A Framework for Integrating Artificial General Intelligence into Engineering Education: Enhancing Human-Centric Approaches for Industry 5.0

Trini S. Balart and Kristi J. Shryock

***Abstract*— In this paper, we present an advanced conceptual framework for integrating Artificial General Intelligence (AGI) into engineering education (Artificial General Intelligence Integration into Engineering Education (AGI^2E^2)). Our aim is to harmonize technical skills with intrinsic human qualities, such as creativity and ethical reasoning, essential for the Industry 5.0 landscape. This framework is based on comprehensive literature reviews and empirical data from student and faculty surveys, analyzed to assess AGI's potential to foster these human-centered qualities. Our proposal includes dynamic, interdisciplinary learning environments, personalized educational trajectories, continuous adaptation, and lifelong learning, addressing the ethical issues of AGI application. This framework not only advances engineering education to meet Industry 5.0 demands but also fosters holistic, human-centered learning experiences, preparing technically competent engineers equipped with vital interpersonal skills. This work builds upon previous research presented at a conference on integrating AI into engineering education.**

***Index Terms*— Adaptive learning, Artificial General Intelligence, Artificial intelligence, ChatGPT, Career development, Curriculum development, Engineering education, Educational programs, Educational technology, Student perceptions**

I. INTRODUCTION

In the era of Industry 5.0, engineering education is at a critical juncture, requiring a reevaluation of pedagogical strategies to integrate technological advances with the development of intrinsic human qualities. This article presents an advanced conceptual framework that aims to create synergies between Artificial General Intelligence (AGI) and human-centered learning in engineering education. The goal is to prepare engineers who are not only technically competent but also possess qualities necessary to solve contemporary challenges, including creativity, critical thinking, metacognition, and self-regulation [1]. This integration is vital for preparing students for the multifaceted challenges and opportunities of the modern, technology-driven world.

This work builds upon the research presented in "A Framework for Integrating AI into Engineering Education, Empowering Human-Centered Approach for Industry 5.0" by Balart and Shryock [2] that introduced a novel conceptual framework for Artificial Intelligence (AI) integration into engineering education. The original framework emphasized dynamic, interdisciplinary learning environments and personalized educational trajectories. This paper expands on these concepts by incorporating insights from recent advancements in AGI and further empirical data from student and faculty surveys.

Relevant literature reveals a gap in current educational paradigms [2]. While the role of AI in skill development is explored, its potential to foster human-centered qualities in engineering students remains underexplored. Studies increasingly highlight the importance of interpersonal skills alongside technical knowledge in engineering education. However, comprehensive frameworks for effective AGI integration that can foster these skills are lacking.

AGI represents a significant leap in AI development, characterized by systems capable of thinking, learning, executing, and coordinating complex multi-tasking behavior similar to humans. Unlike traditional AI systems, AGI can set its own goals, devise strategies, and adapt to new circumstances, mirroring the complex operations of the human brain [3]. This term proposes the development of intelligent machines that possess human-like cognitive capabilities, such as understanding and learning. AGI aims to simulate human intelligence, with its various complexities and abilities such as critical reasoning, problem solving, creativity and adaptability [4]. The transformative potential of AGI in education lies in its ability to act as both an instructor and a peer, offering dynamic, interdisciplinary learning environments and personalized educational trajectories that foster continuous adaptation and lifelong learning [5].

In response, this research combines a broader literature review focused specifically on the impact of AGI in education with empirical data from the same survey of students and faculty at Texas A&M University but one year apart, proposing a multifaceted understanding of the role of AGI in engineering education. More detailed information about the original survey can also be found in [6], [7]. The outcome includes the development of a framework that emphasizes interdisciplinary learning, personalized educational pathways, ethical and emotional intelligence development, participatory pedagogies, and continuous adaptive and feedback mechanisms. This framework moves towards an educational paradigm in which AGI is not a mere technological tool, but a facilitator of holistic, human-centered learning experiences. This research is vital as it contributes both to theory and practice. Theoretically, it expands the discourse on AGI in education, specifically in engineering, by introducing a framework that bridges technological skills with human-centric qualities. Practically, it offers educators and institutions a guide to implement AGI in a way that prepares students not just as professionals but as well-rounded individuals capable of adapting to and thriving in the dynamic landscape of Industry 5.0. Thus, this research makes a

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significant contribution to the evolving field of engineering education, steering it towards a more integrated, balanced, and human-centric future. The research questions of this work are:

1) How can AGI be integrated into engineering education to balance technical skills with intrinsic human qualities such as creativity and ethical reasoning, which are essential in the Industry 5.0 landscape?
2) What gaps exist in current educational paradigms regarding the integration of AGI in fostering human-centered qualities in engineering students, and how can these gaps be addressed?
3) What are the aspects that should be emphasized when integrating AGI into education, particularly in the context of engineering and preparing for Industry 5.0

The integration of AGI in educational contexts, particularly in engineering education, promises to significantly reshape the educational ecosystem. While AGI has the potential to transform educational practices by fostering collaborative learning and personalized education, it also raises concerns about ethical considerations, data privacy, and the impact on traditional educational paradigms. By leveraging AGI's capabilities to facilitate collaborative learning, provide personalized educational paths, and promote continuous adaptation, we can prepare students for the demands of Industry 5.0 and beyond. This research aims to contribute to the ongoing dialogue on the role of AGI in education, offering a framework that balances technical competence with human-centered qualities, thereby fostering a more holistic, inclusive, and dynamic educational experience.

II. Literature Review

This literature review builds upon the foundation laid in the original paper [2]. While the original review covered significant ground in understanding the role of AI in education, this expanded review delves deeper into recent advancements in AGI and their implications for engineering education. We invite readers to refer to the original paper for a more detailed exploration of AI's foundational impacts on education, and the foundation of the proposed framework too.

Recent advancements in AI and its growing influence on educational paradigms have sparked significant interest in redefining engineering education [8]. In the context of Industry 5.0, a shift towards integrating human-centric skills with technical knowledge is becoming increasingly important [9]. This literature review begins exploring the sections defined at [2], where each section has been supplemented with material found in a second exploratory literature review on the impact of AGI on education, and new sections have been identified as well.

The application of AI in education has been diverse, ranging from personalized learning experiences to adaptive curricular design [10]. However, challenges, such as ensuring pedagogical effectiveness and addressing ethical concerns remain. Several studies highlight the potential and limitations of AI for reshaping educational environments. However, most of them have a tendency to adapt these new technologies to the system we have always had and without focusing more on how we can use them to promote a new system.

Holistic education that emphasizes soft skills like critical thinking and emotional intelligence is gaining recognition as a crucial component of engineering education. These skills are not only valuable in professional contexts but also in fostering well-rounded and integral individuals [11]. This body of work suggests a paradigm shift in educational objectives, aligning them more closely with humanistic values.

By the other hand, the interplay between AGI and the role of human educators has been explored [5]. Also the exploratory research on the intersection between AGI and human-centric learning approaches within education, has highlighted the potential of AGI to transform educational practices [12]. This section is structured around the themes of AGI in learning environments, enhancing skills development, fostering lifelong learning, ethical and accessibility considerations, and existing frameworks.

In June 2021, at the International Conference of the Finland Futures Research Centre, Jerome Glenn gave the keynote: “The Transition from artificial narrow intelligence to artificial general intelligence” [13]. In this keynote, he defined three kinds of AI: Artificial Narrow Intelligence (ANI); Artificial General Intelligence (AGI), and Artificial Super Intelligence (ASI). He also stated that the only way to determine if ASI is going to turn up in a beneficial way for humanity is to get the conditions ‘right’, on transition from ANI to AGI. He also states that AGI will change Learning and Education. An analysis of his work can be found in [14].

A. AGI in Learning Environments

With the potential advanced cognitive capabilities of AGI, it can significantly enhance learning environments by creating more interactive and responsive educational settings [5]. AGI systems can adapt to the individual learning pace of each student, providing customized feedback and support. This adaptability can lead to more effective learning outcomes, as students receive immediate assistance tailored to their specific needs [15]. Furthermore, AGI can facilitate collaborative learning by connecting students with peers and educators globally, fostering a rich exchange of ideas and perspectives. The ability of AGI to simulate real-world scenarios and provide experiential learning opportunities can also deepen students' understanding of complex concepts, preparing them for practical applications in their future careers [5].

The authors of [5] also emphasize the importance of interdisciplinary collaborations between educators and AI engineers to advance research and application efforts. This collaboration is crucial for developing responsible AGI use in academic settings and ensuring that AGI implementation in education is culturally relevant and appropriate. This demonstrates the importance of fostering interdisciplinary learning environments to better prepare future generations for a complex, multi-variable and, in essence, interdisciplinary world.

