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Speculative futures: Questioning nanotechnology and sustainable development through industrial design pedagogy

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Abstract

The Fourth Industrial Revolution (4IR) is rapidly blurring the lines between the physical, digital, and biological worlds through advances in artificial intelligence (AI), robotics, and other technologies. While Industry 4.0 is transforming our future realities, it is essential not to lose sight of human needs and basic human rights. Development must balance social, economic, and environmental sustainability, which is why designers need to engage with ethical considerations and social realities. One example of a technology that has both potential benefits and ethical threats is nanotechnology. Nanobots, machine versions of bacteria or viruses, can perform pre-programmed tasks autonomously at the atomic level. While nanotechnology has the potential to address inequalities, climate change, and diseases, it also poses ethical threats to society. Higher education programmes must prepare students for these ethical conundrums, especially in a rapidly changing industry driven by technology.

Speculative Design (SD) is a way to engage students in the future implications of the relationship between science, technology, and humans. It proposes provocative future scenarios that spark debate. In order to prepare students for the changing industry driven by technology, an undergraduate project explored the use of AI as a tool in speculative design. Students imagined advancements in nanotechnology linked to a specific SDG and proposed provocative future scenarios through a realistic magazine-type advertisement. The project aimed to balance technological progress with social, economic, and environmental sustainability and prepare students for ethical considerations and future implications. Through SD, students critically explored and reflected on social challenges and opportunities, a shift in approach to design education that emphasises speculative and theoretical exploration and reflection compared to traditional skills-based methods.

This paper reports on the project outcomes, student reflections, and key findings. Furthermore, it emphasises the importance of balancing technological progress with social, economic, and environmental sustainability and engaging students in ethical considerations and future implications through SD. The research paper argues that the integration of SD in industrial design pedagogy has the potential to foster a critical and reflective approach to design practice that is essential for addressing the complex challenges of sustainable development in today's world.

Keywords: 4IR, artificial intelligence, nanotechnology, speculative design, sustainable development goals.

Introduction

The Fourth Industrial Revolution (4IR) has ushered in a new era of unprecedented technological advancements, blurring the lines between the physical and digital worlds. Artificial intelligence, robotics, and nanotechnology are among the key drivers of this revolution, promising transformative solutions to pressing global challenges (Ade-Ibijola & Okonkwo 2023; Kraemer-Mbula & Lorenz 2022). Within the realm of technological innovation, nanotechnology holds tremendous promise. Nanobots, machine versions of bacteria or viruses, have the capacity to perform pre-programmed tasks autonomously. This capability presents an array of potential applications, including addressing inequalities, mitigating climate change, and combating diseases. Yet, as with any powerful technology, nanotechnology also poses significant ethical threats to society, ranging from concerns about privacy and security to the potential for exacerbating social inequalities.

While Industry 4.0 is transforming our future realities and we embrace the potential benefits of these technological breakthroughs, we must not lose sight of human needs and basic human rights. As designers and educators, it is crucial to reflect on the ethical and social implications of technological advancements, particularly in the context of sustainable development. Industrial Design pedagogy plays a pivotal role in equipping future designers with the necessary knowledge, skills, and critical mindset to navigate the complex challenges of sustainable development (Mokgatla & Moseley 2022, p. 277). Higher education graduates of 4IR should not only be equipped with the technical skills required but must be equipped with the critical thinking skills needed to utilise emerging technology sustainably and ethically (Penprase 2018, p. 220). Design educators should therefore reflect and reimagine their curriculum and teaching practices to foster critical and reflective design approaches. The integration of critical design methodologies – the practice of envisioning alternative futures and provoking critical discourse – is one such approach.

This paper presents findings from the first cycle of a larger action research inquiry that explores the efficacy of integrating critical design concepts in Undergraduate industrial design projects. This project cycle tasked students to imagine possible utopian and dystopian futures of nanotechnology through the lens of sustainable development.

