34th Australasian Association for Engineering Education Conference
3 - 6 December 2023 – Gold Coast, QLD

Interdisciplinarity in a Biomedical Engineering Curriculum Development: A Student's Co-Design Approach

Rita Prestigiacomo[a]; Lauren Kark[a]
[a]*Graduate School of Biomedical Engineering, University of New South Wales*
Corresponding Author Email: *r.prestigiacomo@unsw.edu.au*

CONTEXT
Collaboration and interdisciplinarity are at the heart of Biomedical Engineering, a field that spans engineering, medicine and biology. Biomedical engineers may be expected to work with health professionals to identify solutions to address patients' healthcare needs or collaborate with companies to design and manufacture medical devices. To ensure that biomedical engineers are agile interdisciplinary professionals, they need to have experience with interdisciplinarity within their curriculum. While this responsibility rests on higher education institutions, this task is challenging, especially for a field traditionally concerned with depth over breadth.

PURPOSE OR GOAL
We executed an exercise intended to contribute to the breadth of a biomedical engineering curriculum and increase interdisciplinarity to encourage students' learning mobility across biomedical engineering disciplines, including biomechanics, biomaterials, and bioinstrumentation.

APPROACH OR METHODOLOGY/METHODS
A graduate school of Biomedical Engineering adopted a backward co-design mapping exercise at an Australian university to assess an existing curriculum in which interdisciplinarity is an increasing priority. This involved four coursework and five postgraduate research students with diverse biomedical engineering backgrounds. Thematic analysis was used to analyse the written MS Teams contributions and the digital artefacts produced by the students during five co-design sessions facilitated by the second author of this paper.

ACTUAL OR ANTICIPATED OUTCOMES
Findings show that students produced a comprehensive curriculum map for interdisciplinary curricular development. The curriculum map demonstrates (i) opportunities for intentionally designed interdisciplinarity in the curriculum, (ii) genuine pathways to higher-level electives, and (iii) a career journey from high school to graduate employment.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
These results reveal that students' backward co-design mapping is a promising approach to curriculum development. It enables students to play an active role by inquiring about the curriculum and jointly imagining ways to improve it. Within the context of this study, their involvement contributes to co-constructing a narrative missing from the existing biomedical engineering curriculum.

KEYWORDS
Co-Design, Students, Curriculum Development, Biomedical Engineering

Introduction

Numerous challenges spanning societal, healthcare, economic and technological domains have emerged in today's society, posing disruptive, multi-faceted and open-ended problems (Fritzsche et al., 2020; Patrick et al., 2022). These problems, often ill-structured, wicked, or complex (Schuelke-Leech, 2020), do not have one clear solution path and one identifiable solution. Instead, their lack of clarity in the aims and objectives increases their vagueness and complexity, necessitating a fundamental reconsideration of the conventional role and responsibilities of engineers (Van den Beemt et al., 2020).

Engineers, as problem-solvers, are no longer required to work with the depth of their knowledge through a pre-established deductive and analytical approach to break down a problem and identify a potential solution (Schuelke-Leech, 2020). By contrast, the stratified and multi-faceted complexity of today's problems demands engineers to develop knowledge breadth, defined as the "exposure to a range of engineering topics (across specialisations) as well as some other supporting professional skills and non-technical courses" (Alpay, 2013, p. 31), and leverage collective knowledge and expertise from different disciplines to create positive change and excel in an interdisciplinary environment.

This does not spare biomedical engineers concerned with enhancing healthcare and improving people's lives by developing innovative solutions based on interdisciplinary collaboration with other experts, including scientists, biologists, healthcare professionals, and other engineers. For biomedical engineers to be able to become interdisciplinary professionals with the ability to operate within (depth) and beyond (breath) the boundaries of their disciplines, biomedical engineering education changes are imperative. This suggests the pressing need to surpass academia's traditional discipline-oriented and siloed nature to promote an interdisciplinary approach to learning. Despite the challenge, this responsibility rests on higher education institutions, which need to undergo a structurally significant change to cultivate and nurture a new generation of well-rounded and interdisciplinary biomedical engineers (Lattuca et al., 2017) with technical knowledge and analytical skills alongside professional skills, including creativity, communication, leadership and project management, ethical standards, flexibility, resilience and agility (Terenzini et al., 2007).