B. AGI that Enhances Skills Development

AGI's role in enhancing skills development is multifaceted. According to [16], the rapid advancement of these technologies and specifically the creation of AGI, could

represent an amazing opportunity to enhance flourishing in a significant way, at the same time that present multiple challenges in order to not have an negative impact on human cognitive development. AGI systems can provide personalized coaching and mentoring, helping students develop critical thinking and problem-solving skills through interactive and adaptive learning experiences [13]. By continuously monitoring students' progress and providing real-time feedback, AGI can help students identify areas for improvement and develop effective learning strategies [15]. AGI has the potential to significantly enhance skills development in education by complementing and enriching human capabilities rather than replacing them. By integrating AGI tools into educational practices, educators can create dynamic learning environments that foster critical thinking, creativity, teamwork, and communication [12].

The integration of AGI in skill development is not just about enhancing technical knowledge but also about fostering a holistic set of competencies. This approach prepares engineering students not only for the immediate challenges of their profession but also equips them with the adaptability and critical thinking skills necessary for lifelong learning and professional growth in the ever-evolving landscape of Industry 5.0.

C. AGI's Role in Fostering Lifelong Learning

AGI can significantly enhance lifelong learning by providing continuous access to personalized and adaptive learning resources, the future role of AGI in higher education envisions virtual companions that assist in personalized learning, knowledge curation, and continual education, providing guidance, counsel, and constant support to individuals [17]. AGI systems can recommend learning materials and activities based on individual learning styles and preferences, ensuring that learners remain engaged and motivated. By analyzing learners' performance and feedback, AGI can adapt the learning content to suit their evolving needs and goals [18]. This personalized approach can help learners acquire new skills and knowledge at their own pace, fostering a culture of continuous learning and improvement. AGI's ability to provide real-time feedback and support can also help learners stay on track and achieve their learning objectives.

By the other hand, the AGI' capability of continuous improvement allows educational paradigms to be updated to the different industry needs. AGI systems can continuously learn and adapt based on feedback, improving their effectiveness in supporting both students and instructors. Continuous improvement in teaching is vital because it enhances students' learning experiences, facilitates the adoption of modern teaching techniques, and boosts educators' overall effectiveness. By committing to ongoing growth and development, educators can significantly impact the lives of their students and instill a lasting love for learning. Moreover, continuous improvement helps instructors adapt to changes in curriculum, technology, and student needs, ensuring that instructional methods remain relevant and impactful. This concept emphasizes self-reflection, feedback implementation, and professional development as fundamental strategies for enhancing teaching practices and achieving better outcomes for students. Ultimately, continuous improvement in teaching is an essential journey that requires a growth mindset, openness to feedback, and dedication to lifelong learning to provide the best education for all students [19].

D. AGI in Curriculum Development

For curriculum development and content creation, identifying or developing suitable learning opportunities for students is crucial [12]. Integrating AGI into curriculum development represents a significant leap in the ability to create, deliver, and assess educational content. As mentioned earlier, AGI systems can analyze vast amounts of educational data to identify gaps, recommend improvements, and personalize learning experiences to meet the diverse needs of students [20]. By leveraging data from various sources such as student assessments, learning behaviors, and engagement metrics, AGI can create tailored educational experiences that maximize each student's potential, and personalize curriculum to different learning needs [21].

One of the most significant advantages of AGI in curriculum development is its ability to provide real-time updates to the curriculum. Traditional curriculum development processes are often static and slow to adapt to new information or changing educational standards. AGI, however, can continuously monitor advancements in various fields and incorporate the latest knowledge and skills into the curriculum [5]. This dynamic approach ensures that the curriculum remains relevant and engaging, adapting to the changing needs and interests of students. Additionally, AGI can incorporate various multimedia elements such as videos, interactive simulations, and gamified learning experiences to cater to different learning preferences [12]. By continuously analyzing student interactions with the content, AGI can adjust the difficulty level and presentation style to optimize learning outcomes, including adaptive learning methodologies into the curriculum-building process [18]. It can also support teachers in creating learner-centered lessons and assessing student understanding, enhancing the overall curriculum development process [5].

E. AGI in Instructor Support Systems

Instructors need ongoing guidance and mentoring to navigate the AI era effectively [22]. Developing communities of practice where teachers collaborate, share experiences, and learn from each other can create an encouraging and dynamic learning environment. Mentoring programs, where experienced educators provide advice on integrating AGI, offer valuable insights. Regular feedback and coaching from instructional leaders and technology professionals can help teachers refine their AGI implementation techniques and continuously improve their instructional practices [15]. Promoting a culture of innovation and experimentation is also crucial.

According to [12] AGI in education works best when it collaborates with human educators, supporting and enhancing their pedagogical approaches. Just as these technologies can create personalized learning experiences for students, they could do the same for instructors. AI can provide personalized

professional development opportunities tailored to their individual needs and career goals [23]. By analyzing data on teaching practices, classroom performance, and student outcomes, AGI can identify areas where faculty may benefit from additional training or resources. AGI can facilitate continuous learning and provide real-time feedback to instructors, similar to how it supports students. By monitoring classroom interactions and student engagement, it can offer constructive feedback on teaching methods and suggest adjustments to improve effectiveness, which has been identified as providing a positive impact to the learning experience [24]. This continuous learning model provides a foundation for faculty to constantly improve and adapt to new challenges in education.

AGI can act as an assistant instructor, offering personalized feedback, guidance, and support to students, adapting to individual learning paces, and providing remedial or advanced content as needed. It can assist educators in tailoring instructional methods to align with students' developmental stages and learning needs, enhancing the overall support system in educational settings [5]. It can also significantly streamline curriculum management by automating various administrative tasks, such as scheduling, grading, and resource allocation. This automation can reduce the administrative burden on educators, allowing them to focus more on teaching and mentoring [25].

F. AGI in Assessment and Evaluation

AGI can be used to create assessments for adaptive learning environments [26]. Adaptive assessments can significantly reduce the time required for testing by focusing on the most relevant questions for each student [27]. This efficiency not only saves time but also reduces student fatigue and anxiety associated with lengthy exams [28]. AGI can also provide real-time feedback on assessments, enabling students to understand their strengths and weaknesses immediately [18]. This promotes continuous improvement and helps students stay engaged and motivated in their learning. Real-time feedback is particularly valuable for formative assessments, which are used to monitor student learning progress throughout a course [29]. This is particularly important in engineering where knowledge is often built on prior knowledge.

Traditional assessments often focus solely on academic achievement, but holistic evaluation recognizes the importance of a broader range of skills and competencies [30]. These tools can facilitate holistic evaluation by considering multiple dimensions of student performance, including cognitive, social, and emotional aspects. This provides a more comprehensive understanding of students' abilities and potential. Beyond conventional metrics, complex abilities and competencies including creativity, problem-solving, and critical thinking may be evaluated using AGI-driven assessment systems [31].

G. Ethical Considerations

The integration of AGI in educational environments, as discussed in the preceding sections, necessitates careful consideration of ethical issues. AGI systems often require vast amounts of data to function effectively. Ensuring the privacy and security of this data is paramount [32]. AGI systems must adhere to stringent data protection regulations to safeguard students' personal information from unauthorized access and breaches. Implementing robust encryption methods and secure data storage practices can help mitigate risks associated with data privacy [33].

While AGI can enhance the educational experience, it is crucial to balance its use with human interaction. It is vitally important to take a human centered approach and focus on how the learner interacts with these technologies [12]. AGI incorporation on education should be as a supplementary tool rather than replacement of human interactions [34]. Educators need adequate training and support to effectively integrate AGI into their teaching practices. Professional development programs can equip educators with the skills and knowledge required to utilize AGI tools effectively, ensuring they can enhance learning while maintaining a focus on human-centric skills development [15].

AGI's decision-making processes must be transparent to educators, students, and stakeholders, in order to address concerns related to its responsible use [3]. Understanding how AGI systems arrive at their recommendations and decisions is crucial for maintaining trust. This includes providing clear algorithms explanations, data sources, and architecture of the models [35]. Additionally, there should be mechanisms for accountability, where the decisions made by AGI systems can be reviewed and challenged if necessary [35]. It is also important to encourage open dialogue, create transparent environments to discuss these topics, and provide training to both students and faculty on how to use these tools [34]. Another significant challenge in developing AGI is addressing the biases inherent in the training data. Such biases can lead to discriminatory outcomes, reinforcing societal inequalities. Researchers must diligently identify and mitigate biases to ensure AGI algorithms treat all individuals equitably [3].

H. Accessibility

AGI tools should be designed inclusively to accommodate diverse learning needs, this includes features that support students with disabilities, such as adaptive learning technologies that can be tailored to individual preferences and abilities [5], [36]. Providing multiple modes of interaction, such as voice commands, text, and visual aids, can enhance accessibility for all students. Also, humans learn best with a multimodal system that encompasses different learning styles (visual, auditory), targeting different ways of processing information [12].