Context

In light of much technical advancement, there is much mention of the Fourth Industrial Revolution and its importance in development and furthering technological advancement. However, for developing countries, there are no real insights on how to apply or take advantage of the 4IR appropriately (Ade-Ibijola & Okonkwo 2023, p. 102; Kraemer-Mbula & Lorenz 2022,p. 39; Sutherland 2020). In a world where the industry is rapidly developing to keep up with the trends of the 4IR, our students should not be left in the lurch (Mokgatla & Moseley 2022,p. 277; Adelabu & Campbell 2020, p. 1), and it is, therefore, essential to keep up with these trends within the development of pedagogy (Kayembe & Nel 2019, p. 92; Adelabu & Campbell 2020, p. 1). The development of appropriate applications of emerging technologies needs to be rooted in local contexts and skills (Maisiri, van Dyk & Coeztee 2021, p. 12). This can only be achieved through the development of ready and able actors.

Speculative design proposes an imagined future relationship between science, technology, and humans (Auger 2013). These provocative design proposals are meant to initiate and trigger debate and discussions (Auger 2013; Nabuurs et al. 2023); therefore, speculative design lends itself to be used as a tool to challenge preconceptions (Auger 2013; Nabuurs et al. 2023). The project's aim is to achieve this delicate balance, acknowledging the potential benefits and dangers of nanotechnology in

addressing critical global challenges. Nanotechnology holds promise in tackling issues such as inequalities, climate change, and diseases through its potential applications in various fields, including healthcare, energy, and environmental remediation, wielding the transformative power of nanotechnology in creating a more sustainable future (Auger 2014).

However, alongside its potential benefits, nanotechnology also poses ethical threats to society that warrant careful consideration. The discussion critically examines these ethical challenges, addressing concerns related to privacy (Giri, Maddahi & Zareinia 2021, p. 13), security (Giri, Maddahi & Zareinia 2021, p. 13), environmental impact, and equitable access. By exploring these concerns, the research highlights the need for responsible and ethically conscious design practices in the development and implementation of nanotechnology. It underscores the importance of preparing students to grapple with these ethical conundrums in a rapidly changing industry driven by technology.

The integration of speculative design and industrial design pedagogy emerges as a powerful approach to addressing these complex challenges. Traditional skills-based approaches to design education often prioritise technical proficiency without sufficiently addressing design practice's broader societal and ethical dimensions. The project showcased in this research paper exemplifies how speculative design can engage students in critical thinking and reflection, fostering a more holistic and comprehensive understanding of the implications of emerging technologies. By encouraging students to question prevailing narratives and imagine alternative futures, speculative design enables them to develop a more nuanced perspective on nanotechnology's social, economic, and environmental impacts.

Methodology

In today's world, where products offer solutions to societal problems, it is imperative that designers create inclusive and appropriate solutions that are impactful to both the people and their communities and environments (Ade-Ibijola & Okonkwo 2023; Sutherland 2020). In preparing our students for the world we live in, we need not only to equip them with skills and knowledge that match their contexts, but it is also important that they are equipped with critical consciousness (Watts, Diemer & Voight 2011, p. 44). This calls for a shift in approach to design education that emphasises speculative and theoretical exploration and reflection compared to traditional skills-based methods.

Framed within the critical paradigm (Asghar 2013), this research explores the incorporation of critical pedagogy and critical design methodologies in undergraduate design education as a means of developing critical thinking and reflective design practice among design graduates in the 4IR. Critical pedagogy is a strategy that aims to develop students' critical consciousness, understanding, and reflection, encouraging them to be active participants in their own learning, empowering them to become future agents of social change (Uddin 2019, p. 111).

Speculative Design is a Critical Design methodology rooted in critical thinking which aims to stimulate dialogue or spark debate by proposing future scenarios through satirical or thought-provoking design works (Dunne & Raby 2013, p. 2; Bardzell et al. 2012).