With this in mind, this paper presents a backward co-design exercise executed with biomedical coursework and postgraduate research students to increase interdisciplinarity and contribute to the breadth of an engineering curriculum by encouraging students' learning mobility across biomedical engineering disciplines, including cell technologies, biomechatronics, digital biology and biosensing. We argue that a backward co-design exercise holds promise for interdisciplinary curriculum development and for students to demonstrate their interdisciplinary understanding while spotting their disciplines' strengths and weaknesses, capabilities and limitations.

Within this context, we pose the following research question: *What kinds of insights can a backward design approach offer on an existing biomedical engineering curriculum?* This paper first defines two key concepts – interdisciplinarity and co-design. It then provides an overview of the literature on interdisciplinary curriculum development co-design initiatives. We illustrate the research context and the methodological design and then describe the comprehensive curriculum map produced by the students. We close the paper by discussing the findings and outlining the strengths and limitations of this study.

Interdisciplinarity and co-design practices

Interdisciplinarity has garnered increasing attention and sparked extensive debates over the past two decades. Scholars have offered various definitions and interpretations, contributing to its evolving understanding (Lattuca & Knight, 2010; Lattuca et al., 2017). Lattuca et al. (2017) remark that interdisciplinarity is a process and an outcome. As a process, interdisciplinarity refers to a series of steps to answer a given question, solve a problem or address a topic that is too broad and complex to be solved by a single discipline or profession. As an outcome, as intended in this study, interdisciplinarity synthesises various disciplinary knowledges and methods, achieved through interaction, integration and collaboration, which play a crucial role not only in tackling contemporary challenges and driving innovation (Markauskaite & Wrigley, 2022) but also in co-design practices.

Co-design is a participatory approach that engages end-users in the design process to ensure the relevance and usability of the outcomes (Sanders & Stappers, 2008). Involving diverse perspectives, knowledge, and expertise in the design process is critical to achieving innovation and creating solutions that align with the needs and aspirations of the intended users. Within the context of this study, we adopt Steen's (2013) definition of co-design, which is a collaborative "process of joint inquiry and imagination in which diverse people jointly explore and define a problem and jointly develop and evaluate solutions" (pp. 27-28).

The link between interdisciplinarity and co-design lies in their shared objective of harnessing collective intelligence and expertise. Both emphasise collaboration and diverse perspective integration and seek joint problem-solving. Interdisciplinarity provides the necessary framework for diverse disciplines to come together, while co-design methods facilitate meaningful stakeholder engagement throughout the design process. Together, they enable the exploration of complex problem spaces, the generation of innovative solutions, and the promotion of advancements spanning social, environmental, technological and educational environments.

Related Work

Within the field of education, interdisciplinary studies, driven by diverse motivations and purposes, have witnessed the extensive engagement and collaboration of a wide range of stakeholders, including academics, alums, postdocs, undergraduate students, and industry partners. While a comprehensive overview of the nature of interdisciplinary studies falls outside the scope of this study, our region of interest is to understand how interdisciplinary curriculum development manifests in co-design approaches within engineering disciplines.

Chasteen et al. (2015) conducted a research study centred around course transformation with science faculty from seven different departments and discipline-based postdoctoral education specialists. While they developed learning goals, identified students' difficulties and created assessment materials, the absence of graduate students' involvement can be of significant concern considering their critical role in interdisciplinary collaborations (Ma, 2020). To further emphasise this point, a recent PhD dissertation by McCance (2021) on interdisciplinary collaborations between STEM and education revealed that the limited participation of graduate students as collaborators warrants further investigation. Indeed, McCance noted that faculty primarily served as major collaborators - as expected- for their roles of principal investigators on grant-funded projects, their direct involvement with teaching and learning and university reform implementations. These observations are consistent with the "2020 Vision" report (Lattuca et al., 2014), which remarked on the scarcity of formal opportunities for students to work with their peers from other engineering disciplines. Such limited interactions restrict the potential for interdisciplinary collaboration among students within the engineering domain.

