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Data-Driven Competency Mapping Through Visualisations

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ABSTRACT

CONTEXT

Despite competency-based education gaining significant traction within engineering programs, one of the major design challenges is retaining a bird's eye view of overall program-level capabilities while scaffolding individual competencies longitudinally. This has been particularly challenging for academics in general and course convenors, leading to a lack of understanding and buy-in for competency-based models.

PURPOSE OR GOAL

Using data-driven visualisation as a key capacity building tool, this study aims at enhancing course convenors and educators' buy-in and understanding of competency-based education in the degree within which they teach. Such a tool will enable to navigate one of the main challenges in effective implementation of competency-based education within engineering degrees.

APPROACH OR METHODOLOGY/METHODS

To increase buy-in and understanding of competency-based education for course convenors, we develop a set of visualisation techniques to map competencies and their relationship to course learning outcomes, and assessments.

ACTUAL OR ANTICIPATED OUTCOMES

As a part of competency-based curriculum redesign initiative, we present a set of visualisations to facilitate buy-in from course convenors in the implementation of competency-based education within an engineering degree. These visualisations allow for any convenors to have a bird's eye view of competencies scaffolding within a degree and would enable better contextualisation and integration of core activities and assessments tasks with the competencies to be attained within this degree.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The visualisations are very helpful as conversation starters in terms of identifying at which stage in the program and which courses are better suited for scaffolding competencies. They also enable understanding of the types of assessment to choose to drive a set of learning outcomes within the context of a specific degree.

KEYWORDS

Competency based education, Learning outcomes, Assessment, Visualisation.

Introduction

In recent years, there has been a shift towards competency-based education (CBE) in professional programs such as medicine, engineering, and other applied fields. Unlike traditional models of education that focus on students' progression through discrete courses, competency-based models emphasise the mastery of clearly defined domains of knowledge and skills, with these competencies being scaffolded longitudinally throughout the program (Gervais, 2016).

In engineering education, competency-based approaches are increasingly recognised as effective and meaningful for developing a range of professional competencies, such as problem-solving, teamwork, and leadership, alongside technical expertise. These models offer a more holistic approach to education that aligns with the growing demand for graduates who are job-ready and able to adapt to rapidly changing technological environments (Malhotra et al., 2023; Valero, 2022). However, transitioning from traditional, course-based models to competency-based frameworks is complex and faces multiple challenges.

One of the significant challenges in designing and implementing longitudinal scaffolding for competencies is the lack of a deep understanding and buy-in from educators (Henri et al., 2017). Many educators may struggle with visualizing how discrete sets of knowledge, skills, and attitudes fit into the broader competency framework, which can hinder the effectiveness of these educational reforms (Frank et al., 2010). Additionally, institutional constraints, such as limited resources and inadequate professional development opportunities, exacerbate this issue, making it difficult for educators to fully embrace competency-based approaches (Albanese et al., 2010; Stoffman, 2022). Addressing these concerns through structured faculty development and providing clear frameworks for how competencies are scaffolded across programs can significantly improve the implementation of CBE (Snell, 2014).

In this paper, we showcase innovative ways to visualise competency-based designs within a 4-year Bachelor of Engineering (Honours) degree, with the aim of enhancing staff understanding of how, when, where, and why such designs facilitate the scaffolding of various competencies. These visualisations, developed through a review of a degree specialisation, map competencies to both accreditation body requirements and the university's graduate attributes, offering a clear framework for educators to follow. This approach seeks to bridge the gap between theoretical competency models and practical implementation in educational settings.

Context

The UNSW Engineering is a faculty comprising eight schools which deliver undergraduate and postgraduate degrees in the area of biomedical, chemical civil, environment, electrical, telecommunication, mechanical, mineral and resources and renewable energy engineering (*Engineering | UNSW Sydney*, n.d.). The context of this study is curriculum renewal initiated by the School of Photovoltaic and Renewable Energy Engineering; to shift towards a competency-based integrated curriculum, our purpose is to enhance our diverse educators' literacy and appreciation for advantages of competency-based educational reforms. To this end, we undertook a step-by step approach of creating visual competency maps with the purpose of developing training packages to upskill staff and academics as well as a tool to facilitate benchmarking and review of the degree to better scaffold competencies. Scaffolding within university curricula has been shown to improve employability by equipping students with essential competencies and facilitating learning and mastery of complex concepts, which are critical for career readiness (Chen, 2014).