This research aims to explore the efficacy of integrating critical design concepts in Undergraduate industrial design projects, through iterative, practice-led inquiry. Action research (AR) is an educational research approach used by educators to examine, reflect on, and ultimately improve their pedagogy and teaching practice (Clark et al. 2020, p. 8; Sagor & Williams 2016). Given that this study aimed to assess the efficacy of integrating critical teaching methods into undergraduate curricula, this approach was deemed appropriate for the research.

This paper presents the first 'cycle' of this AR project. This cycle followed the four steps of AR, namely: Plan, Act, Observe and Reflect (Clark et al. 2020, p. 11, 12). The 'Plan' phase encompassed the development of the project brief and the definition of project requirements and assessment criteria. The 'Act' phase involved students executing the project brief, as described in more detail below. During the 'Observe' phase, lecturers assessed the project outcomes in accordance with the assessment criteria. As reflection is a crucial component of AR and generating reflective knowledge, lecturers and students were asked to reflect on the project (Schratz 1992, p. 83). Students were requested to complete unstructured written reflections and a semi-structured online questionnaire (Schratz 1992, p. 87). Subsequently, lecturers analysed these qualitative responses alongside their observations of project outcomes, sharing key findings, discussed in this paper, to guide the subsequent cycle. This methodological approach enabled the exploration of student experiences, insights, and challenges (Sagor & Williams 2016), contributing to the broader understanding of the potential of integrating sustainable development and speculative design in industrial design education.

Project brief

This research took place in the Department of Industrial Design at the University of Johannesburg. The project was undertaken by 37 first-year Industrial Design students, in both the Digital Media (2D Digital communication) and Engineering Media (3D CAD) modules. The project took place in the second term, once students had developed basic skills in the respective modules' prescribed software.

For this project, students were challenged to speculate possible utopian/dystopian advancements within the field of nanotechnology, aligned with specific SDGs, and present these speculated future technologies in the form of a realistic magazine-type advertisement, from the year 2040. Students were pre-allocated one of four pre-selected sustainable development goals (SDGs) from which they could identify a specific topic on which to focus their research and design. The pre-selected SDGs included SDG 3: 'Good health and well-being', SDG 5/10: 'Gender Equality'/'Reduced Inequalities', SDG 6: 'Clean water and sanitation' and SDG 7: 'Clean Energy'. Students in each of these groups were then split between Utopian and Dystopian perspectives.

This student design project was undertaken during the 'Act' phase of the AR cycle. The project had a 5-week duration and followed four steps: Research, Ideate, Develop, and Deliver. During the 'Research' phase, students had to conduct desktop research to familiarise themselves with the fundamental concepts of the brief, namely Technology (AI, 4IR, Nanotechnology), their allocated SDG as well as Utopian or Dystopian paradigms. In the 'Ideation' phase, students used keywords identified from their research to define prompts that they then used with image-based AI-generative tools to conceptualise their envisioned nanobot (Figure 1).

