SPARK FRAMEWORK FOR HUMAN-CENTRED GENERATIVE ARTIFICIAL INTELLIGENCE INTEGRATION IN CDIO EDUCATION

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ABSTRACT

The rapid emergence of Generative Artificial Intelligence (Gen-AI) is transforming how students in engineering courses learn, design and create. In higher education, this shift raises a fundamental tension on how institutions can preserve mastery of disciplinary fundamentals while preparing graduates to collaborate effectively with intelligent systems. This paper aims to provide a conceptual pedagogical framework named SPARK within the CDIO Innovation Process that guides educators in redesigning teaching and assessment in which Gen-AI acts as a trusted partner in thinking, creating and learning for students. SPARK represents **S**cope the Problem, **P**ropose Solutions, **A**ssess Critically, **R**efine and Integrate, and **K**nowledge Artefact and Presentation. Each phase corresponds to a CDIO stage where students conceive by scoping authentic problems, design by ideating and proposing solutions, implement through testing and refinement, and operate by communicating artefacts and reflections. The model is grounded in constructivism, self-regulated learning, reflection-in-action and authentic assessment, ensuring that pedagogy rather than technology anchors Gen-AI integration. SPARK also advances several CDIO Standards. It strengthens Standard 2 (Learning Outcome) by embedding Gen-AI literacy and ethical reasoning. It can enhance Standards 7 and 8 through active learning and integrated learning experiences and it supports Standards 9 and 10 by providing a vehicle for faculty competence and pedagogical innovation. As a design-based reasoning framework, SPARK moves fluidly across contexts and remains resilient to technological change. Its focus on inquiry, reflection and ethics renders it relatively immune to rapid disruption. Future implementation at Singapore Polytechnic will test SPARK in authentic modules, examining its impact on student agency, self-directed learning and cognitive engagement. Findings will inform its effectiveness and lessons learnt. In doing so, this work contributes to CDIO's global mission of preparing engineers who can conceive, design, implement and operate responsibly in a Gen-AI enabled world.

KEYWORDS

Generative Artificial Intelligence, Critical Thinking, Creative Thinking, Systems Thinking, SPARK Framework, CDIO Innovation Process, CDIO Standard 8

INTRODUCTION

The rapid advancement of Generative Artificial Intelligence (Gen-AI) has prompted educators to rethink how engineering education shall be transformed. Gen-AI tools such as ChatGPT, Copilot and DALL·E influence how students conceive problems, design solutions and communicate outcomes. While these technologies offer unprecedented opportunities for creativity and productivity, they also raise fundamental questions about the nature of learning itself, particularly whether reliance on Gen-AI may erode students' conceptual reasoning and problem-solving abilities (Williamson & Eynon, 2024; Zawacki-Richter et al, 2019).

Educators face a dual challenge, that is to leverage Gen-AI as a learning partner while safeguarding the disciplinary fundamentals that underpin engineering thinking. As Holmes et al (2023) observed, the potential of Gen-AI in education lies not in automating cognition but in amplifying it through guided pedagogy and ethical design. Yet most institutional responses to Gen-AI adoption have centered on assessment integrity or tool policies rather than rethinking the pedagogical processes that shape students' engagement with knowledge. The threats and opportunities introduced by Gen-AI are discussed in later sections of this paper and this discussion serves to identify the existing gap that this paper aims to address by recommending a pedagogical framework that embed Gen-AI meaningfully within the teaching and learning cycle, preserving human agency, metacognition and ethical judgement. The recommended pedagogical framework, named SPARK Framework, could be used to guide educators in designing learning experiences for students that integrate the use of Gen-AI meaningfully and ethically while strengthening the CDIO thinking skills.

A HUMAN-CENTERED PEDAGOGICAL PHILOSOPHY

Gen-AI has evolved from a novel tool into a foundational component of professional and academic life. Students should be empowered to harness Gen-AI tools to explore ideas, identify and solve complex problems, and develop habits of self-directed learning and learning to learn while upholding ethical and responsible use. Gen-AI can act as a trusted partner in thinking, creating and learning. Through this approach, every student is supported by a personalised learning assistant that enhances adaptive engagement while maintaining mastery of disciplinary fundamentals. This philosophical stance aligns with Luckin's (2018) concept of "intelligence augmentation" which positions Gen-AI as an amplifier of human potential rather than its replacement. Similarly, Muller (2023) emphasises the importance of "AI resilience", ensuring that students retain deep disciplinary cognition and critical judgement even when assisted by intelligent systems.