Similarly, a systematic literature review by Horn et al. (2023) analysed 11 existing inter- and transdisciplinary higher education programmes. The study found that in only three of these programs, students were involved in the joint framing, the initial stage of a co-design approach, encompassing research definition and preparation. Notably, Horn and colleagues remarked that a lack of students' involvement in the early stage of a co-design project hinders their training opportunities in inter- and transdisciplinary co-creation. The small number of studies engaging students can be controversial when successful stories of curriculum co-creation promote the role of students as partners as a sustainable and practical way to produce engaging curricula (Darestani et al., 2022).

With these factors in mind, our study aims to address this gap. By recognising our students' vast knowledge, understanding, and expertise in the school's subjects and contents of biomedical engineering, we sought to offer them the formal opportunity to contribute to curriculum development by leveraging their disciplinary expertise and skills as well as their opinions, values and perceptions, as valuable academic members. The subsequent section of this paper will delve into the specifics of our approach.

Methodology

This internally funded project was conducted at a graduate biomedical engineering school in a large metropolitan university in Australia. Several gaps had been identified in the current biomedical engineering curriculum, including (i) a need for on-ramp processes to facilitate seamless entry, (ii) a lack of cohesion in course offerings and timings, and (iii) repeated introductory content in several higher-level electives. The assessment of an existing biomedical engineering curriculum, with a particular focus on interdisciplinarity, had the ultimate aim to (i) propose on-ramp introductory and interdisciplinary courses covering fundamental key concepts, (ii) develop clear and deliberate educational and career pathways through the curriculum, and (iii) streamline courses to prevent content repetition and excessive overlapping.

An expression of interest email was sent to all coursework and postgraduate research students enrolled in a biomedical engineering program at our university. We recruited students to create a diverse cohort (e.g., gender, discipline of study, and stage of study). Table 1 offers an overview of the diverse biomedical engineering profiles and backgrounds of coursework (*n*=4) and postgraduate research students (*n*=5).

Table 1: Overview of the participants' profiles

Variable	Coursework	Stage of Study	Postgraduate Research
Gender			
Women	1		2
Men	3		3
Engineering Discipline			
Chemical	1	4th year	1
Computer Science and Engineering	1	1st year	0
Electrical	0		2
Material	1	4th year	1
Mechanical	1	4th year	1

The co-design exercise recognises diverse stakeholders' expertise, skills and contextual knowledge (course work and postgraduate research students). It aims to foster collective creativity and collaborative knowledge development by enhancing a product (a biomedical engineering curriculum). Our co-design initiative was inspired by a backward co-design approach (Wiggins & McTighe, 2005), in which students engaged in a process that iteratively moved backwards and forward in time. They first started with 'what is' to understand what had already been done and then looked forward to exploring 'what could be done'. This forward-looking perspective involved harnessing their imagination and envisioning alternative solutions and approaches.

This co-design study consisted of five face-to-face sessions - an initial two-hour introductory session, followed by four one-hour fortnightly follow-up sessions- facilitated by this paper's second author from October to December 2022. These sessions were supplemented with iterative between-session exchanges on a private MS Teams channel, which was created as a primary mode of interaction to ensure the participants’ effective communication and work progress but also for data management. During the introductory session, participants had the opportunity to introduce themselves and gain insights into the current challenges of a biomedical engineering curriculum. Additionally, the aims, the nature of activities, and the expected workload (i.e., four-hour weekly commitment) were outlined. The first session concluded with a pair-based exercise that required the students to identify biomedical engineering courses relevant to their respective undergraduate disciplines. The first and second follow-up sessions focussed on discussing the backward mapping of existing courses. The third delved into the backward mapping of proposed electives of the students’ choosing. The final session revolved around a design activity where students were encouraged to design their program.

