Reflectively Mapping the Zone of Proximal Development in Industrial Engineering

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1 Introduction

Industrial engineering (IE) is a multi-disciplinary field of study that relies upon four primary knowledge areas: manufacturing systems engineering, human factors engineering, operations research, and management systems (Salvendy, 2001). The major advantage of drawing from different knowledge areas is that industrial engineering graduates can find jobs not only in a variety of industries but also in a variety of roles. While this is a good thing in terms of career prospects after graduating, students do not always understand why they must take courses in all these seemingly disconnected knowledge areas. Consequently, this affects the level of effort they put into some of these courses, particularly the ones they deem to be less related to engineering (Murphy *et al.*, 2006). Furthermore, as motivated by Dwight *et al.* (2006), students do not immediately recognise how these knowledge areas contribute to the broader society in terms of sustainable development goals (SDGs) and graduate attributes (GAs). These are two key features of the new International Engineering Alliance (IEA) graduate competency guidelines (2021), which govern the Knowledge, Skills, Practices and Values expected of graduates upon successful completion of their degree or programs. Sustainability is woven throughout these guidelines. The SDGs are a set of global goals put forward by the United Nations (UN) in efforts aimed at ensuring prosperity and peace not only for everyone in the world but also for the world itself by tackling some of the world's most pressing social, economic, and environmental issues (United Nations, 2015). Engineering is the profession at the heart of achieving our collective SDGs, and engineering educators are tasked with the development of the GAs. The context for the paper is the IE programme at a research-intensive university in South Africa, where the researchers had noted that students do not always see the connection between some courses and their link to SDGs and GAs. Given our task of empowering engineers of the future who are able to implement creative solutions with broad societal impact, a need exists to integrate among these disconnected spheres using scaffolded teaching practices. Of particular concern in this IE programme are the Engineering Economics (E-Econ) and Enterprise Design (E-Des) courses, which students anecdotally perceive as low priority. This study set out to encourage these two IE student cohorts to collaboratively reflect on their respective module 'content', the three pillars of the SGDs (i.e., social, economic, and environmental) and two specific GAs (i.e., GAs 7 - related to sustainability and the impact of engineering activity, and GA 8 - team and multi-disciplinary working) as captured in figure 1.

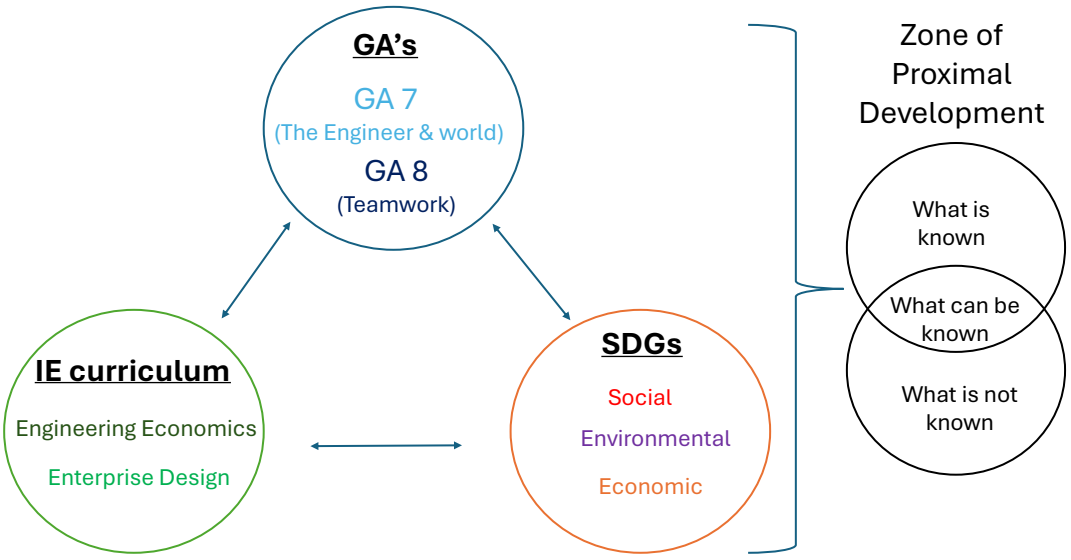

Figure 1 Course, GA and SDG contextualisation with ZPD

The programme in question is located in an engineering faculty which follows a socio-culturally mediated educational ethic. In other words, learning is seen as moving from the known to the unknown in a social context and is facilitated through mediating artefacts. These include texts, discussions, case studies and group work, all of which are intended to scaffold student learning. This scaffolding embodies Vygotsky's (1956) concept of the Zone of Proximal Development (ZPD) constructivist in nature (Payong, 2020), where

different students require different kinds of support to progress across three distinct ZPD stages: i) What is known, ii) What can be known and iii) What is not known. Using this as a framework, the research design (figure 1) is intended to determine the relationship and interactions between the student perceptions of their ZPD stages in two specific courses, the relevant GAs and the three pillars of the SDGs. The question for this exploratory practice paper is: What are our student' perceptions of the nature of and relationship between their curriculum, GAs and SDGs, and how can we better scaffold their learning and support integrative thinking?