The widespread adoption of AI technologies can increase economic inequalities by centralizing wealth and power among a few, marginalizing disadvantaged groups, and worsening social disparities [35]. To counter this, policies and interventions are needed to promote equitable access to AI technologies, ensure fair distribution of benefits, and empower underrepresented communities in the digital economy [35]. Additionally, fostering inclusive innovation ecosystems and promoting diversity in AI research and development can address systemic biases and enhance social justice in AGI

deployment. Ensuring equitable and inclusive quality education to all students is essential, and AGI-driven educational tools can help achieve this goal [5]. Equitable access to AGI technology can help bridge the digital divide and provide equal learning opportunities for all students [37].

As was already mentioned, algorithmic bias is another thing to take into consideration on evaluating accessibility and inclusivity. Ensuring that ethical considerations guide AGI development requires identifying and correcting these biases to prevent harm and enhance fairness and to ensure AGI algorithms treat all individuals equitably [3]. Enhancing diversity in data collection is essential for reducing bias and promoting inclusivity, ensuring AGI systems serve all societal segments fairly [3].

I. Related Research

Balart and Shryock explored existing frameworks for integrating AI into education in [2], and additional insights were considered for this revised version. However, it is important to also highlight research that specifically addresses the potential and challenges of incorporating AGI into education.

Latif et al. [5] discusses the emergence of AGI and its transformative potential in education through its ability to replicate human intelligence. AGI performs complex tasks requiring human-like reasoning, problem-solving, and emotional understanding. Unlike traditional AI, AGI can adapt to individual student needs, offering personalized learning experiences and comprehensive feedback, thereby enhancing intelligent tutoring systems, educational assessments, and evaluation procedures. The authors underscore the necessity of interdisciplinary collaboration between educators and AI engineers to ensure responsible and effective AGI integration in education. They also highlight ethical concerns such as data bias, fairness, and privacy, advocating for codes of conduct to guide AGI use in academic settings. The paper concludes by encouraging further research into AGI's impact on pedagogy, curriculum design, and the evolving role of human educators amidst advancing machine intelligence.

The paper by Lee et al. [12] presents a comprehensive examination of how multimodal AI approaches are advancing towards the realization of AGI in educational settings. It highlights the importance of multimodality in AI, which includes auditory, visual, kinesthetic, and linguistic modes of learning. The integration of AGI in education is seen as transformative, enhancing teaching and learning effectiveness, addressing gaps in existing methodologies, and focusing on ethical considerations. The paper emphasizes AGI's capability to process and integrate diverse data types, making it suitable for complex, real-world applications. It discusses the potential of AGI to improve peer assessment, personal, and adaptive learning processes. Initiatives such as the generative AI (GAI) initiative and the AI4STEM Education Center at the University of Georgia are highlighted as efforts to integrate AGI into educational contexts. The paper concludes by addressing the ethical considerations and advocating for responsible AGI.

According to [38], AGI’s ability to comprehend, learn, and perform tasks akin to human cognition, generates significant anticipation across scientific, commercial, and societal fields, particularly within the Internet of Things (IoT). This research explores the opportunities and challenges of integrating AGI into IoT, starting with the fundamentals of IoT and the critical role of AI, then delving into AGI basics and proposing a framework for AGI's seamless integration within IoT. In this article, a broad spectrum of AGI-based IoT applications in different domains, including education are explored. It highlights AGI technologies that enhance education by providing personalized and interactive learning experiences, offering formative assessment prompts, feedback and relevant references to drive student engagement and understanding. It is also mentioned that these tools help teachers plan lessons by expanding content knowledge and perspectives, resulting in more effective and engaging lessons. AGI facilitates individualized and adaptive learning, tailoring instruction and assessment to the needs of each learner, which improves educational outcomes and student success. In addition, the integration of AGI encourages educators to adopt innovative teaching methods, fostering students' creativity and critical thinking skills.

C. Chan [34] developed an AI education policy for higher education. She commented that “while GPT-3.5 and GPT-4 are not true AGI systems, they represent significant progress towards achieving AGI”. Which presents both opportunities and challenges for academic settings, but has the potential to significantly impact education by revolutionizing teaching and learning processes. On one hand, AGI can enhance personalized learning by providing real-time feedback, adaptive learning paths, and support to students, potentially improving learning outcomes and digital competence. However, there are concerns about academic integrity, as these tools can facilitate cheating and plagiarism. Moreover, the reliance on AGI could undermine the development of critical thinking and writing skills among students. As a result, educational institutions must develop comprehensive AI policies that address ethical considerations, data privacy, and equitable access to AI technologies. By fostering an environment where AI is used responsibly and ethically, universities can leverage the benefits of AGI while mitigating its risks, preparing students for an AI-driven future and ensuring the integrity of educational practices while underscoring the importance of human-AI collaboration to enhance pedagogical approaches and create efficient, adaptable learning environments.

P. Godbole [18] states that AGI holds the potential to revolutionize education by enhancing learning processes and academic systems. AGI's capabilities, such as human-like understanding, reasoning, learning, and problem-solving, can be harnessed to create personalized learning experiences, tailored curricula, and automated assessment procedures. By analyzing vast amounts of student data, AGI systems can customize educational programs to individual needs, improving engagement and learning outcomes. AGI-driven tutoring systems can provide real-time adaptive assistance, enhancing comprehension and retention. Additionally, AGI can automate and refine assessment processes, offering immediate feedback and deeper insights into student performance. However, the integration of AGI also

necessitates addressing ethical considerations, ensuring fairness and inclusivity, and continuously adapting to the evolving educational landscape.

Finally, in "Redefining the teacher's role in education through Artificial General Intelligence" [15]. It is discussed that the integration of AGI in education holds transformative potential, redefining traditional teacher roles and improving pedagogical methods. AGI, with its human-level cognitive capabilities in various tasks, can process large volumes of data, providing personalized learning experiences tailored to the individual needs of students. This technology enables real-time feedback, adaptive learning and collaborative environments, fostering student engagement and improving academic outcomes. In addition, AGI can help teachers create dynamic and interactive lessons, address knowledge gaps, and facilitate critical thinking and creativity. However, the adoption of AGI in education requires careful consideration of ethical issues such as data privacy, algorithmic bias, and equitable access to the technology. By equipping educators with the skills and support necessary to harness the capabilities of AGI, the education system can ensure a harmonious coexistence of human teachers and advanced technology, ultimately preparing students for a rapidly evolving future.

III. Survey

To gain insights and attempt to understand perceptions of GAI at Texas A&M University, after the release of ChatGPT, two surveys were designed, one directed at students at the university and the other to faculty/staff on campus. In the first distribution a couple of months after the release of GAI, ChatGPT, there were 243 responses from faculty/staff members and 813 responses from students. In both the faculty/staff and student surveys, the largest number of responses came from the engineering faculty, with about 80% of the responses. The full survey and some preliminary data can be found at [6], [7]. A year later this same survey was conducted again targeting the same community, with an impressive interest from the faculty/staff community, reaching around 600 responses in the first 24 hours. After a few weeks, a total of 103 student responses and 884 faculty/staff responses were received. Preliminary results of the analysis of the faculty responses in this second version can be found at [39].

The main goals of the survey include, understanding how students and faculty/staff use ChatGPT for various academic activities such as research, tutoring, content generation, and personalized learning; evaluating the comfort level of the academic community in integrating ChatGPT and other AI tools into their educational or teaching practices; investigating perceptions of academic dishonesty associated with AI use; examining the impact of AI on critical engineering skills like problem-solving, critical thinking, and teamwork, as well as aspects of student development like self-efficacy and academic performance; and try to anticipate how AI might influence various academic disciplines in the future.

The survey consists of a range of quantitative and qualitative questions to obtain detailed insights. Preliminary findings suggest a mixed reaction towards AI, with some recognizing its potential to enhance learning and others concerned about its impact on academic integrity and skill development. The results of this survey are intended to inform educational strategies and policies, helping institutions to adapt to the evolving landscape of AI in education. The survey's comprehensive nature, covering multiple facets of AI in academia, makes it a valuable tool for understanding the current state and future potential of GAI in educational settings. For the purpose of this particular analysis, we considered only responses from faculty and students to the question: How do you think AI tools like ChatGPT will influence the future of your discipline?

A. Main Insights from Faculty

The responses from faculty members regarding the impact of AI tools like ChatGPT on their disciplines highlight a range of perspectives, concerns, and potential applications. These insights reflect both the opportunities and challenges posed by the integration of AI into academic and professional settings.

1) Enhancement of academic efficiency

In the first place, faculty members recognize the potential of AI tools to streamline administrative and academic tasks, such as email drafting and basic research activities. They appreciate the efficiency these tools bring, allowing for more focus on complex and creative tasks. In 2024, one of ChatGPT's most frequently mentioned advantages remains its ability to handle routine academic tasks efficiently. Professors highlight how AI can streamline processes such as report writing, email management and basic code generation, allowing students and professionals to focus on more complex and creative tasks.