Data collection and analysis

The data for this study was collected using the written contributions on MS Teams and the digital artefacts (mind maps) produced on Miro, a digital collaborative platform. These methods allowed for comprehensively capturing the participants' ideas, discussions, and visual representations throughout a backward co-design process. MS Teams enabled the students to contribute their thoughts, feedback, and reflections in a written format, which, as primary data, were analysed using thematic analysis by adapting the following stages of (i) familiarisation, (ii) generation of initial codes, (iii) searching, (iv) review and (v) naming of themes as outlined by Braun and Clarke (2006). First, written contributions via Teams were carefully and iteratively read to develop familiarity with the data and gain general insights. Second, initial codes of relevant segments of data were generated with the research question in mind. Third, upon examining the codes, some of them clearly fitted together into a theme. For example, several codes revolved around the curriculum-industry relatedness. Hence, we collated these into an initial theme: curriculum design and future work opportunities. Fourth, each broad theme was collectively reviewed, to ensure coherence. Finally, each theme was named.

The use of Miro allowed the participants to create and share visual artefacts such as diagrams and curriculum maps. These were treated as secondary data and added richness to the data providing additional insights into the participants’ co-design activities. Integrating these two data collection techniques offered a rich dataset incorporating textual and visual elements, facilitating a thorough analysis of the co-design outcomes.

Findings

From the data analysis of the written MS Teams contributions and the digital artefacts produced on Miro, several key findings were identified, and three themes emerged:
1. intentionally designed interdisciplinarity in the curriculum,
2. genuine pathways to higher-level electives, and
3. a career journey from high school to graduate employment.

Intentionally designed interdisciplinarity in the curriculum

The students demonstrated a strong inclination towards intentionally designed interdisciplinarity in the curriculum. In a disciplinary mapping exercise, figure 1 illustrates the interrelationship between the biomedical engineering courses being offered (i.e., BIOM9640). It showcases students’ efforts to establish connections between prerequisite topics (in purple), intended as ‘*what is needed*’, to move to the following course (i.e., BIOM9650), in line with the fundamental outcomes (in blue), aiming to minimise potential overlap.

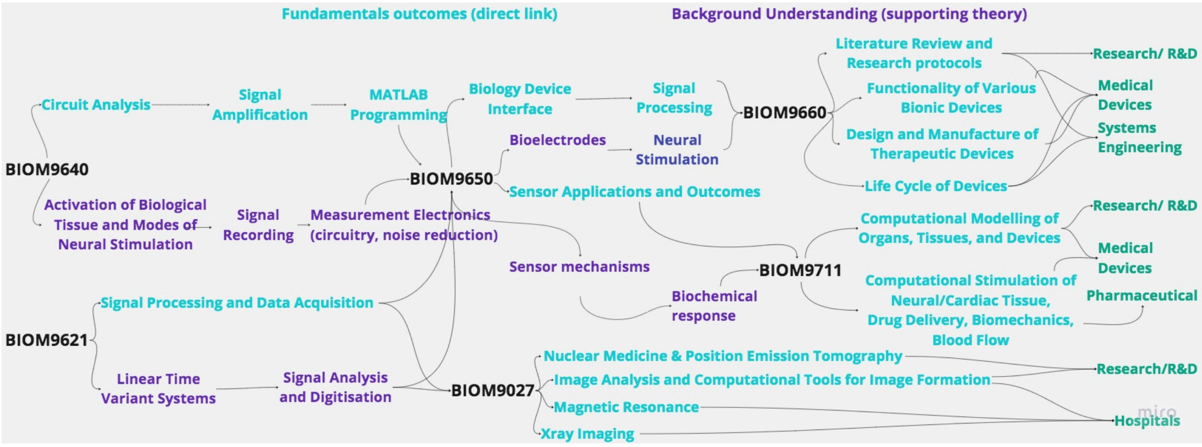

Figure 1: Disciplinary mapping of biomedical engineering courses, with pre-requisite topics and course learning outcomes