2 Methods in context

On average, 100 students are enrolled annually in 3rd year E-Econ and 4th year E-Des. The course objective of E-Econ is to introduce students to macroeconomic concepts within companies, with a specific focus on time value of money and capital budgeting. E-Des is concerned with empowering students with the working knowledge and tools associated with the specification, design, analysis, development and implementation of new or existing features of an enterprise in its entirety. Both courses entail group work and case studies, which align with GAs 7 and 8, as well as the three SDG pillars. Conversations with current students and previous feedback supported the observation that these students experience a disconnect between the curriculum, SDG relevance and Graduate Attributes.

With the newly released International Engineering Alliance competency profiles foregrounding sustainability and inclusivity (IEA, 2021), together, these two courses offer an ideal opportunity to speak to the social, environmental and economic SDGs, and build in forms of pedagogic engagement that address the attributes needed to engage socially in the broader engineering environment.

Collaborating lecturers on the two courses designed a learning activity to investigate the level of disconnect, by using the three-stage descriptors of Vygotsky's concept of the Zone of Proximal Development: i) What is known, ii) What can be known; iii) What is not known.

The objectives were to 1) map the ZPD current state for both courses and 2) determine the possible interaction between the two courses, three SDG pillars and GA 7 & 8.

Students from both cohorts were first introduced to the intent of the research, the three pillars of the SDGs, adaptations of GA 7 and 8, and a reflection on course objectives. The second part of the activity tasked students with consciously reflecting on the content and having them complete the ZPD diagram by detailing each stage of the ZPD associations, as illustrated in Figure 1. The 3rd year E-Econ activity was done asynchronously with a Google Form, whereas the 4th year E-Des activity was done synchronously using a live Google Slides that the entire cohort completed simultaneously. A total of 92 students completed the tasks. All data were consolidated on a spreadsheet, and unique terms were included for analysis and categorisation according to the three ZPD stages. Findings are presented as graphic summaries using Figures 2 and 3 that visualise the ZPD for E-Econ and E-Des, with colour coding corresponding to those that featured in Figure 1. This has been colour coded such that "societal impact of investments" speaks to social sustainability (red) alongside GA 7 (light blue). The colour-coding technique is a visually illustrative and accessible means to immediately identify key patterns and clustering of student responses.

3 Discussion of Findings

3.1 Current state ZPD analysis

The E-Econ cohort mentions under 'what is known' the general curricular concepts already familiar to students, namely: course content, study units and course objectives to do with accounting practices, investments and stock markets They consciously recognise that they do *not* know, but *can* know how these concepts play out at both a macroeconomic level in the real world (GA 7, and the economic SDG pillar), as well as a micro, technical and software-orientated level. The feedback focuses on quantitative techniques,

software, visualization and coding in traditional hard sciences as elements that can be known. Interestingly, for what is 'not known', students mention "how the JSE works", despite having engaged in a collaborative JSE simulation activity which mimics real-world collaborative engagement (GA 8) which concerns the sustainability narrative (all three pillars). The activity requires students to collaboratively develop an investment portfolio (GA 8) and invest virtual money in the stock exchange. Students must then track the portfolio's economic performance in the market and reflect on the broader social and environmental sustainability implications of said performance (all pillars).