Spring 2023:

- "I think it will move students from effort in some areas to effort in other areas. As an engineer, it will make them more efficient as in able to complete more work per unit time."
- "More efficient, writing feedback, customize problems/ solutions, explore topics, brainstorm"

Spring 2024:

- "AI tools like ChatGPT will reduce the amount of time mundane tasks take, such as report writing, email, and even code generation for modeling and simulation, allowing for more time to focus on creative and complex tasks." "More efficient, writing feedback, customize problems/solutions, explore topics, brainstorm"
- "It has already benefited my discipline tremendously in its ability to help with developing outlines and editing materials. Writing tasks that used to take a couple hours can now be accomplished in just a small fraction of that time."

2) Pedagogical adaptation and curriculum redesign

There's a consensus that AI tools necessitate a rethinking of pedagogical strategies. Faculty members foresee a shift towards assignments and assessments that promote critical thinking and originality, making it hard for AI to replicate student work. The traditional methods of teaching and assessment, such as homework and exams, are likely to evolve in response to AI tools. Faculty members suggest a move towards in-class assessments, oral exams, and synchronous evaluations to mitigate the potential misuse of AI for cheating. A year later, the perception among educators is still that they

must adapt their teaching practices to integrate AI tools, ensuring that students learn to critically analyze and verify AI-generated information. Developing skills that go beyond mere automation is essential to prepare students for a future in which AI is ubiquitous.

Spring 2023:

- "I've had to rethink how I'll administer my final exam...it will have a very significant impact."
- “A lot of homework exercises would have to be redesigned. Coding exercises are easy to get help from ChatGPT.”

Spring 2024:

- “Traditional teaching using homework and exams will go away”
- “It will require faculty to level up their teaching. Gone are the days when we rely on essays and multiple choice tests or problems that we have given out for the last 20 years. We have to rise to the challenge and ensure that we are teaching how to critically think and problem solve for ourselves within the world we are sending these students into.”

3) Impact on critical thinking and problem-solving

A frequent concern among faculty is the potential decline in students' critical thinking and problem-solving skills. The ease of access to information and solutions through AI tools could lead to a dependency that undermines these essential skills. At the same time, they stress the positive impact that empowering these skills with technology could have if used correctly. The professors mention the importance of balancing AI support with human intellect and creativity. They stress that while AI can offer substantial assistance, it cannot replace the nuanced understanding and critical judgment provided by human educators. A year later, concerns from faculty about over-reliance on the tools seem to have increased. They comment that overuse of these tools could hinder the development of students' critical thinking and problem-solving skills. Faculty members advocate integrating AI in a way that continues to foster deep learning and creativity, ensuring that students do not become dependent on AI to the detriment of their intellectual growth.

Spring 2023:

- “Students *could* have a negative impact to critical thinking skills by using AI to do their homework for them. However, students could also see a positive impact if they use AI as a tool for enhancing their learning and diving deeper into a subject or asking deeper questions with more immediate feedback relative to emailing instructors or attending office hours.”
- “I believe that this tool will likely reduce the amount of time spent in foundational/rote/brute force writing and thinking skills. However, this does not substitute for creative and critical thinking and writing skills.”

Spring 2024:

- “I fear that people will become less creative in their thinking and ability to formulate and solve problems, because they will rely on a tool to do these things for them. This dependence on technology to organize thought and seek information will degrade people's ability and appetite to take the time and energy to contemplate, explore, fail, learn, and achieve.”
- “Overall, it will have a positive impact in the long term. However, it will take some time for everyone to learn how best to use AI to enhance human creativity, intelligence, and humanistic values.”

4) Ethical and academy integrity considerations

The ethical use of AI in academia, especially concerning academic integrity, is a significant concern. Faculty members are wary of the potential for AI to facilitate plagiarism and academic dishonesty, impacting the authenticity of student work. Some faculty members also raise concerns about the accessibility of AI tools and the potential for exacerbating educational inequities. Ensuring equal access to these advanced technologies is seen as a critical challenge. There is a consensus that AI can foster innovation and productivity if leveraged responsibly. ChatGPT can help save time and automate low-reward tasks, but it should not replace critical thinking and deep engagement with problems. Responsible use involves ensuring that AI aids learning rather than becoming a crutch. Faculty members stress the importance of developing clear policies and ethical guidelines for AI use in academia. Ensuring that student work remains authentic and original is critical, and new strategies are required to address this challenge.

Spring 2023:

- "Until we can figure out how to easily detect it, we will likely need to adjust our grading scheme...I can no longer trust that students completed homework on their own."
- “I worry about students cheating on lab reports. I worry more about students getting incorrect chemistry information from ChatGPT. It does not understand chemistry and it is terrible at working through chemistry problems.”

Spring 2024:

- “I think AI could be a powerful tool that would foster important innovations in my field IF and only if leveraged responsibly.”
- "Students need to know the basics, have strong ethical values, exercise compassion and empathy, and develop skills that AI currently cannot replicate."

5) Inclusivity and Accessibility

Faculty members highlight the role of AI tools in making education more inclusive and accessible. AI tools can be particularly beneficial for students with learning and/or physical disabilities or those who are non-native English speakers. By improving academic performance and task management, AI can make education more inclusive and accessible, helping all students succeed. Results from the spring 2023 survey related to faculty did not provide any specific references to these in the qualitative , no information on this topic was found in the spring 2023 data. This demonstrates in part that the ways of using these tools have evolved and new uses and approaches have been found. As in this case, learning disabilities, accessibility and inclusivity.

Spring 2024:

- "As a disabled faculty member, ChatGPT is a valuable tool that helps me complete the more administrative tasks of my job quickly and effectively, making education more accessible."
- “From the standpoint of biology as a discipline, they will save tremendous time in all types of writing (grants, lesson plans, memos, recommendation letters, reports, etc.), as well as serve

as a valuable repository of knowledge to draw upon for developing lectures and/or research projects. Additionally, they will save time and enhance inclusivity in creating assessments to test student knowledge in a class."

6) Adapting to a rapidly evolving AI landscape

There is an acknowledgment of the rapid evolution of AI tools and the need for faculty and institutions to keep pace. This includes staying informed about the latest developments and integrating these tools responsibly into the curriculum. Faculty members express the need to prepare students for a future workforce where AI tools are commonplace. This involves teaching students not only how to use these tools effectively but also how to critically evaluate their outputs. In the second version of the survey, faculty members across various disciplines acknowledge the transformative potential of ChatGPT and other large language models (LLMs). Many draw parallels to the impact of past technological advancements, such as the web browser, suggesting that the integration of AI in education could be equally, if not more significant, and is here to stay.

Spring 2023:

- "ChatGPT is one of the contemporary tools. This type of tool will only expand in its presence in various domains. It is our responsibility to make sure our students know how to take advantage of tools like ChatGPT and use them correctly."
- "AI-based natural language generation tools, such as OpenAI ChatGPT, are still in development and have known bugs, but they are rapidly evolving and here to stay, so they should be introduced to the future workforce."

Spring 2024:

- "ChatGPT and other LLMs will definitely transform my field and many other STEM disciplines. I cannot predict how, but its impact may be similar to that of the web browser (if not greater)."
- "Working to "block" the usage of AI tools is a very short-sighted closed-minded way of thinking. Just like limiting Google search would be. We need to embrace these technologies and utilize them to create more productive, more capable and more hirable students and professionals."

B. Main Insights from Students

Based on the student responses provided, it is evident that AI tools, such as ChatGPT, have a profound impact on engineering education and the future of various disciplines. They highlight the need for balancing AI tool utilization with skill development, ethical considerations, and the cultivation of a mindset geared towards adaptation and continuous learning in the Industry 5.0 era. In the response we can see reflections on its potential impacts on various aspects of learning and professional development. These insights are pivotal in understanding the evolving landscape of education in the context of emerging technologies.

1) Learning and understanding

Many students find that the ability to use ChatGPT enhances learning and understanding. Some students mention that AI tools are beneficial educational aids, similar to having a TA available at all times. They mention that it is beneficial for understanding complex concepts. Such insights suggest that when used ethically, AI tools can significantly enhance learning experiences, offering personalized and accessible explanations. A year later, students still have similar perceptions about it; they comment that AI tools like ChatGPT significantly enhance learning for students by providing instant explanations and support outside traditional classroom hours. Students appreciate the ability to get help with time-consuming tasks like writing emails and scheduling, which frees up time for more critical learning activities. Students find AI particularly useful for gaining unbiased information on complex topics like climate change, making the learning process more straightforward and less politically charged. Overall, from the student perspective AI could serve as a valuable tutor-like resource, offering quick, reliable assistance that complements classroom learning.