Method

First, we gathered information about all the courses in the degree from the course description website. This included collating course name, code, aims, learning outcomes, assessments and teaching strategies for each course. We also extracted the mapping of course learning outcomes to competencies and the mapping of assessments to course learning outcomes. This allowed us to map competencies to course assessments. This data was then collated into a hierarchical database as a JSON file. We also used a typical student study plan, that outlines the most typical succession of courses a student takes.

Once this competency extraction and mapping was established, we conducted analyses to identify how well the degree covers all required competencies. For each course, we counted how many competencies were represented and calculated the weighted competency contribution for each course. For example, if a math course contained only the competency 1.1 science fundamental, the weight of competency 1.1 would be 100%. If a specialisation course contained, 1.1, 1.2, 1.3 and 1.6, each of these competencies would be assigned a weight of 25% for this course. Importantly, the competency percentage was not weighted by the assessments weight for that course. Both approaches have pros and cons and here we decided to keep them unweighted by the assessment.

This data was then visualised using radar chart and colour coded heatmaps. The visualisations were shown to course convenors to increase their understanding of how their course fit within the degree, and their buy-in in terms of competency-based learning.

What competencies to scaffold?

After reviewing the competencies as mandated by the accreditation body and internal discussion with the key educators, we mapped course learning outcomes that contributed towards demonstration of the competencies.

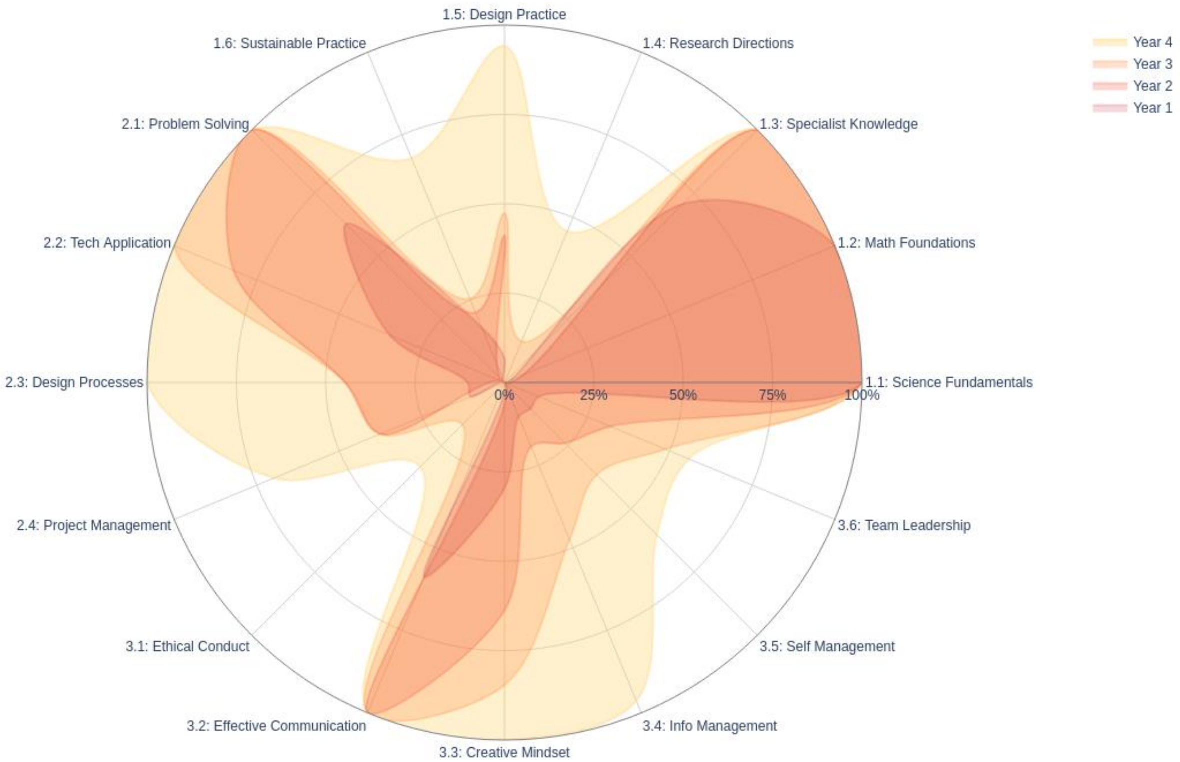

Figure 1: Cumulative competencies radar chart. The competencies 1.1, 1.2, 3.6 refer to the Engineers Australia's Stage 1 competency standards for professional engineers.