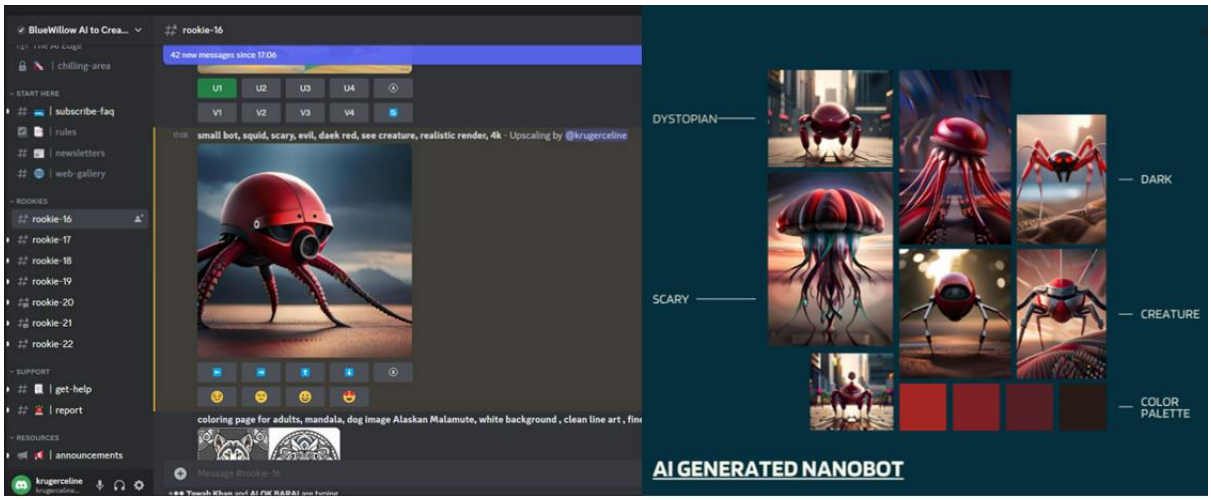

Figure 1: Student example of the AI image generation with Midjourney AI engine

A minimum of five AI-generated images had to be created using these prompts, from which one final Image/concept was chosen to develop further in the next stage. In the 'Develop' phase, students were required to test their newly acquired 3D modelling skills and recreate the chosen AI-generated design in SolidWorks. The final 3D CAD model was rendered to produce photorealistic images of the nanobot design. Finally, in the 'Deliver' phase, students used these renders, along with sourced background images and text, to create a Mixed-Media Advertisement in an open-source Bitmap editing software, GIMP. The final advertisements were presented with an accompanying 300-word write-up explaining the identified problem/opportunity and describing the nano-technology and message of their speculative design outcome.

Project outcomes

The 'Observe' phase involved lecturer assessment of project outcomes. This section presents a selection of project outcomes (3 Utopian and 3 Dystopian) to showcase the efficacy of the project and to provide context to the research findings and lecturer observations.

Utopian

In relation to technology, a Utopian future is one that regards technology as the medium through which positive social transformation can be achieved (Eskelinen, Lakkala & Laakso 2020; Reuter 2022).

Advert 1: The first nanobot in Figure 2 takes inspiration from starfish in both form and function through biomimicry. With a specific focus on addressing SDG 6 concerning clean water and sanitation, the student conceptualised a nanobot designed to filter, absorb, and compact nano-plastics present in our water sources.

Figure 2: Starfish nanobot for water cleaning and sanitation

Advert 2: iCAN (Figure 3) is a nanobot equipped with sensors and a camera, used to monitor nuclear plants for any signs of radiation leakage. Boasting a welder on its upper section, the nanobot can autonomously repair any minor leaks it detects to prevent further deterioration.

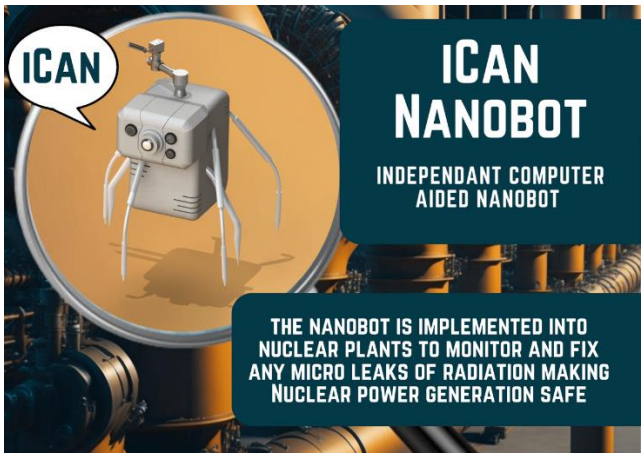

Figure 3: iCan Nanobot for energy plant monitoring and repair

Advert 3: The Sci-Fi Flying Drone depicted in Figure 4 represents a remote-controlled nanobot designed to cure deafness by facilitating the direct delivery of medication into the patient's inner ear.