Spring 2023:

- "ChatGPT is like having a TA available outside office hours, without the embarrassment of asking 'stupid' questions."
- "I will use AI to help my learning, I specifically try not to cheat, because I actually want to learn."

Spring 2024:

- "I honestly think it is very helpful in explaining concepts when the professor isn't or you are unable to find the solution to what you're looking for online. It also helps you get time-consuming activities done like writing emails, scheduling, etc."
- "A partner that has a knowledge base on every topic is the equivalent of having a professor as a tutor. Obviously it can be used for mal intentions, but more so for bettering self. One can learn topics that take weeks in hours through spending dedicated time engaging in discussion and participating with gpt."

2) Accessibility

The role of AI in democratizing education and providing personalized learning experiences is highlighted. Students remark that AI tools could play a significant role in making education more accessible and tailored to individual learning needs. By providing explanations and simplifying complex topics, AI tools like ChatGPT can make various disciplines more accessible, particularly for students who might struggle with traditional learning methods. Students appreciate the ability of AI to facilitate easier access to research materials and streamline the process of gathering information. This capability is especially valuable for those in fields that require extensive literature reviews and data analysis. The personalized nature of AI tools can help cater to the unique learning styles and needs of individual students, ensuring a more inclusive educational experience.

Spring 2023:

- "I feel that ChatGPT makes high-level understanding more accessible as it is trained on a survey of internet knowledge"
- "ChatGPT is going to vastly change the way that students learn and are tested in academics. Whether you think it is negative or positive, it is here and it is accessible to students of all ages. It promotes less critical thinking skills and hinders students from really working through problems- but, it opens up the opportunity to learn further and have so many resources

and such vast information at one's fingertips. It is changing the future of the college of engineering, and we need to be prepared for both the good and the bad."

Spring 2024:

- "AI tools will provide a quicker way of accessing research material and allow for more ideas to flow. It will not be used to solve the ideas because of the common mistakes it makes."
- "I think AI tools make my discipline more accessible to people. I'm an Environmental Geosciences student and being able to ask AI about climate change and other environmental topic makes the information significantly more accessible and less likely to be politically charged. My hope is that it will allow people to look at the environment in a less divisive and political point of view."

3) Critical thinking and problem-solving

The potential impact of AI on critical thinking and problem-solving skills has mixed comments. While some students fear a diminishment of these skills due to over-reliance on AI, others see an opportunity for enhancement. They worry that reliance on AI for tasks like coding and research might devalue these skills. AI's ability to quickly provide research materials and generate ideas is appreciated, but its tendency to make common mistakes highlights the importance of human oversight. The challenge lies in ensuring that AI tools enhance learning without replacing the critical thinking and problem-solving skills that are crucial for academic and professional success. At the same time, students find AI tools like ChatGPT invaluable for support and problem-solving. These tools offer a reliable backup for understanding difficult concepts, especially when traditional resources are unavailable. AI aids in troubleshooting, debugging, and answering questions, making it easier for students to overcome academic challenges. This support can prevent frustration and encourage persistence, transforming seemingly insurmountable problems into manageable tasks. The key is using AI as a supplementary resource that enhances learning and problem-solving abilities without diminishing the importance of personal effort and understanding. This perspective underscores the need for a balanced approach to AI integration, ensuring that these tools complement rather than replace critical thinking and problem-solving exercises.

Spring 2023:

- "ChatGPT may have mixed effects on problem-solving skills. On one hand, it can provide instant solutions to problems, which could reduce the need for students to actively engage in problem-solving processes."
- "AI tools like chatGPT allow the productivity of one person to be greatly increased. There is also a lot of critical thinking that goes into creating the prompts for chatGPT to get the best results. This is why I say it can actually have a positive impact on problem solving and critical thinking. There are new problems that must be solved in new ways."

Spring 2024:

- "Using AI tools during education kills many important skills, most importantly critical thinking which is quite essential for Human Intelligence."
- "I think the way AI tools are used greatly differs from people to people, and that is the real problem. If used with good intentions, AI tools can provide ways to think outside of your knowledge, reduce time constraints, etc. If used to just solve homework or project quickly without critical thinking, it would hinder academic achievement."

4) Academic dishonesty

On the other hand, there is an acknowledgment of the potential misuse of AI tools for plagiarism and academic dishonesty. Students express concerns about ethical implications and the importance of responsible use. The need for ethical guidelines and professional responsibility in the use of AI tools is also highlighted. This apprehension accentuates ethical challenges posed by AI tools in academic settings, emphasizing the need for robust policies and ethical guidelines to govern their use. In the second version of the survey, the ethical use of AI tools is still a major concern among students. They emphasize that AI should not replace the human element in their work and express worries about the inaccuracies AI can produce. Responsible use of AI, where it complements rather than replaces student effort, is crucial. This includes using AI to understand complex topics or improve the quality of work, rather than letting it do the work outright. The consensus is that while AI can be a powerful tool, its use must be balanced with a commitment to maintaining academic integrity and personal accountability.

Spring 2023:

- "It's up to the students if they want to make the decision to negatively impact their own learning by using an AI to do all of their work."
- "I am concerned that it will make all at-home work done meaningless."

Spring 2024:

- "ChatGPT and other AI tools like it, take humanness out of work. It is not perfect and can create lies about whatever topic it is on."
- "Overall, ChatGPT will help increase productivity across the board if it's used correctly and ethically."

5) Impact on Curriculum, Teaching Methods, and Professional Development

AI tools are expected to significantly reshape curriculum and teaching methods. Students believe that AI will help eliminate redundant coursework that does not contribute to critical thinking or professional advancement. Instructors may need to adapt by incorporating more in-class assessments and focusing on creative and critical thinking skills. The integration of AI into education will require a shift away from traditional assignments towards more dynamic and interactive learning experiences, ensuring that students develop the necessary skills to thrive in an AI-enhanced world. AI is anticipated to transform professional and career development by automating routine tasks and requiring deeper expertise from human workers. AI might handle most associate-level tasks, pushing professionals to engage in more complex problem-solving early in their careers. This shift emphasizes the need for students to develop a deep understanding of their fields to remain competitive. AI's role in professional settings highlights the importance of continuous learning and adaptation to leverage these tools effectively and advance in their careers.

Spring 2023:
- "Similar to how the industrial revolution eliminated many jobs in the manufacturing industry, AI will probably eliminate jobs that don't constitute critical thinking, problem solving, or advanced interpersonal communication skills."
- "Both industry and education need to pivot to making the best of these new AI tools for their students and employees, or they will be left behind."

Spring 2024:
- "In an academic context, I think it will affect the way that students navigate their coursework, for better or for worse. In some classes, using outside materials…will help students find another way to explain a tricky concept or break a complex task into chunks. However, some students may use it to avoid engaging in the sometimes uncomfortable work of learning new material."
- "I think they will change the curriculum of the school, so for example I currently have GPT premium and they released this thing called custom GPTs so I can make my own, so for my POLS class I uploaded the entire 800 page textbook into it and now the only information it knows is from the textbook and since the class is online and open note, all the readings we have to do I just make it summarize those readings and any test question I ask it pulls directly from the notebook."

6) AI-integrated future

Students acknowledge that AI tools like ChatGPT are integral to the future workforce and industry practices, necessitating a shift in educational focus towards these technologies. They also recognize that AI tools require a transformation in educational methodologies and job market preparation. This indicates the anticipation of a paradigm shift in how education is delivered and the skill sets required in the evolving job market. This perspective underscores the importance of integrating AI tool proficiency into educational curricula to prepare students for the demands of Industry 5.0. A year later, the future integration of AI into various disciplines is seen as inevitable and transformative. Students recognize that AI will significantly impact every industry, acting as a tool that can enhance productivity and efficiency. In technical majors, while AI currently faces limitations, its potential for future applications, such as in computer-aided design and advanced data analytics, is immense. AI is expected to become an integral part of the professional toolkit, much like calculators and computers did in the past. Embracing AI technology is essential for staying current and unlocking new levels of creativity and collaboration.

Spring 2023:
- "It's the future, it's coming and it's here. We need to adapt to it."
- "It will be essential to learn how to use AI tools to increase your personal productivity within software development to keep up with the movements in the industry"

Spring 2024:
- "AI will heavily impact every industry and aspect of society"
- "Embracing these technologies isn't just about staying current, it's about unlocking new levels of creativity and collaboration as we navigate the ever-evolving landscape of manufacturing engineering."

IV. Conceptual Framework

The conceptual framework of this research centers on integrating AGI into engineering education, fostering a human-centric approach in the era of Industry 5.0. This framework is built on the premise that engineering education must evolve to balance technical skills with intrinsic human qualities, such as creativity, critical thinking, self-awareness, and emotional intelligence [7]. The framework comprises five interconnected components, each designed to address specific aspects of this integration.

