales-Navarro and Yasmin B. Kafai. Investigating youths' everyday understanding of machine learning applications: a knowledge-in-pieces perspective, 2024.

[34] Hyejin Park, Han Sung Kim, and Han Woo Park. A scientometric study of digital literacy, ict literacy, information literacy, and media literacy. *J. Data Inf. Sci.*, 6(2):116–138, 2021.

[35] Aakash Gautam, Khushboo Gandhi, and Jessica Eileen Sendejo. Enhancing reentry support programs through digital literacy integration, 2024.

[36] Mathilde Neugnot-Cerioli and Olga Muss Laurenty. The future of child development in the ai era. cross-disciplinary perspectives between ai and child development experts, 2024.

[37] Myles Joshua Toledo Tan and Nicholle Mae Amor Tan Maravilla. Shaping integrity: Why generative artificial intelligence does not have to undermine education, 2024.

[38] Jinkyung Park, Vivek Singh, and Pamela Wisniewski. Toward safe evolution of artificial intelligence (ai) based conversational agents to support adolescent mental and sexual health knowledge discovery, 2024.

[39] Zhicheng Lin. Beyond principlism: Practical strategies for ethical ai use in research practices, 2024.

[40] Yoshija Walter. Embracing the future of artificial intelligence in the classroom: the relevance of ai literacy, prompt engineering, and critical thinking in modern education. *International Journal of Educational Technology in Higher Education*, 21(1):15, 2024.

[41] Ji-Yeon Hong and Yungsik Kim. Development of digital and ai teaching-learning strategies based on computational thinking for enhancing digital literacy and ai literacy of elementary school student. *Journal of the Korean Association of Information Education*, 26(5):341–352, 2022.

[42] Wuraola Oyewusi. Ai literacy in low-resource languages:insights from creating ai in yoruba videos, 2024.

[43] Margarida Romero. Collaborative design of ai-enhanced learning activities, 2024.

[44] Anuj Gupta, Yasser Atef, Anna Mills, and Maha Bali. Assistant, parrot, or colonizing loud-speaker? chatgpt metaphors for developing critical ai literacies, 2024.

[45] Antonette Shibani, Simon Knight, Kirsty Kitto, Ajanie Karunanayake, and Simon Buckingham Shum. Untangling critical interaction with ai in students written assessment, 2024.

[46] Sri Yash Tadimalla and Mary Lou Maher. Ai literacy for all: Adjustable interdisciplinary socio-technical curriculum, 2024.

[47] Madelyne Xiao, Mona Wang, Anunay Kulshrestha, and Jonathan Mayer. Account verification on social media: User perceptions and paid enrollment, 2023.

[48] Rita Stampfl, Barbara Geyer, Marie Deissl-O'Meara, and Igor Ivkić. Revolutionising role-playing games with chatgpt, 2024.

[49] Nasreen Khan, Abdullah Sarwar, Tan Booi Chen, and Shereen Khan. Connecting digital literacy in higher education to the 21st century workforce. *Knowledge Management & E-Learning*, 14(1):46–61, 2022.

[50] Nicolas Pope, Juho Kahila, Henriikka Vartiainen, Mohammed Saqr, Sonsoles Lopez-Pernas, Teemu Roos, Jari Laru, and Matti Tedre. An xai social media platform for teaching k-12 students ai-driven profiling, clustering, and engagement-based recommending, 2024.

[51] Yueqiao Jin, Roberto Martinez-Maldonado, Dragan Gašević, and Lixiang Yan. Glat: The generative ai literacy assessment test, 2024.

[52] Gaoxia Zhu, Xiuyi Fan, Chenyu Hou, Tianlong Zhong, Peter Seow, Annabel Chen Shen-Hsing, Preman Rajalingam, Low Kin Yew, and Tan Lay Poh. Embrace opportunities and face challenges: Using chatgpt in undergraduate students' collaborative interdisciplinary learning, 2023.

[53] Ayesha Ali and Ihsan Ayyub Qazi. Countering misinformation on social media through educational interventions: Evidence from a randomized experiment in pakistan, 2021.

[54] Semere Kiros Bitew, Amir Hadifar, Lucas Sterckx, Johannes Deleu, Chris Develder, and Thomas Demeester. Learning to reuse distractors to support multiple choice question generation in education, 2022.