Note that the percentages calculated within this paper are not scaled by the assessment weight, they are equally weighted by the mapped learning outcomes. The evolution of cumulative competency count for the degree is illustrated in Figure 1. Note that less than 100% at the end of the degree does not mean that this competency is not attained by the cohort, but rather that this is a starting point for collective deliberations of curriculum improvement. In other words, this chart does not represent indicators of attainment, but rather how often such competency is embedded into the degree.

When to scaffold and measure competency?

While a competency radar chart clarifies what competencies could be more integrated within a program, they are not granular enough to understand at what stage of the program and which course(s) in the degree this integration with the outcomes and assessments take place. We therefore use the previous metric of cumulative percentage of course learning outcomes which integrates current competencies to create the cumulative competency heatmap shown in Figure 2.

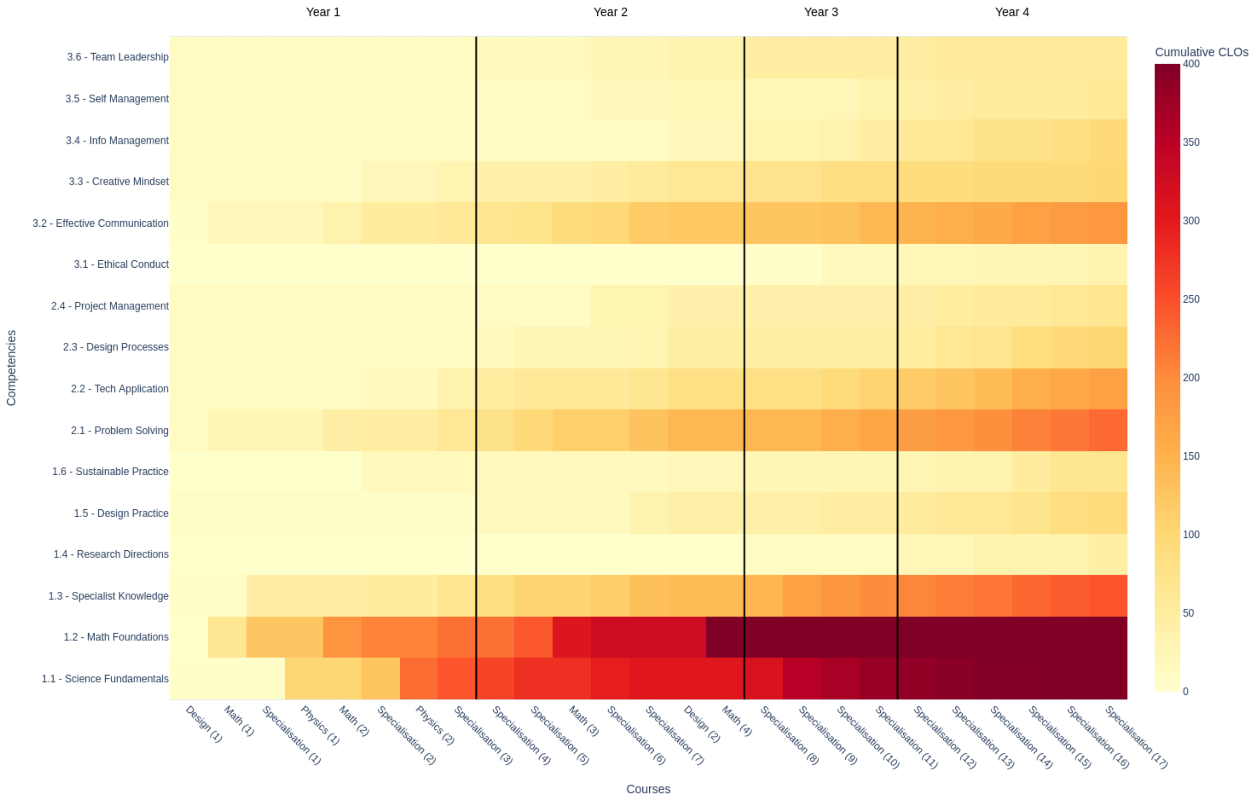

Figure 2: Cumulative competency scaffolding heatmap

By mapping competencies across the degree, we can identify trends in terms of competency scaffolding. We can see that the degree focuses more on foundational knowledge (competencies 1.1 and 1.2) than others and that this starts early in the degree. Some higher level competencies such as management type of skills are also scaffolded later in the degree.

Where (in which course) to integrate competencies?

The cumulative competency heatmap allowed us to identify stages in the degree where competencies can be scaffolded. The next stage from a curriculum design point of view was to identify which courses are well suited for competency scaffolding. An individual competency heatmap (Figure 3) enabled us to illustrate the proportion of course-level learning outcomes containing each competency within every course in the program.