The development of this conceptual framework is supported by literature highlighting gaps in current educational paradigms and is refined with survey data from faculty and students that revealed specific needs and preferences in engineering education [2]. It blends technical skill development with intrinsic human qualities, such as creativity, critical thinking, and ethical reasoning. The framework comprises several interconnected components, each playing a vital role in shaping a comprehensive engineering educational experience.

The AGI Integration into Engineering Education (AGI^2E^2) framework proposed in this work, as shown in Figure 1, is based on the five core interconnected components related to a human-centered approach for Industry 5.0 originally described by Balart and Shryock [2], [39]. These elements include: Dynamic Interdisciplinary Learning Environments, Personalized Educational Trajectories, Continuous Adaptation and Lifelong Learning, 21st-century Skills Development, and Ethical Considerations. The AGI^2E^2 framework (see Fig 1) is an expansion of the previous work and provides additional data regarding the potential impact of AGI on education in each of the original components and includes a new set of elements related to essential supports needed for the five core components.

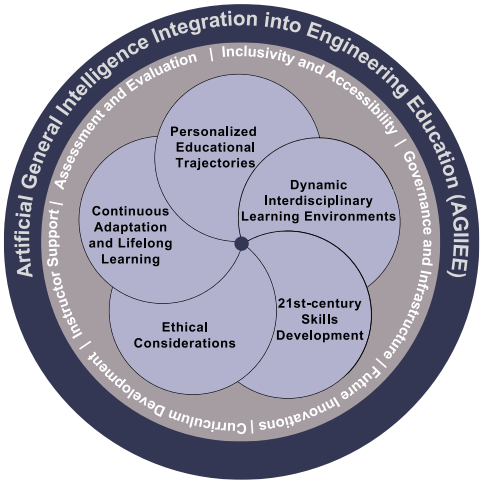

Fig. 1. AGI^2E^2 Framework.

Figure 2 provides more details on the five core interconnected components related to a human-centered approach for Industry 5.0 that are shown in the center of the AGI^2E^2 framework. These are expanded from the model previously depicted by Balart and Shryock in [2], [39] to include additional considerations in each of the five elements. Specifics on each of

these elements are provided in the following sections, A-E. Next, sections F-J provide aspects of the next layer in the AGI^{2}E^2 framework shown in Figure 1 that includes elements related to essential supports needed for these five core components.

Fig. 2. Five core interconnected educational components related to a human-centered approach for Industry 5.0.

A. Dynamic Interdisciplinary Learning Environments

In [2], the use of AI to create dynamic, interdisciplinary learning environments is evaluated. Using AI "...highlights the importance of multidisciplinary approaches by evaluating platforms that go beyond traditional engineering education, integrating humanities, social sciences and ethical studies. The approach broadens the scope of education, fostering well-rounded engineers with a global perspective" [2].

In these settings, AGI serves as a bridge, connecting various disciplines to provide a cohesive and interconnected learning experience. This approach takes advantage of the possibility of bringing together elements from engineering, humanities, social sciences, and ethical studies, fostering well-rounded engineers with a global perspective. Also, this technology promotes a dynamic and interactive learning environment, fostering lifelong learning and collaboration among educators, institutions, and students [18].

In the context of engineering education, the integration of AGI to create dynamic, interdisciplinary learning environments is especially important. Modern engineering challenges are often complex and multifaceted, requiring solutions that go beyond the boundaries of traditional engineering. So by integrating insights from the humanities, social sciences and ethical studies, engineers are better equipped to develop solutions that are not only technically sound, but also socially responsible and ethically grounded. On the other hand, exposure to different fields, such as the arts and humanities, can inspire engineers to think creatively, approach problems differently and devise novel solutions [40]

The intersection of various disciplines, facilitated by AGI, could foster innovative thinking, as exposure to different fields can inspire engineers to think creatively, approach problems differently, and devise novel solutions. It can also create simulated real-world scenarios that allow students to apply their knowledge in practical contexts, enhancing their understanding of complex concepts and preparing them for real-world applications. These simulations provide hands-on experience, bridging the gap between theoretical knowledge and practical skills.

A. Personalized Educational Trajectories

The original framework leverages AI data processing to deliver personalized educational experiences tailored to each student's preferences and goals. By analyzing learning behaviors, strengths, and interests, AI algorithms facilitate personalized learning trajectories, aligning each student's path with their unique capabilities and industry needs. AI-driven tools have shown effectiveness in enhancing student engagement, satisfaction, and academic performance [41]. Personalized learning through AI allows students to progress at their own pace and in their preferred style, improving outcomes and nurturing individual strengths [42]. Additionally, AI technologies like intelligent tutoring systems, chatbots, and automated grading increase efficiency and provide consistent feedback.

Educators can also benefit from AI technologies by automating administrative tasks, generating instructional materials, and delivering personalized feedback to students, allowing them to individualize their teaching approach and create more engaging learning environments [43]. On the other hand, AGI could be helpful in creating more personalized teaching experiences, and even in proposing appropriate faculty development strategies for each instructor. In the same way that AGI can develop personalized learning paths tailored to individual students' needs, learning styles, and preferences.

By continuously analyzing students' performance and feedback, AGI can adjust the curriculum and provide targeted support to optimize learning outcomes. For example, AGI can automate the creation of individualized learning schedules that align with each student's pace and progress. It can also handle the grading of assignments and assessments, providing instant feedback to students and freeing up educators' time for more personalized interactions. Can provide real-time feedback and support to students, helping them identify areas for improvement and develop effective learning strategies. This personalized approach enhances students' motivation and engagement in the learning process, ensuring that each student's educational path is aligned with their unique capabilities and future industry needs.

C. Continuous Adaptation and Lifelong Learning

AGI^{2}E^2 framework recognizes the need for continuous adaptation and lifelong learning in response to the rapid evolution of technology and industry needs. AI is pivotal in this process, offering ongoing learning opportunities and resources that align with industry trends and personal development, ensuring graduates stay relevant and adaptable in a dynamic professional landscape.

As new skills become essential with industry evolution, AGI can identify these by analyzing job market trends, industry publications, and academic research. This enables educational

programs to quickly integrate new topics and skills, ensuring students learn relevant, up-to-date content for their future careers. AGI bridges academia and industry by providing real-time insights, integrating real-world case studies into the curriculum, facilitating collaborations, and enabling virtual internships and projects with industry partners.

Central to lifelong learning is cultivating a growth mindset, the belief that abilities and intelligence can develop over time. AI supports this by offering optimally matched challenges, feedback, encouragement, and helping set and achieve incremental goals, fostering resilience and a positive attitude towards continuous learning. Leveraging AGI, our framework creates a dynamic educational environment that equips students with current knowledge and skills and instills a culture of continuous growth and adaptability. This approach ensures graduates are competent for today's challenges and ready to lead in future technological landscapes, promoting lifelong learning.

D. 21st-Century Skills Development

The framework [2] underscores the importance of developing 21st-century skills, such as critical thinking, creativity, communication, collaboration, and innovation on the integration of AI in engineering education. AGI integration in engineering education is pivotal in cultivating these skills, ensuring that graduates are well-equipped to navigate and contribute effectively to the Industry 5.0 landscape.

AGI-powered tools present students with complex problems and scenarios that require critical thinking and creative problem-solving. These tools encourage students to analyze, evaluate, and create innovative solutions. AGI also could enhance communication and collaboration by facilitating teamwork and simulating real-world engineering projects, preparing students for global engineering challenges. AGI can support the development of creativity and innovation skills by providing opportunities for students to engage in complex problem-solving tasks and collaborative projects. AGI can suggest new ideas and perspectives, inspiring students to think creatively and develop novel solutions. This approach helps students develop analytical and strategic thinking abilities, preparing them for real-world engineering challenges. It can also integrate interactive experiences and simulations that immerse students in scenarios requiring ethical judgment and emotional understanding. These experiences enhance students' ethical decision-making abilities and emotional intelligence, crucial for effective leadership and teamwork and many other skills.

E. Ethical Considerations

Regarding the ethical considerations, there is a need to teach students about the ethics and sociotechnical implications of AGI development and usage. The use of AGI in education could involve the collection and processing of large amounts of personal data from students, raising significant privacy concerns. It is imperative to establish robust data protection measures and policies that comply with legal standards and respect the confidentiality of student information. We address critical issues such as data privacy, algorithmic transparency, and bias, ensuring that AGI is used responsibly and equitably. Students should be educated on AGI ethics, understanding the risks and concerns related to its use, and will be prepared to apply these principles in their professional lives. As mentioned above, AGI systems can inadvertently perpetuate biases if not carefully designed and monitored. Thus, it becomes imperative to periodically monitor AGI systems for biases and implement diverse training datasets to ensure that AI algorithms perform fairly across different learner populations.