The students displayed awareness of the limitations inherent in their disciplines, recognising the necessity for interdisciplinary integration. As evidenced by a postgraduate research student's comment, they sought input from individuals with different backgrounds, demonstrating a commitment to ensuring the comprehensiveness and effectiveness of the curriculum. This aspect is illustrated in the following comment:

> *I had a look over the mapping of the modelling/physics-oriented branches. These look good to me as well as the mechanical branches; however, I am not familiar enough with the mechanical concepts to know if anything else could be added/changed or if any other MECH/BIOM courses overlap with these sub-topics. It would be greatly appreciated if someone with a mechanical background could quickly look over the mechanics branches of the course.*

Genuine pathways to higher-level electives

The students established clear pathways to higher-level electives (Figure 2) to provide biomedical engineering students with a high-quality and consistent educational experience and promote transparency in elective selection. As a postgraduate research student stated:

> *This initiative aimed to counteract a prevailing student culture where electives are chosen because they are convenient, familiar, and 'easy' but not necessarily out of interest and enthusiasm.*

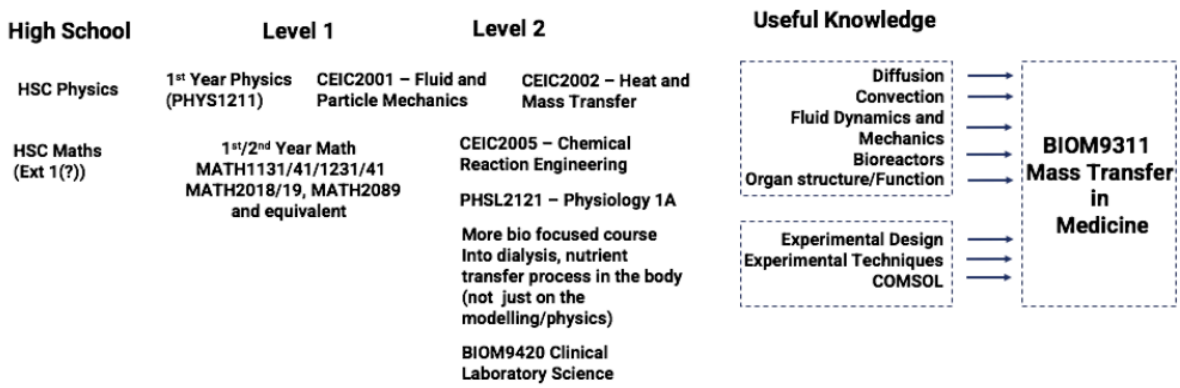

Figure 2: Pathway mapping from high school to electives

Students emphasised the need for electives to form cohesive and comprehensive modules to shape a well-versed biomedical engineering graduate. One postgraduate research student stated:

Progress through these modules builds on key concepts whilst also developing highly competent and adept engineers to work in various biomedical fields.

A career journey from high school to graduate employment

The students' mapping exercises underscored the significance of linking biomedical engineering courses to future employment opportunities, as depicted in Figure 3. The students recognised the value of explicitly highlighting to potential biomedical engineering students how their courses relate to industry-relevant prerequisite knowledge and their future careers.