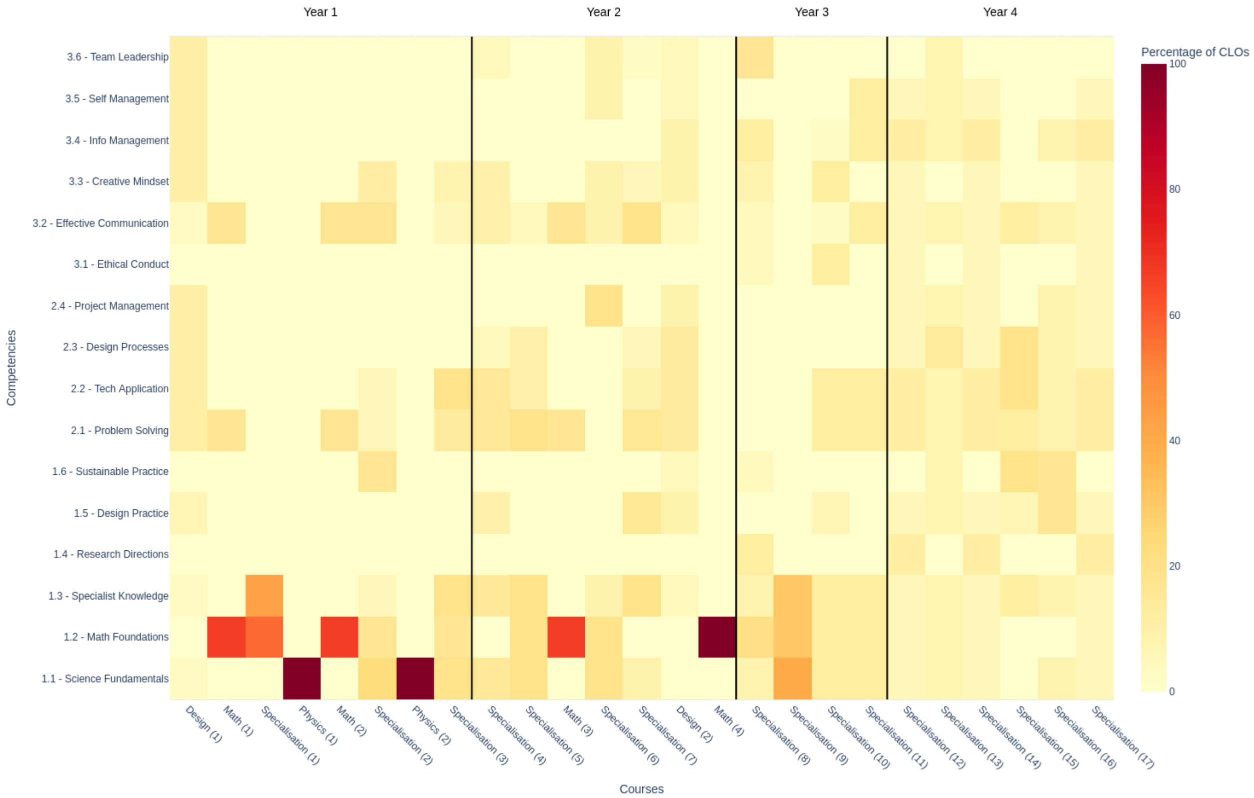

Figure 3: Individual competency heatmap

Looking at the heatmap, it becomes clear which courses in year 1 and year 2 focus heavily on foundational science and math knowledge. This highlights new opportunities for courses in which to scaffold level 2 and level 3 competencies.

How to scaffold certain competencies?

Having a better understanding of what competencies could be implemented in which courses, there remains the question of how to embed these competencies. Driving a wide range of competencies requires using a diverse set of assessment methods (Baartman et al., 2006). In this section, we explore what assessments drive which competencies.

Figure 4 shows the assessment competency heatmap which displays the proportion of each competency in every class of assessments within a program. For example, test and quizzes type of assessments address the foundational knowledge as shown by the dark red in the bottom left corner of this heatmap.