Within this context, the Conceive, Design, Implement, Operate (CDIO) Framework (Crawley et al, 2014) offers an ideal foundation for integrating Gen-AI into engineering education. CDIO's experiential emphasis on authentic problem-solving, reflection and iterative design aligns naturally with Gen-AI's capacity to support inquiry, ideation and evaluation processes. However, as Gen-AI tools become increasingly embedded in learning, CDIO institutions must rethink how students conceive and evaluate solutions in an Gen-AI enabled landscape. Thus, there is a need for pedagogical models that bring CDIO's disciplinary rigour with the reflective, human-centered ethos of Gen-AI.

THREATS BROUGHT ABOUT BY GEN-AI

Gen-AI is already reshaping student behaviour, blurring the lines between academic and personal life. Students are relying on these tools for efficiency, from automating research to drafting assignment reports. This offers new avenues for personalised learning but also raises concerns about potential cognitive dependence. The ease of access to powerful Gen-AI tools also creates a knowledge asymmetry, making it imperative that educators train students to critically evaluate information and understand the ethical implications of Gen-AI use, including biases and misinformation. Gen-AI's disruptive effect evident in some industries. For example, the Finance sector uses Gen-AI for fraud detection and algorithmic trading (Forbes, 2024). Occupations with repetitive, knowledge-based tasks are at high risk of disruption particularly in administration roles (Brinkmann et al, 2023). Our graduates will not be entering a world where Gen-AI is a distant concept; they will be joining a workforce where it is a foundational, embedded component. In order to prepare students for a Gen-AI augmented job market, educators must adapt the engineering curriculum to emphasise a new hierarchy of skills. Traditional teaching methods and assessments are at risk of being circumvented by Gen-AI. To mitigate the risk of cognitive degeneration, we must innovate our teaching and assessment methods.

The ease with which students can generate self-reflections using Gen-AI poses a significant challenge to authentic assessment. Students can readily craft prompts that enable Gen-AI tools to produce reflections on their learning experiences. When these reflections pertain to a common activity undertaken by a large cohort, this practice can lead to a homogenisation effect where submissions lack individuality and originality. Such uniformity undermines the integrity of assessment, as lecturers struggle to differentiate genuine, thoughtful reflections from Gen-AI generated content. Consequently, appropriate grading becomes difficult, and more critically, the learning process is compromised where students bypass the essential cognitive exercise of reflection and critical thinking, which are central to deep learning.

OPPORTUNITIES WITH GEN-AI

Gen-AI has transformed the landscape of knowledge acquisition by providing immediate, accurate responses to prompts that require factual recall and conceptual understanding. This capability challenges the traditional role of mass lectures as a primary mode of knowledge transmission, rendering them increasingly obsolete. Lower-order learning outcomes in Bloom's taxonomy such as those require recalling definitions or explaining foundational engineering principles can now be efficiently addressed through Gen-AI tools. Consequently, engineering education must pivot toward fostering higher-order cognitive skills, even within introductory courses. Competencies within the CDIO syllabus such as Systems Thinking (2.3), Creative Thinking (2.4.4), and Critical Thinking (2.4.5) have become more essential for mitigating cognitive atrophy and ensuring that students engage deeply with the purpose and relevance of their learning.

According to Monat et al (2022), Systems Thinking (2.3) provides a holistic perspective that recognises the relationships among system components. The components and the environment that the system interacts with are as important as the components themselves. This is particularly applied in the CDIO Innovation Process where students are taught to understand the technical system, its function and behaviour as well as its elements, and Gen-AI can be used to aid them in understanding the psychological, cultural, economic and environmental implications of their engineering decisions.

Creative Thinking (2.4.4) is largely used in conceptualisation and ideation in the CDIO Innovation Process. Without Gen-AI, students carry out these tasks through brainstorming that relies heavily on their past experiences, prior knowledge and by searching and combing through the internet in search for inspiration and ideas. The conceptualisation and ideation process is divergent initially then students need to converge to a few practical ideas to move forward to the Implement phase of the CDIO Innovation Process. Students typically require a few weeks within the semester to complete the Conceiving and Designing phase. With Gen-AI, this process can be shortened with the both divergent and convergent tasks being done by Gen-AI, creating more time for students to use Critical Thinking to deliberate ideas.

When students deliberate ideas using Critical Thinking (2.4.5), they can challenge the assumptions made, have logical arguments to discuss fallacies and consider multiple perspectives so that they can make informed and concerted decisions that includes societal and multidisciplinary aspects.

As Gen-AI entered higher education with extraordinary speed, reshaping how students search, write, design and communicate, students must learn to adapt to changes (CDIO Syllabus 2.4.3) and learn to use it with integrity and ethically (CDIO Syllabus 2.5.1). It is important to discern validity, applicability and implications of recommendations from Gen-AI. This is another opportunity for students to compare and contrast the information provided by Gen-AI, thereby applying Critical Thinking.