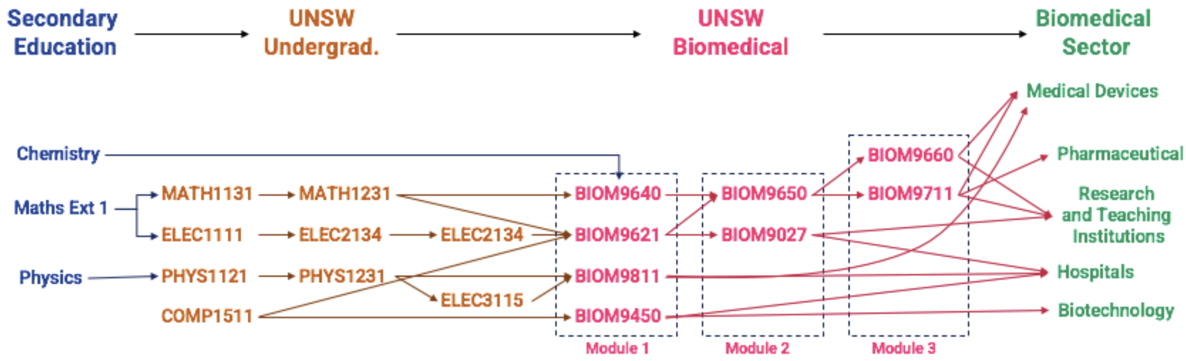

Figure 3: High-school mapping to graduate employment

One coursework student remarked the following.

I would like to link all of the courses I have back mapped to industry relevant prerequisite knowledge so that we can let students know that BIOM courses will be preparing them in some way for getting hired or work.

By emphasising this connection, biomedical engineering students would better understand how their coursework would prepare them for employment. This finding suggests the awareness of biomedical engineering students of the practical applications of their studies, and their desire (especially for those in their fourth year of their degree who had completed their placement) to ensure that their curriculum is aligned to the various demands of the industry.

These findings indicate that students' insights and efforts contribute to co-constructing a curriculum that promotes interdisciplinary thinking, enhances students' preparedness for the industry, and fosters a more thoughtful approach to elective selection.

Discussion and Conclusion

This study adopted a backward co-design approach and explored the contributions of students with diverse biomedical engineering backgrounds engaged in assessing and developing an existing biomedical engineering curriculum with a focus on promoting interdisciplinarity. Despite the inherent complexity and challenges of designing an interdisciplinary curriculum, the findings showed that students generated a comprehensive curriculum map demonstrating intentional interdisciplinary design. Notably, the exercise helped the students tell a story of all the courses combined. It also facilitated their critical and relational thinking, enabling them to identify disciplinary gaps and limitations and propose ways to address them (Van den Beemt et al., 2020).

By establishing genuine pathways to higher-level electives, the study offered the opportunity to initiate a discussion on the importance of striking a balance between breadth and depth in engineering education. This intentional and initial shift from knowledge building to skill development and application is expected to support students' professional skill development (Alpay, 2013) and equip them to face issues beyond the field of engineering (Judson et al., 2015; Lattuca et al., 2014).

Interestingly, the reconstruction of a learning pathway from high school to graduate employment cannot be separated by the ultimate objective of any graduate: industry employment. This may point to the need for (i) a best practice curriculum, (ii) high-quality exposure to engineering practice, and (iii) effective delivery by educators who possess expertise in educational best-practice and contemporary engineering practice (Male & King, 2019). The backward co-design approach empowered students to voice their needs and fostered the co-construction of a narrative absent from the biomedical engineering curriculum through joint inquiry and exploration.

This study suffers from several limitations - a small sample size and a limited number of students within the same discipline. Consequently, the findings may not be representative of the broader student population. Hence, future studies could be undertaken with a larger and more diverse sample to enhance the generalizability of the findings. Despite this, co-design results in a promising process for fostering meaningful curriculum enhancement by emphasising students' voices, consultation, and collaboration since the initial stage of co-design. Additionally, co-design could prove invaluable when engaging industry partners in curriculum co-design endeavours. The approach developed in this study proposes guidance to higher education institutions interested in joint curriculum development.

References

Alpay, E. (2013). Student attraction to engineering through flexibility and breadth in the curriculum. *European Journal of Engineering Education*, *38*(1), 58–69. DOI: 10.1080/03043797.2012.742870

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Chasteen, S. V., Wilcox, B., Caballero, M. D., Perkins, K. K., Pollock, S. J., & Wieman, C. E. (2015). Educational transformation in upper-division physics: The science education initiative model, outcomes, and lessons learned. *Physical Review Special Topics Physics Education Research*, *11*(2), 020110. https://doi.org/10.1103/PhysRevSTPER.11.020110

Darestani, M., Jones, C. E., & Peseta, T. (2022). *The magic of partnering with students to create transdisciplinary STEM curricula.* Paper presented at the Australasian Association for Engineering Education Annual Conference, Sydney, NSW.