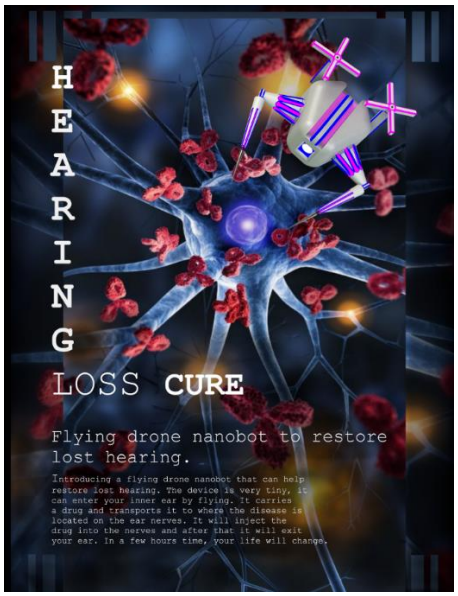

Figure 4: Flying nanobot for healing hearing loss

Dystopian

Speculating a future through a dystopian lens – one pictures a world in such disarray that technology is not used to help bridge inequality gaps but rather exacerbate them.

Advert 4: The nanobot in Figure 5 is a bioweapon used to courier deadly bacteria, such as TB. These Nanobots are almost invisible to the naked eye, so transmission without any detection is almost guaranteed, allowing for targeted infections and even assassinations.

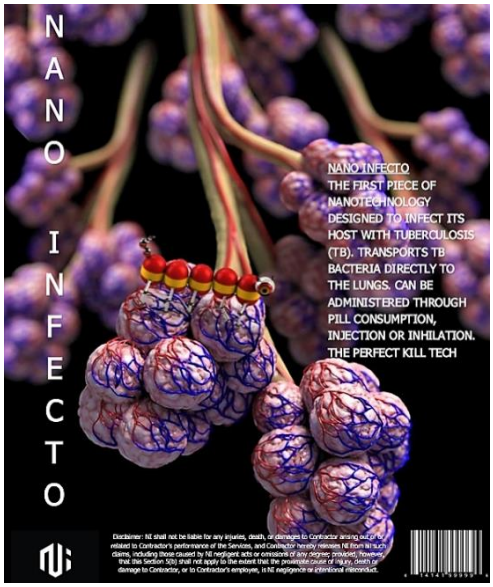

Figure 5: Caterpillar Nanobot for spreading bacterial diseases

Advert 5: The nanobot in Figure 6 is a water-purifying nanobot used to decontaminate water. This student envisioned a nanobot that can be programmed to target specific pollutants in water in a variety of settings, including rivers, lakes, oceans, and even drinking water. While this may at first seem like a utopian example, these nanobots can be programmed to target certain groups of people,

such as dissidents or political enemies, allowing the government to silence dissents and maintain its grip on power. The wealthy and powerful would have access to clean water, while the poor and marginalised would be left to drink dirty water.