Another essential component of our framework is the integration of an AGI ethics curriculum in engineering education programs. This curriculum is designed to educate engineering students about the ethical implications of AGI in their field, including responsible AGI usage, understanding AGI limitations, and the societal impact of AGI technologies. By incorporating case studies and real-world examples, students are encouraged to critically engage with ethical dilemmas in AI, preparing them to make responsible decisions in their professional lives.

AGI systems must adhere to stringent data protection regulations to safeguard students' personal information. Implementing robust encryption methods and secure data storage practices can help mitigate risks associated with data privacy. On the other hand, AGI's decision-making processes must be transparent and accountable. Providing clear explanations of algorithms and their potential biases can help build trust and ensure fairness in educational outcomes.

The ethical implications of GAI in education extend beyond privacy and bias. They include considerations about the impact of AGI on the learning process, student autonomy, and the potential for AGI to replace human interaction in education. Balancing AGI use with human interaction is crucial for developing social and emotional skills. Over-reliance on AGI could lead to a reduction in human engagement, which is essential for developing social and emotional skills. Ensuring that AGI systems complement rather than replace human educators can help maintain a holistic educational approach.

Recognizing the complexity of ethical issues in AI, our framework promotes a collaborative approach involving educators, students, AI developers, and policy-makers. This collaboration aims to create a shared understanding of ethical AI use in education and to develop guidelines and best practices that reflect diverse perspectives and needs. As we can see, ethical considerations in AI implementation form a critical pillar of our framework, ensuring that AGI is used in a way that respects individual privacy, operates transparently, addresses biases, and upholds the highest ethical standards. It is essential that both faculty and students understand these AGI concepts and their ethical considerations to act accordingly and introduce them into education. By embedding these considerations into the fabric of AGI-driven engineering education, we aim to prepare students not only as technically proficient engineers but also as ethically aware professionals, capable of navigating and shaping the AGI-influenced landscape of Industry 5.0.

F. Curriculum Development

AGI has the potential to significantly impact curriculum

development by offering innovative solutions and resources for educators. It can contextualize learning experiences by integrating real-world scenarios and problem-solving tasks into the curriculum. By simulating industry-specific challenges and case studies, AGI can provide students with hands-on experience that closely mirrors professional environments. This practical approach not only enhances understanding but also prepares students for real-world applications of their knowledge.

In rapidly evolving fields like computer science and engineering, AGI' ability to provide real-time updates to the curriculum can ensure that the curriculum includes the most current technologies, programming languages, and industry practices. This real-time updating capability ensures that students are always learning the most relevant and up-to-date information, better preparing them for the workforce. It can generate engaging and interactive course outlines, including components like course overview, objectives, activities, and assessments, providing educators with valuable tools for designing curriculum content. AGI can be used as a supplement to traditional textbooks and resources, liberating instructors from limitations and broadening their content knowledge. Faculty can access a variety of content and resources generated by AGI to enrich lesson planning and assist students in expanding their perspectives.

Our framework also promotes the integration of AGI with real-world applications and industry needs. By fostering collaboration between academia and industry, AGI facilitates the practical application of theoretical knowledge, increasing the relevance and impact of engineering education. This integration ensures a consistently up-to-date curriculum that enables students not only to acquire technical knowledge, but also to know how to apply it in real-world contexts to address current and future industry challenges.

By leveraging AGI's capabilities, educational institutions can develop curricula that are continuously updated, contextually relevant, and tailored to the diverse needs of students. This not only enhances the quality of education but also prepares students for the ever-evolving demands of the modern workforce. As AGI technology continues to advance, its role in curriculum development is likely to expand, offering even more innovative and impactful solutions for education.

G. Instructor Support

The integration of AGI into instructional support systems offers a transformative potential to enhance teaching effectiveness and efficiency. By providing personalized professional development, assisting with classroom management, and offering tailored instructional support, AGI can support faculty to deliver high-quality education and foster a positive learning environment.

With AGI capability to enable personalized experiences, it could provide professional development opportunities for faculty, helping them stay updated with the latest educational practices and technologies. For example, AGI can recommend specific professional development courses, workshops, or certifications based on an instructors' strengths and areas for improvement. This targeted approach ensures that professional development is relevant and impactful, helping faculty enhance their skills and stay updated with the latest educational practices and technologies. It is important to emphasize that AGI should enhance, not replace, instructors, emphasizing the unique human skills of emotional intelligence, adaptability, and building meaningful student connections.

AGI can assist with classroom management by monitoring student behavior and engagement in real-time. Using data from various sensors and classroom technologies, AGI can detect patterns that indicate potential issues, such as decreased student participation or disruptive behavior. For instance, AGI can alert instructors to students who may need additional support or intervention, allowing them to address issues promptly before they escalate. This proactive approach helps maintain a positive learning environment and ensures that all students receive the attention they need to succeed.

As AGI technology continues to evolve, its role in supporting instructors is likely to expand, offering even more innovative solutions to address the challenges of modern education. This holistic approach ensures that faculty are well-equipped to meet the diverse needs of their students and thrive in an increasingly dynamic educational landscape.

H. Assessment and Evaluation

The integration of AGI in assessment and evaluation could represent a paradigm shift in how student performance and progress are measured. AGI can offer innovative solutions that provide more accurate, efficient, and fair methods for assessing student learning. Continuing with AGI's capabilities to personalize learning experiences, it can create adaptive assessments that adjust their difficulty based on the individual student's responses [5]. Unlike traditional standardized tests, adaptive assessments dynamically tailor questions to the learner's ability level, providing a more accurate measure of their knowledge and skills. AGI offers transformative potential in assessment and evaluation practices, providing more accurate, efficient, and fair methods for measuring student performance and progress.

In the first place, as we already discuss in depth, it can create adaptive assessments that adjust their difficulty based on the individual student's responses. Unlike traditional standardized tests, adaptive assessments dynamically tailor questions to the learner's ability level, providing a more accurate measure of their knowledge and skills. For example, if a student answers a question correctly, the subsequent question might be more challenging. Conversely, if a student struggles with a question, the following question might be easier. This approach ensures that assessments are neither too difficult nor too easy, maintaining an optimal level of challenge for each student. Adaptive assessments help identify specific areas where students excel or need additional support, enabling more targeted interventions. Additionally, adaptive assessments can be more engaging for students, as they are continually challenged at an appropriate level, which can enhance their motivation and interest in the subject matter.

The possibility of having real-time feedback on assessments, could allow students to understand their strengths and weaknesses immediately. This instant feedback helps students recognize their mistakes and learn from them, promoting a

continuous improvement cycle. If after completing an assessment, students receive detailed feedback on each question, including explanations for correct and incorrect answers, this allows them to learn from their mistakes in real time. AGI can also provide personalized recommendations for further study, guiding students on how to improve their understanding and performance in specific areas. AGI can generate ongoing assessments that provide immediate feedback, helping teachers and students adjust their strategies as needed to achieve learning goals. This approach ensures that students receive timely support and guidance, enhancing their overall learning experience.

With the potential to understand context and different human capabilities, AGI can facilitate holistic evaluation by considering multiple dimensions of student performance, including cognitive, social, and emotional aspects. AGI can assess not only students' knowledge and problem-solving abilities but also their collaboration, communication, and critical thinking skills. By analyzing data from various sources such as classroom interactions, project work, and peer feedback, AGI can provide a comprehensive evaluation of students' overall development. AGI can support contextual and competency-based evaluation, which assesses students' ability to apply their knowledge and skills in real-world scenarios. This approach aligns with the demands of modern education and the workforce, where practical competencies are increasingly valued.

Finally, with its extensive data processing and data analysis capabilities, AGI can generate detailed performance analytics that help educators understand each student's learning journey. These analytics can include trends in performance over time, specific areas of strength and weakness, and comparative analyses with peer groups. It can track a student's progress in mastering specific concepts and provide visual reports that highlight improvement areas. This detailed analysis helps educators tailor their instruction to meet the unique needs of each student, promoting a more personalized learning experience. Can also be used to forecast students' future performance based on current and historical data. This capability allows educators to identify students who may be at risk of falling behind and intervene early with targeted support.

By providing personalized adaptive assessments, real-time feedback, and holistic evaluations, AGI can ensure that students' learning progress is accurately measured and supported. As AGI technology continues to advance, its role in assessment and evaluation is likely to expand, offering even more sophisticated and impactful solutions for education. Which could eventually transform assessment and evaluation practices by providing more accurate, efficient, and fair methods for measuring student performance and progress. This comprehensive approach ensures that students are well-prepared for their future careers, equipped with both technical knowledge and essential soft skills.

I. Inclusivity and Accessibility

The framework emphasizes the importance of inclusivity and accessibility in AGI implementation. It ensures that students from diverse backgrounds have equitable access to AGI-driven educational tools, addressing disparities in technology access and usage. By designing inclusive learning environments, the framework supports diverse learning needs, including those of students with disabilities, ensuring that all students can benefit from AGI-enhanced education. Regular audits and updates to AGI algorithms can help minimize biases and ensure inclusivity in educational outcomes. Designing AGI systems that consider diverse learning needs and backgrounds is essential for creating an equitable educational environment.