Fritzsche, H., Boese, A., & Friebe, M. (2020). How do we need to adapt biomedical engineering education for the health 4.0 challenges? *Current Directions in Biomedical Engineering*, *6*(3), 604-607. https://doi.org/10.1515/cdbme-2020-3154

Horn, A., Scheffelaar, A., Urias, E., & Zweekhorst, M. B. M. (2023). Training students for complex sustainability issues: A literature review on the design of inter- and transdisciplinary higher education. *International Journal of Sustainability in Higher Education*, *24*(1), 1-27. https://doi.org/10.1108/IJSHE-03-2021-0111

Judson King, C., & Pister, K. S. (2015). How best to broaden engineering education? *Engineering Studies*, *7*(2-3), 150–152. https://doi.org/10.1080/19378629.2015.1062489

Lattuca, L., & Knight, D. (2010). *In the eye of the beholder: Defining and studying interdisciplinarity In engineering education*. Paper presented at the Annual Conference and Exposition, Atlanta.

Lattuca, L., Terenzini, P., Knight, D., & Ro, H. K. (2014). 2020 Vision: Progress in preparing the engineer of the future.

Lattuca, L. R., Knight, D. B., Ro, H. K., & Novoselich, B. J. (2017). Supporting the development of engineers' interdisciplinary competence. *Journal of Engineering Education*, *106*(1), 71-97. https://doi.org/10.1002/jee.20155

Ma, G. (2020). Sparking interdisciplinarity: Let's take framing students as customers in higher education seriously. *Interdisciplinary Science Reviews*, *45*(4), 461–476. https://doi.org/10.1080/03080188.2019.1695171

Male, S. A., & King, R. (2019). Enhancing learning outcomes from industry engagement in Australian engineering education. *Journal of Teaching and Learning for Graduate Employability*, *10*(1), 101–117.
Markauskaite, L., & Wrigley, C. (2022). How can we co-design for interdisciplinarity? Three entwinements of design and interdisciplinarity. *Journal of Design, Business & Society*, *9*(1), 3-8. https://doi.org/10.1386/dbs_00043_2
McCance, K. R. (2021). *Investigating the potential of interdisciplinary collaborations between education and science/engineering in higher education* [Doctoral Dissertation, North Carolina State University, Awarding the Degree].
Patrick, C. W., Machek, J., Avazmohammadi, R., Alge, D. L., Peak, C. W., & McShane, M. (2022). Process for faculty-driven, data-informed curriculum continuity review in biomedical engineering. *Biomedical Engineering Education*, *2*(2), 265–280. https://doi.org/10.1007/s43683-021-00063-y
Sanders, E. B., and P. J. Stappers. 2008. Co-Creation and the New Landscapes of Design. CoDesign *4*(1), 5–18. https://doi.org/10.1080/15710880701875068
Schuelke-Leech, B.-A. (2020). The place of wicked problems in engineering problem solving: A proposed taxonomy. Paper presented at the 2020 IEEE International Symposium on Technology and Society (ISTAS)
Steen, M. (2013). Co-Design as a process of joint inquiry and imagination. *Design Issues*, *29*(2), 16–28. https://doi.org/10.1162/DESI_a_00207
Terenzini, P. T., Lattuca, L. R., & Harper, B. J. (2007, 2007). Special session - preparing the engineers of 2020: A dialogue. Paper presented at the Annual Frontiers in Education Conference-Global Engineering: Knowledge Without Borders, Opportunities Without Passports (pp. F2E-1). IEEE.
Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., van Baalen, S., Klaassen, R. G., & Boon, M. (2020). Interdisciplinary engineering education: A review of vision, teaching, and support. *Journal of Engineering Education*, *109*(3), 508-555. https://doi.org/10.1002/jee.20347
Wiggins, G. P., & McTighe, J. (2005). *Understanding by Design*. Ascd.

Acknowledgements

We thank the students participating in this study.

Copyright statement