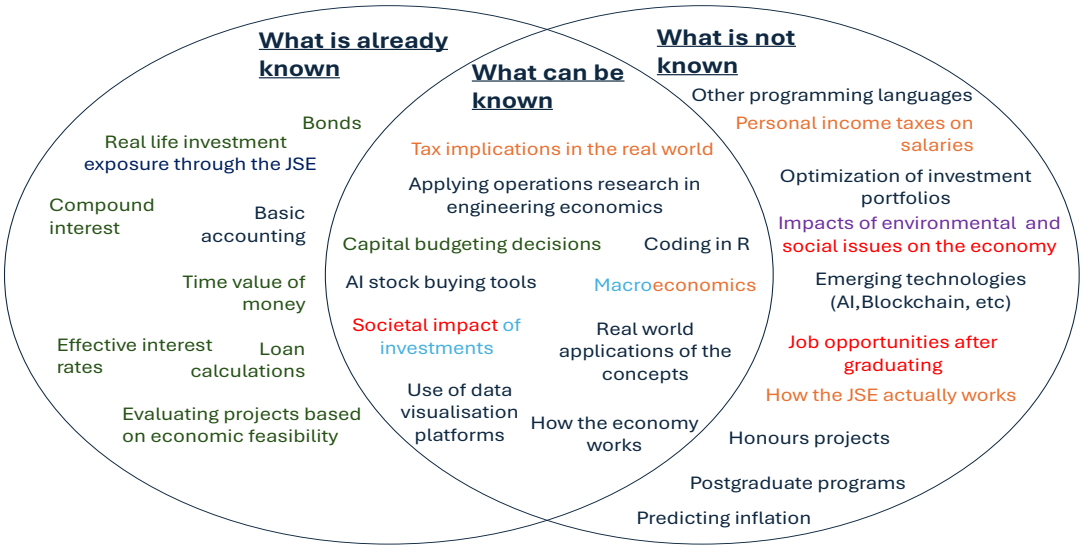

Figure 2 ZPD diagram for Engineering Economics cohort

The Enterprise Design cohort (Figure 3) provided a more industrial engineering-focused reflection on several topics tied to preceding courses under the 'what is known' category. As final-year students, this is to be expected.

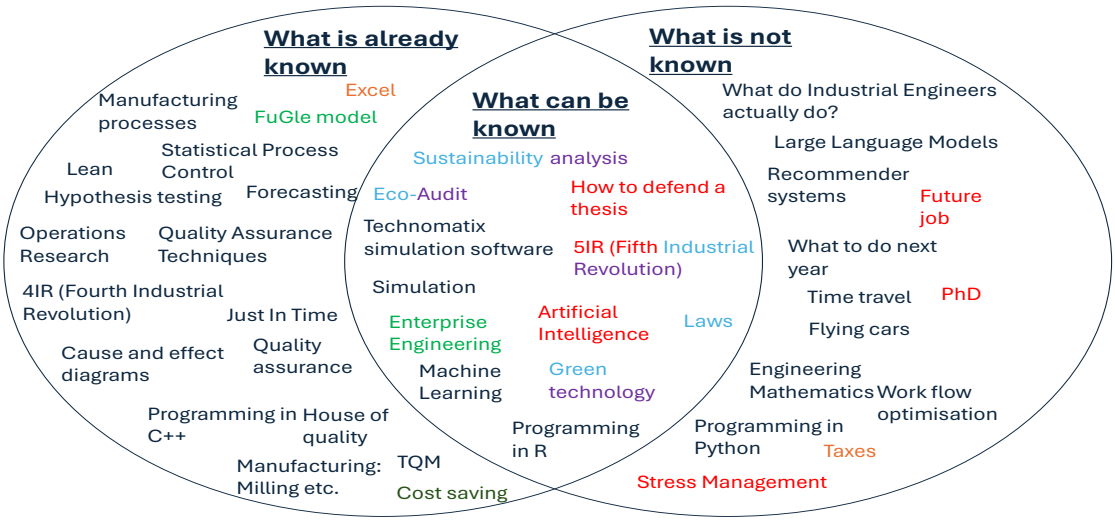

Figure 3 ZPD diagram for Enterprise Design cohort

Students identified the potential to learn about software packages as well as technology-driven and technical content. All the students on the programme do the same programming courses (namely, C++ and R). It is interesting that they perceive other possible useful programming languages (such as Python) as being within different ZPD achievability stages. This cohort is intrigued (can be known) by sustainability, 5IR and innovative future thinking as well, linking perfectly to the three pillars. In this cohort interestingly enough, "what

Industrial Engineers actually do" emerges as an unknown. However, there were no GA associations directly tied to teamwork. The only evident forms tied to laws, industry and the environment despite the group project within the course. This project tasks students with designing an enterprise from an idea to a coherent business plan.

Much like the E-Econ ZPD diagram, the focus for E-Des has evolved. The students from both courses list future personal and societal elements as key unknowns. Both cohorts also are interested in post-grad and job opportunities and the role IEs have in the workplace. They share concerns about their futures as functioning adults in society (e.g., taxes). The 4th year cohort is able to provide a holistic reflection across multiple knowledge areas. In contrast, the 3rd year cohort focuses on one knowledge area (economics) solely.