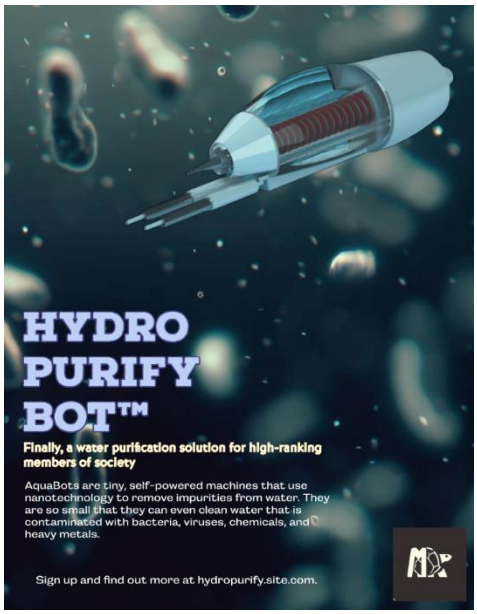

Figure 6: Selective water purifying nanobot for rich areas and persons

Advert 6: Finally, The GendAIr nanobot in Figure 7 operates based on the principles of Placement Theory, actively assigning and positioning individuals within the constructed gender hierarchy. It goes beyond the surface-level features and delves into the core of one's gender identity and expression, dictating their placement within this oppressive system. By providing pre-set options for physical appearance, it restricts the scope of self-expression and encourages conformity to societal expectations of masculinity and femininity. This reinforcement of gender norms fuels the objectification of both genders and undermines efforts to challenge or dismantle harmful stereotypes.

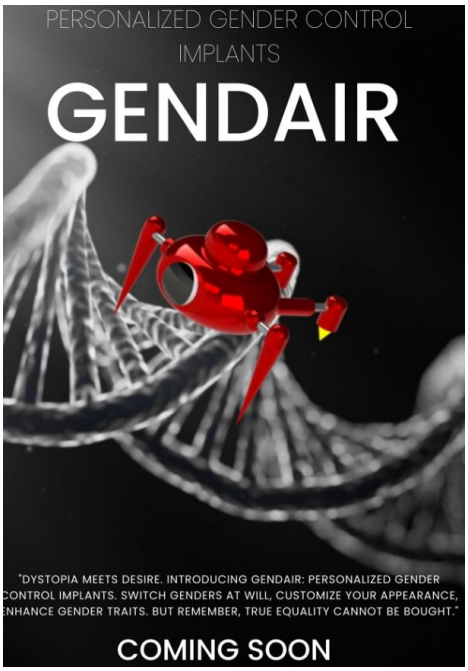

Figure 7: Dystopian eugenics nanobot for selective reproduction

Student reflections

At the end of the project, students were required to complete unstructured written reflections and a semi-structured online questionnaire (Schratz 1992, p. 87). While most students completed the personal reflection essay, it must be noted that only 7 of the 37 students responded to the questionnaire. We therefore acknowledge this limitation when looking at the findings, and therefore want to facilitate a second cycle, to build on these findings and gather more detailed and rigorous feedback.

This questionnaire gathered insights on what the students perceived as their understanding of the different key topics of the project at the beginning and at the end of the project.

Table 1: Summary of student survey questions

General	• What about the project did you find **successful and useful?** • What about the project did you find **unsuccessful and ineffective?**
Speculative Design	• How did you find the **speculative nature** of the project? • Did you feel the **speculative design** aspect **was relevant and added value** to the project?
Technology	• Did your views on **technology** change at all during this project? • In your opinion, is the advancement of technology a positive or negative thing? or both?
Sustainability	• Had you heard of the **UN SDGs** before this project? • Did you learn anything new regarding these goals through the completion of this project? • Did you feel that linking to the **SDGs was relevant and added value** to the project?

AI Tools	• How was your experience using **AI generative tools** in your ideation phase?
	  • Did you find it useful/difficult/boring/exciting?
	  • Would you use AI as an ideation tool again?
	  • Did you feel that **using AI** added value to the project?

Questions were divided into the four topics/focus areas of the project brief, namely Technology/4IR, Speculative Design methodology, Sustainability, more specifically the SDGs, the use of AI tools. Students were also asked to reflect on what they felt was successful and what was unsuccessful (Table 1). Responses were analysed by the lecturers. Some key findings are presented below:

- Overall, the students found the project to be difficult in terms of them having to learn multiple, complex concepts in a relatively short project.
- Specific ‘successes’ and ‘failures’ spoke to the practical execution of deliverables rather than the brief itself.
- Most respondents felt that the speculative design methodology was confusing (as it falls outside of the traditionally pragmatic discipline) but they also described it as “interesting” and “thought-provoking” and all respondents felt it added value to the project.
- Some respondents did not feel the need to engage with futuristic technologies, such as nanotechnology, as they did not find it relevant to the South African context.
- Most of the respondents did not know about the UN SDGs prior to this project

- All respondents felt that the inclusion of SDGS was relevant as it grounded the project in real-word problems but would have preferred to choose their own SDG of interest.
- Majority of students enjoyed the use of AI and found it to be a useful inspiration/ideation tool. While some voiced their frustration when prompts did not generate the desired outcome.
- Overall, the students thought the inclusion of AI added value to the project.