AGI tools could significantly enhance the educational experience for students with disabilities by providing personalized support and adaptive learning techniques. For instance, AI can help in converting text to speech for visually impaired students or generate subtitles and transcripts for students who are hard of hearing. Moreover, AI can assist in creating more accessible learning materials tailored to the specific needs of students with disabilities, thus ensuring they have equal opportunities to succeed. These tools can also provide translations, simplify complex texts, and offer grammar and writing assistance. A personalized approach could be beneficial for students who may struggle with traditional teaching methods, ensuring that they receive the support they need to excel. By providing resources that cater to diverse learning needs, AI tools contribute to creating a more inclusive learning environment. These tools can offer various formats for learning materials, such as videos, interactive modules, and quizzes, accommodating different learning styles and preferences.

The accessibility considerations for integrating AI in education emphasize the importance of ensuring that students from all socioeconomic backgrounds have access to AI-driven educational tools, which involves providing the necessary hardware, software, and internet connectivity, especially to underprivileged students. Equitable access to advanced technology is crucial in the field of engineering, a globally significant industry with a substantial economic impact. In this domain, innovation is key, and technology greatly influences the competitiveness of individuals, companies, and nations. Additionally, educators require sufficient training and support to effectively incorporate AI into their teaching methods, ensuring they can utilize these tools to enhance learning while focusing on developing human-centric skills.

J. Governance and Infrastructure

The integration of AGI into educational settings necessitates robust institutional governance and infrastructure to ensure effective and ethical implementation. Establishing policies for clear governance is a crucial early step for the responsible implementation of AGI in educational institutions. These policies should address various aspects, including data privacy, ethical use, and equitable access. According to Nguyen et al. (2023), governance frameworks should ensure that AI systems adhere to stringent data protection regulations to safeguard students' personal information. Additionally, transparency in AI's decision-making processes is vital to maintain trust among educators, students, and stakeholders.

Institutional or governmental policies should also focus on the ethical considerations of AGI use, such as preventing

biases and ensuring fairness in educational outcomes. Regular audits and updates to AGI algorithms can help mitigate biases and ensure inclusivity. By fostering an environment where ethical guidelines are integral to AGI development and deployment, institutions can uphold high standards of integrity and accountability.

To support the integration of AGI, educational institutions should invest in the necessary technological infrastructure. It should be capable of handling the computational demands of AGI systems and ensuring seamless access for students and faculty. Furthermore, educational institutions should provide the necessary hardware, software, and internet connectivity to ensure equitable access to AGI-driven tools. This is particularly important for underprivileged students, who may otherwise be at a disadvantage. Ensuring that all students have access to the necessary technology is essential for creating an inclusive learning environment .

Effective resource management is critical for optimizing the use of AGI in educational settings. AGI can help streamline the allocation of educational resources by analyzing usage patterns and student performance data. This ensures that resources such as textbooks, digital tools, and lab equipment are utilized efficiently and effectively. For instance, AGI can identify which resources are most beneficial for student learning and recommend their wider adoption, while also pinpointing underutilized resources that may need reevaluation or repurposing. Additionally, AGI can support faculty in finding and utilizing the best educational resources for their classrooms. By analyzing course learning outcomes and student needs, AGI can recommend textbooks, digital tools, and multimedia resources that align with instructional goals.

Creating a supportive institutional environment is essential for the successful integration of AGI. This includes establishing communities of practice where educators can collaborate, share experiences, and learn from each other. Mentoring programs, where experienced educators provide guidance on integrating AGI, offer valuable insights and support. Regular feedback and coaching from instructional leaders and technology professionals can help faculty refine their AGI implementation techniques and continuously improve their instructional practices.

Promoting a culture of innovation and experimentation is also crucial. Educational institutions should encourage faculty to explore new teaching methods and technologies, providing the necessary support and resources to implement innovative practices. By fostering an environment that values continuous improvement and adaptation, institutions can ensure that their educational programs remain relevant and effective in the face of rapid technological advancements. In conclusion, the successful integration of AGI into educational institutions requires comprehensive governance policies, advanced infrastructure, effective resource management, ongoing professional development, and robust institutional support structures. By addressing these components, educational institutions can create an environment that maximizes the benefits of AGI while ensuring ethical and equitable use, ultimately enhancing the quality of education and preparing students for the challenges of Industry 5.0.

K. Future Innovations in AGI for Education

The future of AGI in education holds immense potential for creating personalized learning paths and adaptive learning environments. The core educational components in the AGI^2E^2 framework could be fundamental in guiding this evolution. AGI systems are expected to revolutionize education by offering real-time customization of lesson plans, pacing, and assessments tailored to individual student needs. Predictive analytics can forecast student performance, allowing for proactive interventions to address learning gaps. This personalization ensures that each student's educational journey is optimized for their unique learning style and pace, enhancing overall learning outcomes.

Furthermore, AGI can significantly enhance collaborative learning and lifelong education, building on the components of continuous adaptation and lifelong learning. Advanced virtual learning environments powered by AGI will enable students from diverse geographical locations to collaborate in real-time, fostering a global educational community. AI-driven peer learning platforms can match students with peers for subject-specific assistance, promoting peer-to-peer learning. Additionally, AGI can support lifelong learning by acting as AI mentors and coaches, guiding individuals through their continuous education journeys and providing personalized advice and resources.

Addressing ethical and societal challenges, another core component, will be crucial as AGI becomes more integrated into education. Ensuring the ethical development and use of AGI, with a focus on transparency, accountability, and fairness, will be essential to prevent biases and protect student privacy. Future research should also explore the broader societal impacts of AGI, including its effects on job markets, educational equity, and access to resources. Innovations in curriculum development, such as dynamic curriculum design and interdisciplinary integration, will further prepare students for the evolving demands of the job market, ensuring that education remains relevant and effective in an AGI-enhanced world.

V. Conclusion and Future Directions

In conclusion, the AGI^2E^2 framework represents a progressive step towards adapting to the demands of Industry 5.0. With a holistic approach that balances technical competence with the cultivation of human-centered qualities such as ethical reasoning, emotional intelligence, and continuous personal and professional development, this framework aims to create a more inclusive, dynamic, and responsive educational experience. Building upon previous research, this work contributes to the ongoing dialogue on AI's role in education, providing a foundation for future exploration and development.

Future developments in AGI should focus on enhancing human-AI collaboration, enabling more seamless and effective interactions between educators, students, and AI systems. This includes developing AI systems that can understand and respond to human emotions and behaviors, creating a more empathetic and supportive learning environment. By fostering stronger human-AI partnerships, educators can leverage AI to

augment their teaching practices, allowing for a more personalized and responsive educational experience. This collaboration can also extend to student projects and research, where AI can assist in data analysis, provide insights, and facilitate complex problem-solving tasks. Ultimately, the goal is to create a synergistic relationship where human creativity and emotional intelligence complement the analytical and processing power of AI, leading to more innovative and effective educational outcomes.

Innovations in ethical AI design could focus on creating transparent, fair, and accountable AGI systems that prioritize the well-being and rights of all learners. This includes developing frameworks and guidelines for the ethical use of AGI in education, ensuring that AI technologies are used responsibly and equitably. Ethical AI design involves rigorous testing to identify and mitigate biases, ensuring that AI systems do not inadvertently perpetuate inequalities. Additionally, ethical AI practices must include transparency in how decisions are made by AI systems, allowing educators and students to understand and trust AI's role in their education. By embedding ethical considerations into the core design and implementation of AGI, educational institutions can build systems that respect privacy, promote fairness, and enhance the overall learning experience without compromising ethical standards.

The integration of AI into engineering education, as outlined in this framework, has the potential to significantly enhance the educational experience by providing personalized learning paths, fostering interdisciplinary collaboration, and supporting continuous learning and skill development. By addressing ethical considerations and ensuring equitable access, this framework also aims to create a more inclusive and fair educational environment. In doing so, this work helps to shape a future in which AI-driven education is more inclusive, dynamic, and responsive to the needs of students and society. The evolution of AI in education holds promise not only for improving educational outcomes but also for preparing a generation of engineers who are well-equipped to lead and innovate in the face of future challenges.

This framework thus contributes to the broader goal of creating an educational system that not only imparts technical knowledge but also nurtures the holistic development of individuals, ensuring they are ready to contribute positively to an increasingly complex and interconnected world. In summary, this paper advocates for a balanced integration of AI in engineering education, emphasizing the importance of technical expertise and human-centric skills. It calls for ongoing research, dialogue, and collaboration among educators, policymakers, and technologists to refine and implement strategies that will shape the future of education in the era of Industry 5.0.

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