3.2 Alignment between GAs and SDGs with course intent

With these findings in mind, as well as a continuous improvement ethic, the collaborating lecturers highlighted key curricular themes as a stepping stone to developing a framework not only to better align the course objectives with the GAs and SDGs, but to enable a more explicit framing of their interactions (Table 1). These themes (as indicated by the colour coding in the ZPD diagrams in section 3.1) are unpacked so as to demonstrate the current interaction between the SDGs and GAs using the course-specific context. This collaborative exercise has pointed to insufficient alignment and reflectively enabled opportunities for more explicit leveraging and linking of the SDGs with GAs 7 and 8 using concepts already familiar to students in preceding courses (e.g. basic accounting for economic sustainability). Ultimately, this analysis creates more awareness and suggests opportunities for broader integration/collaboration across the two curricular domains through potential strategies such as shared case studies. through course content in broader contexts.

Table 1 Course alignment with GAs and SDGs

E-Econ						
Curricular themes	ECSA GA		Pillar			Context
	7	8	Ec	En	S	
Real life investment exposure		X				The investment simulation is done in groups, and teamwork is one of the three major components of GA 8.
Macroeconomics	X		X			Understanding macroeconomics can contribute towards efforts aimed at achieving sustained economic growth (SDG 8). Furthermore, an awareness of the macroeconomic impact of engineering activity is a component of GA 7.
Societal impacts of investments	X		X			An awareness of the societal impact of engineering activity aligns with GA 7. Societal impacts can contribute towards efforts aimed at reducing inequalities (SDG 10).
Tax implications in real world			X			Tax revenue can be used to fund industry, innovation, and infrastructure (SDG 9) and have effects on job creation and decent work (SDG 8) and reducing inequalities (SDG 17).
How the JSE works			X			Investments in stock market such as the JSE works can have major effects on the growth of economies (SDG 8).
Personal income taxes			X			Income taxes paid by individual can playing a major role in sustaining economic growth (SDG 8).
Job opportunities					X	Securing a good job after graduation is a form of decent work (SDG 8).
Environmental and social issues' impact			X	X		Responsible production (SDG 12) and climate action (SDG 13) are some of the environmental issues that are affected by economic decisions. On the social issues, economic decisions can affect efforts aimed at reducing poverty (SDG 1).
E-Des						
Curricular themes	ECSA GA		Pillar			Context
	7	8	Ec	En	S	
Excel			X			Financial management software to study economic growth (SDG 8)

Sustainability analysis	X		X	X	X	The impact of engineering activities tries to explicitly speak to sustainability narratives (e.g. carbon footprint) across all three pillars.
Stress Management					X	Stress management protects Good Health and wellbeing (SDG 3).
Thesis defence & PhD					X	The crux directly speaks to quality education (SDG 4)
Laws	X					Legal frameworks are a core component of the GA 7 definition. Peace, justice and strong institutions (SDG16) is directly governed by laws promulgated
5IR	X			X	X	5IR inherently speaks to sustainable and society which are subsets of GA 7. The definition of 5IR tries to remedy the environmental and societal disconnect from 4IR
AI					X	Quality education (SDG4) could be created with AI
Green technology	X			X		Affordable and cleaner technology (SDG 7) are a direct product from green technology
Eco-audit	X			X		SDG 12 on responsible consumption and production is facilitated by eco-auditing process
Future job			X			Decent work and economic growth (SDG 8) are supported by job creation and acquisition
Taxes			X			Economic growth (SDG 8) is instilled by the tax funding mechanism

4 Conclusions and recommendations

This study set out to map student perceptions of the course objectives, three SDG pillars (economic, environmental, social) and two particular GAs (engineer in the world, teamwork). Using three stages of the concept of the ZPD, students in two IE courses captured their perceptions as diagrams in an interactive learning activity. The analysis of the data demonstrated a distinct disconnect between the three sustainability pillars and the two GAs. The absence of explicit referencing of the GAs and SDGs in the ZPD diagrams reaffirms the disconnect. The connections between these concepts and the curriculum under study were siloed amongst course objectives, assessment and student perception. As part of an ongoing improvement initiative, the collaborating lecturers have developed a framework to more explicitly link the course objectives to the said SDGs and GAs. Furthermore, the framework offers opportunities to also model more detailed levels of scaffolding for the two courses, similar to the work executed by Burger (2022). The deficiency in GA and SDG alignment calls for innovative teaching practices that can introduce these concepts more explicitly in the curriculum, along with appropriate assessment strategies. The analysis portrays varied levels of understanding and scaffolding that the courses can create. Possible ways of expanding the study are to extend this to other courses in the programme, changing student perceptions or executing a cross-sectional study with other cohorts. Alternatively, the same learning activity can be repeated each year to monitor the impact of preceding course changes, which respond to the new GAs and the SDGs.

5 References

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