[55] Jiayi Wang, Ruiwei Xiao, and Ying-Jui Tseng. Generating ai literacy mcqs: A multi-agent llm approach, 2024.

[56] Kate Pearce, Sharifa Alghowinem, and Cynthia Breazeal. Build-a-bot: Teaching conversational ai using a transformer-based intent recognition and question answering architecture, 2022.

[57] Sebastian Krügel, Andreas Ostermaier, and Matthias Uhl. Zombies in the loop? humans trust untrustworthy ai-advisors for ethical decisions, 2021.

[58] Mohamed El Louadi. On the preservation of africa's cultural heritage in the age of artificial intelligence, 2024.

[59] Fabrizio Dell'Acqua, Edward McFowland III, Ethan R Mollick, Hila Lifshitz-Assaf, Katherine Kellogg, Saran Rajendran, Lisa Krayer, François Candelon, and Karim R Lakhani. Navigating the jagged technological frontier: Field experimental evidence of the effects of ai on knowledge worker productivity and quality. *Harvard Business School Technology & Operations Mgt. Unit Working Paper*, (24-013), 2023.

[60] Divya Shanmugam, Monica Agrawal, Rajiv Movva, Irene Y. Chen, Marzyeh Ghassemi, Maia Jacobs, and Emma Pierson. Generative ai in medicine, 2024.

[61] Anton Korinek. Generative ai for economic research: Use cases and implications for economists. *Journal of Economic Literature*, 61(4):1281–1317, 2023.

[62] Tao Long, Katy Ilonka Gero, and Lydia B. Chilton. Not just novelty: A longitudinal study on utility and customization of an ai workflow, 2024.

[63] Denis Newman-Griffis. Ai thinking: A framework for rethinking artificial intelligence in practice, 2024.

[64] Diletta Abbonato. Public sentiments on the fourth industrial revolution: An unsolicited public opinion poll from twitter, 2024.

[65] Suresh Venkatasubramanian, Nadya Bliss, Helen Nissenbaum, and Melanie Moses. Interdisciplinary approaches to understanding artificial intelligence's impact on society, 2020.

[66] Bogdana Rakova and Rumman Chowdhury. Human self-determination within algorithmic sociotechnical systems, 2019.

[67] Tilman Michaeli, Stefan Seegerer, and Ralf Romeike. What students can learn about artificial intelligence – recommendations for k-12 computing education, 2023.

[68] Jimin Mun, Liwei Jiang, Jenny Liang, Inyoung Cheong, Nicole DeCario, Yejin Choi, Tadayoshi Kohno, and Maarten Sap. Particip-ai: A democratic surveying framework for anticipating future ai use cases, harms and benefits, 2024.

[69] Mohit Chandra, Suchismita Naik, Denae Ford, Ebele Okoli, Munmun De Choudhury, Mahsa Ershadi, Gonzalo Ramos, Javier Hernandez, Ananya Bhattacharjee, Shahed Warreth, and Jina Suh. From lived experience to insight: Unpacking the psychological risks of using ai conversational agents, 2024.

[70] Simone Grassini. Shaping the future of education: Exploring the potential and consequences of ai and chatgpt in educational settings. *Education sciences*, 13(7):692, 2023.

[71] Julia Feerrar. Development of a framework for digital literacy. *Reference Services Review*, 47(2):91–105, 2019.

[72] Soojong Kim. Perceptions of discriminatory decisions of artificial intelligence: Unpacking the role of individual characteristics, 2024.

[73] Mária Csernoch, Ádám Gulácsi, and Júlia Csernoch. Subject integration with spreadsheets – ignoring education is the greatest risk ever, 2024.

[74] Jose Gomez-Galan. Media education as theoretical and practical paradigm for digital literacy: An interdisciplinary analysis, 2018.

[75] Lixiang Yan, Samuel Greiff, Ziwen Teuber, and Dragan Gašević. Promises and challenges of generative artificial intelligence for human learning, 2024.

[76] Sofia Serrano, Zander Brumbaugh, and Noah A. Smith. Language models: A guide for the perplexed, 2023.

21

[77] Sumedh Rasal. An artificial neuron for enhanced problem solving in large language models, 2024.