The project was a success for the students.

> I found this project very interesting because of how technology is changing, it made me think/imagine how the future of the world be like and how nanotechnology may affect the world.

The majority of the students were not aware of what sustainable development goals were and their intended purpose in today's world, and how their role as designers fits into the solving or achieving of these goals. For a few students, the project was difficult in terms of them having to learn a lot of these new concepts in such a short project. The project was a success in terms of getting the students to experiment with the AI image generators. However, it is quite evident from the student reflections that some students did not enjoy the project because of the frustrating process of generating the image or scene they had envisioned. Some students also did not feel the need to engage with emerging technologies, such as nanotechnology as it is not relevant to the South African context.

Lecturer observations

This project aimed to assess the effectiveness of incorporating critical design concepts into undergraduate industrial design projects. However, the project's complexity posed challenges for first-year students as it introduced numerous new concepts simultaneously. Additionally, students were required to familiarise themselves with previously unused software. The timing of the project's introduction, in the early second term (March to May), was less than ideal. In order to enhance future iterations, we recommend a staggered approach, allowing students to gradually engage with the theory and become comfortable with the software tools before tackling such a complex project. Analysing project outcomes and student reflections, the authors have noted the below key findings:

1. The lecturers were expecting a lot more enthusiasm from students in terms of using AI generation tools, however, this was not the case. A few students struggled with creating prompts for the AI engines and were frustrated with some of the outputs that they got. Although a few classes and tutorials have been given to students with time being given for experimentation, in future, a more guided one-on-one consultation approach might yield better results.
2. A fear of the lecturers was that students would use these AI image generators too well and heavily rely on them without developing their own creative and critical problem-solving abilities. However, through feedback from the students, they did not view the AI generation tools as a replacement for their ideation process. The images generated are far too literal without context and still rely on the students' own understanding of the application of the product or service.
3. Students need to engage with discourse on SDGs in the early undergraduate years. Although the outcomes may not be resolved or implementable, it gives the students an opportunity to design for a purpose through real-world problem solving.
4. Speculative Design Theory is interesting to students as it gives them the potential to explore their creativity without being constrained to any practicality of use and/or application.
5. The nanobot designs were limited by the CAD abilities of the students. Some good innovative designs were simplified so as to be easily modelled.

As this was an undergraduate first-year project, there was no expectation for the students to fully grasp the key problems they were trying to solve with their nanobots. However, some of the outcomes far exceeded these expectations. The solutions were creative, and the project was fun enough to keep the students engaged through its entirety.

Conclusion

This project served as a starting point to gain insights on how we can further develop our curriculums and pedagogy to answer to the trends and opportunities of the Fourth Industrial Revolution. For students, it also was a reflective creative outlet they used to engage with big-world problems that they did not normally engage with, especially at the first-year undergraduate level. The introduction of higher-level theories is often difficult to integrate seamlessly into teaching and learning in earlier undergraduate years. Students, however, need exposure to such to prepare them for their roles as change-makers in the world. Though the starting point, this paper's research findings and student reflections underscore the transformative potential of integrating speculative design within industrial design pedagogy. This approach encourages students to think beyond immediate constraints and envision possibilities that challenge existing paradigms. By engaging in speculative futures thinking, students develop critical thinking skills, interdisciplinary collaboration, and an awareness of the social, cultural, and environmental contexts in which their designs operate. This prepares them to navigate the ethical considerations and future implications associated with emerging technologies.

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