SPARK Framework

In order to strengthen the development of Systems Thinking, Creative Thinking and Critical Thinking, a SPARK Framework is proposed to engage students in iterative process that preserve disciplinary rigour while leveraging Gen-AI for higher-order learning. Figure 1 illustrates the pedagogical reasoning cycle that enables educators to design learning experiences that integrate Gen-AI meaningfully and ethically thereby strengthening the CDIO thinking skills.

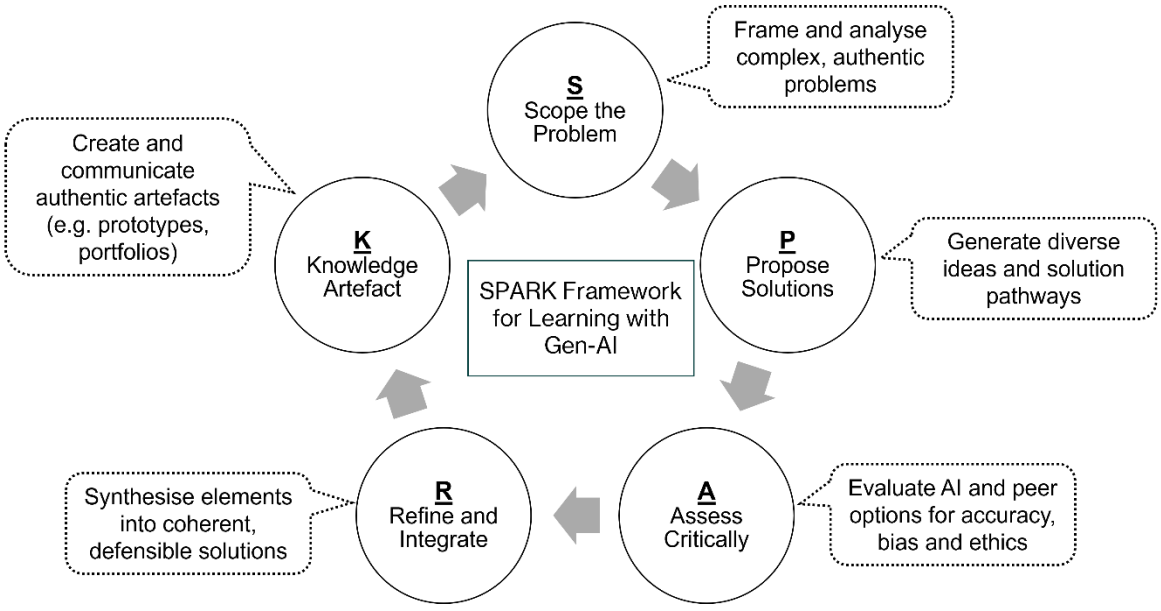

Figure 1. SPARK Framework for learning with Gen-AI

Educators can use the SPARK Framework to guide the redesigning of learning experiences for the era of Gen-AI. Developed within the context of engineering education, SPARK

Framework consists of five iterative phases to strengthen CDIO thinking skills: **S**cope the Problem, **P**ropose Solutions, **A**ssess Critically, **R**efine and Integrate, and **K**nowledge Artefact and Presentation. Each phase supports students in working with Gen-AI while maintaining cognitive ownership, critical evaluation and ethical reflection. This framework is pedagogically anchored in constructivism (Vygotsky, 1978), self-regulated learning (Zimmerman, 2002), and reflection-in-action (Schon, 1983), providing a structured yet flexible approach adaptable across disciplines.

Implementation of SPARK Framework is guided by Biggs' constructive alignment model (Biggs & Tang, 2011). Educators review learning outcomes, design active learning tasks aligned to SPARK's phases and redesign assessments to emphasise reflection and ethical use of Gen-AI. By situating SPARK within the constructive alignment, educators ensure that Gen-AI adoption remains sustainable and evidence-based, anchored in outcomes, not tools.

Table 1 illustrates the pedagogical intent of each phase of the SPARK Framework applied within the CDIO Innovation Process (CDIO Syllabus 4), role of Gen-AI and suggests what lecturers should focus on when re-designing learning activities and assessment for students.