[78] Nicolas Pope, Juho Kahila, Jari Laru, Henriikka Vartiainen, Teemu Roos, and Matti Tedre. An educational tool for learning about social media tracking, profiling, and recommendation, 2024.

[79] Mohammad Hossein Jarrahi and Stanley Ahalt. What human-horse interactions may teach us about effective human-ai interactions, 2024.

[80] Kavindu Ravishan, Dániel Szabó, Niels van Berkel, Aku Visuri, Chi-Lan Yang, Koji Yatani, and Simo Hosio. From voice to value: Leveraging ai to enhance spoken online reviews on the go, 2024.

[81] Simon Hudson and Matija Franklin. Science communications for explainable artificial intelligence, 2023.

[82] Karl Krauth, Yixin Wang, and Michael I. Jordan. Breaking feedback loops in recommender systems with causal inference, 2022.

[83] Minja Axelsson, Micol Spitale, and Hatice Gunes. "oh, sorry, i think i interrupted you": Designing repair strategies for robotic longitudinal well-being coaching, 2024.

[84] Huixin Zhong, Eamonn O'Neill, and Janina A. Hoffmann. Regulating ai: Applying insights from behavioural economics and psychology to the application of article 5 of the eu ai act, 2024.

[85] Kathryn MacCallum, David Parsons, and Mahsa Mohaghegh. Identifying the components of foundational artificial intelligence (ai) literacy-early results from a delphi study. *ASCILITE Publications*, pages 157–166, 2023.

[86] Shachar Don-Yehiya, Ben Burtenshaw, Ramon Fernandez Astudillo, Cailean Osborne, Mimansa Jaiswal, Tzu-Sheng Kuo, Wenting Zhao, Idan Shenfeld, Andi Peng, Mikhail Yurochkin, Atoosa Kasirzadeh, Yangsibo Huang, Tatsunori Hashimoto, Yacine Jernite, Daniel Vila-Suero, Omri Abend, Jennifer Ding, Sara Hooker, Hannah Rose Kirk, and Leshem Choshen. The future of open human feedback, 2024.

[87] The rise of artificial intelligence in educational measurement: Opportunities and ethical challenges.

[88] Yiheng Qian, Tejaswi Polimetla, Thomas W. Sanchez, and Xiang Yan. How do transportation professionals perceive the impacts of ai applications in transportation? a latent class cluster analysis, 2024.

[89] Dito Anurogo, Hardin La Ramba, Nabila Diyana Putri, and Ulfah Mahardika Pramono Putri. Digital literacy 5.0 to enhance multicultural education. *Multicultural Islamic Education Review*, 1(2):109–179, 2023.

[90] Banny SK Chan, Daniel Churchill, and KF Chiu. Digital literacy learning in higher education through digital storytelling approach. *Journal of International Education Research*, 2017.

[91] Marcus Leaning. An approach to digital literacy through the integration of media and information literacy. *Media and communication*, 7(2):4–13, 2019.

[92] Subaveerapandiyan A and Anuradha Maurya. Digital media and information literacy: A way to paperless society, 2022.

[93] Krish Chetty, Liu Qigui, Nozibele Gcora, Jaya Josie, Li Wenwei, and Chen Fang. Bridging the digital divide: measuring digital literacy. *Economics*, 12(1):20180023, 2018.

[94] Yiming Luo, Patrick Cheong-Iao Pang, and Shanton Chang. Enhancing exploratory learning through exploratory search with the emergence of large language models, 2025.

[95] Hiromu Yakura, Ezequiel Lopez-Lopez, Levin Brinkmann, Ignacio Serna, Prateek Gupta, and Iyad Rahwan. Empirical evidence of large language model's influence on human spoken communication, 2024.

[96] Qiaosi Wang, Chidimma L. Anyi, Vedant Das Swain, and Ashok K. Goel. Navigating ai fallibility: Examining people's reactions and perceptions of ai after encountering personality misrepresentations, 2024.

[97] Jasper Roe, Mike Perkins, and Daniel Ruelle. Understanding student and academic staff perceptions of ai use in assessment and feedback, 2024.

[98] Duri Long and Brian Magerko. What is ai literacy? competencies and design considerations. In *Proceedings of the 2020 CHI conference on human factors in computing systems*, pages 1–16, 2020.

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