Table 1. SPARK Framework for Learning with Gen-AI

SPARK Phase	Pedagogical Intent	CDIO Innovation Process	Role of Gen-AI	Suggestion on learning design
Scope the Problem	Frame and analyse complex, authentic problems	Conceiving, System Engineering and Management (CDIO Syllabus 4.3)	Use Gen-AI for sense-making	Curate open-ended contextual problems; guide students on ethical Gen-AI use
Propose Solutions	Generate diverse ideas and solution pathways	Designing (CDIO Syllabus 4.4)	Use Gen-AI as creative catalyst	Design tasks that require divergent thinking
Assess Critically	Evaluate Gen-AI outputs for accuracy, bias	Implementing (CDIO Syllabus 4.5)	Use Gen-AI as analytical collaborator	Scaffold reflection, critique and evaluation
Refine and Integrate	Synthesise elements into coherent and defensible solution	Implementing (CDIO Syllabus 4.5)	Use Gen-AI as a reflective partner	Document revisions, rationale and learning growth
Knowledge Artefact	Create and communicate authentic prototypes and portfolios	Operating (CDIO Syllabus 4.6)	Use Gen-AI as co-creator and feedback generator	Balance process and product; incorporate oral presentation or reflection

By positioning Gen-AI as a cognitive collaborator rather than a content generator, SPARK Framework encourages lecturers to design learning environments where students interrogate,

critique and extend Gen-AI generated ideas that strengthens the CDIO thinking skills. The framework thus contributes to the evolving discourse on Gen-AI pedagogy by reasserting the educator's role as designer of learning, not gatekeeper of tools.

SPARK Framework's strength lies in its pedagogical core. As a reasoning-based model, it transcends specific Gen-AI tools and can be applied across disciplines. It is focused on inquiry and reflection, ethics makes it resilient, if not immune, to immediate technology disruption (Luckin, 2018). The SPARK Framework also fosters self-direction, meta-cognition and ethical awareness, cultivating engineers who can work with Gen-AI responsibly (Zimmerman, 2002; Schon, 1983). This parallels CDIO's goal of producing reflective professionals who continually design, implement and operate within complex systems.

The SPARK Framework can also serve as a faculty development framework, equipping lecturers to align learning outcomes, learning activities and assessments with Gen-AI-enabled pedagogy. It advances CDIO Standards 9 and 10 by deepening competence in learning design and reflective practice. Over-reliance on Gen-AI, bias, ethics and faculty readiness can be potential challenges, so SPARK Framework can mitigate these through reflection checkpoints, structured evaluation and professional development.

Overall, SPARK Framework offers a pedagogically sustainable, cross-contextual and human-centered model for Gen-AI integration, reaffirming that while Gen-AI can generate information, only pedagogy transforms it into learning.

CONCLUSION AND FUTURE WORK

This paper proposed the SPARK Framework as a pedagogical approach for guiding educators in redesigning teaching and assessment in which Gen-AI acts as a trusted partner in thinking, creating and learning for students to support the CDIO thinking skills. By grounding Gen-AI integration in pedagogy rather than technology, SPARK repositions educators as architects of learning and Gen-AI as a cognitive collaborator. It ensures that engineering education remains human-centered, ethical and adaptive amid accelerating technological change.

Despite the potential benefits brought by the SPARK Framework, the use of Gen-AI within the framework presents notable risks. Technological advancement is rapid and it may out-pace lecturer's readiness in facilitating the use of Gen-AI with students. Uneven Gen-AI literacy and access among lecturers and students can lead to inconsistent and inequitable use. Specifically, differences in access for Gen-AI tools such as disparities between free and subscription-based versions may give rise to unequal learning experiences. Students with enhanced access to advanced features can engage in more frequent iterations and refined performance improvements thereby gaining potential advantages. Conversely, students with limited access may face constraints that hinder their ability to fully benefit from AI-supported learning activities. Such disparities risk unintentionally introducing inequities even where SPARK Framework is designed to promote inclusive and equitable learning outcomes.

So, the next phase will involve testing and implementing SPARK across multiple programs at Singapore Polytechnic. This will begin with a systematic review of learning outcomes in all modules, followed by the application of Constructive Alignment (Biggs & Tang, 2011) to redesign learning activities and assessments. Pilot studies will explore student learning experiences, including perceptions of agency, engagement and cognitive development in Gen-AI-supported environments, as well as lecturer adoption and teaching design practices

Focus group discussions with lecturers could yield in-depth insights into the aspects of SPARK Framework that were effective versus those that were less successful. In addition, evidence drawn from students' reflective journals could offer rich perspectives on their learning experiences in using Gen-AI as a learning collaborator. Future publications will share findings from SPARK's implementation, its impact on teaching and learning and insights for scaling across CDIO and other global contexts.

By anchoring Gen-AI in pedagogy, SPARK contributes to the sustainability of teaching and learning innovation, ensuring that as technology evolves, the essence of education remains human.

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BIOGRAPHICAL INFORMATION

Katerina YANG is a Senior Education Advisor at the Department of Educational Development, Singapore Polytechnic. She has more than 20 years of experience in pre-employment training and continuing education. She spearheaded the curriculum design and development for a diploma program adopting the spiral curriculum model and successfully led two international re-accreditation exercises for the program. She is actively engaged in advancing professional development initiatives for educators, leveraging her extensive experience to enhance teaching and learning practices.

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