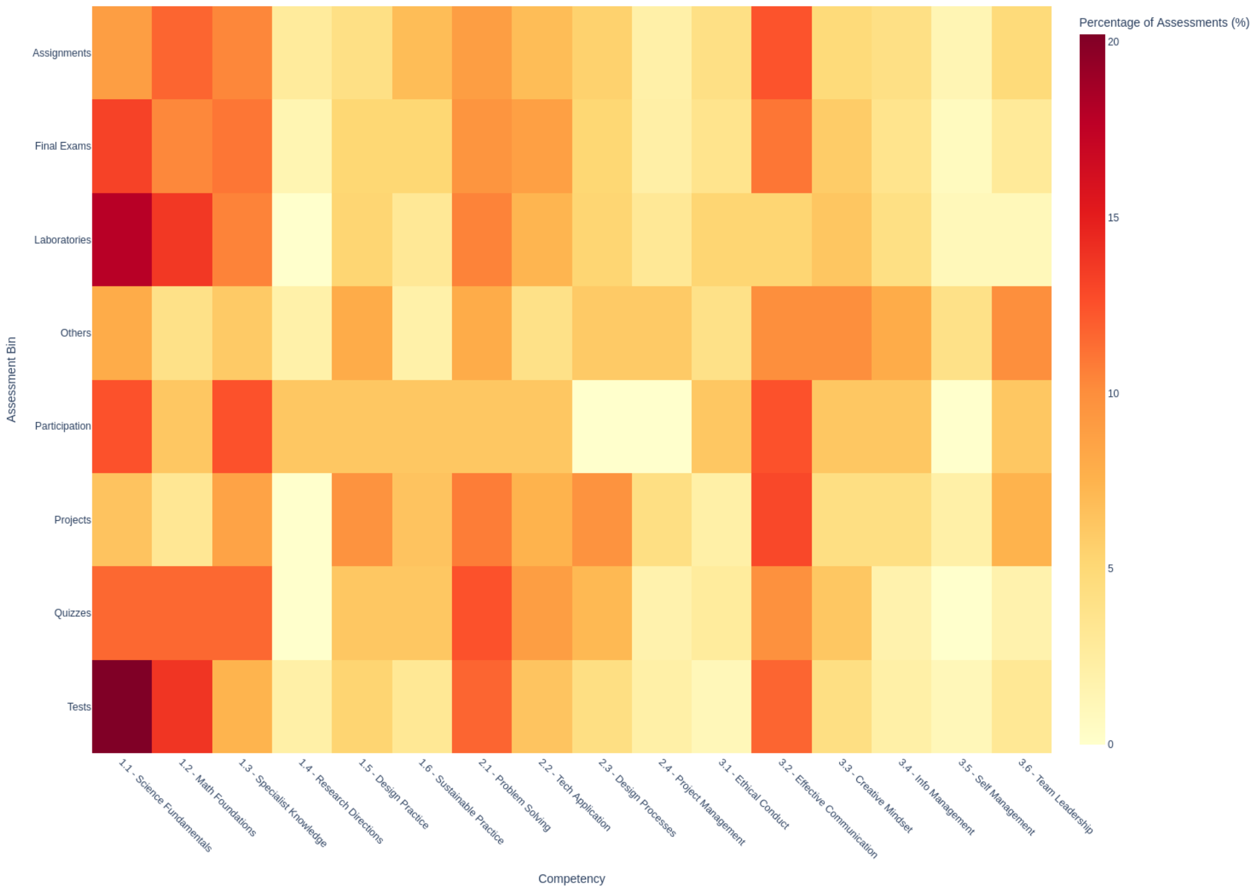

Figure 4: Assessment competency heatmap.

One of the easiest ways to scaffold higher level competencies is, thus, by changing the type of assessments we use in courses. This is because some assessments automatically drive certain competencies as seen in the graph above (e.g. quizzes drive knowledge, projects drive teamwork). For instance, authentic assessments, which are designed to reflect real-world tasks and challenges, have been shown to significantly enhance student competencies. Setiawati et al. (2022) emphasise that authentic assessments, when paired with clear rubrics, provide a structured way for educators to evaluate student competencies accurately, thereby facilitating a deeper understanding of the material and its application in practical contexts (Setiawati et al., 2022). This is in line with Gonczi, who suggests using more direct and relevant assessments (e.g. projects and labs) as opposed to indirect assessments such as exams (Gonczi, 1994).

Why are some competencies underrepresented?

Having identified courses where competencies could be more scaffolded, the question as to why some competencies are underrepresented remains to be unpacked. This is a complex issue, and our research team is still investigating optimal solutions to this. To begin with we are initiating the further review of courses within the degree to identify duplication of assessments including those that may be redundant or need to be transformed significantly. As shown in figure 4, assessment inherently drives a specific set of competencies. To inform this assessment analysis we then look at what competencies co-occur. Figure 5 is a competency co-occurrence probability heatmap. The higher the value, the more likely two competencies are likely to occur together.

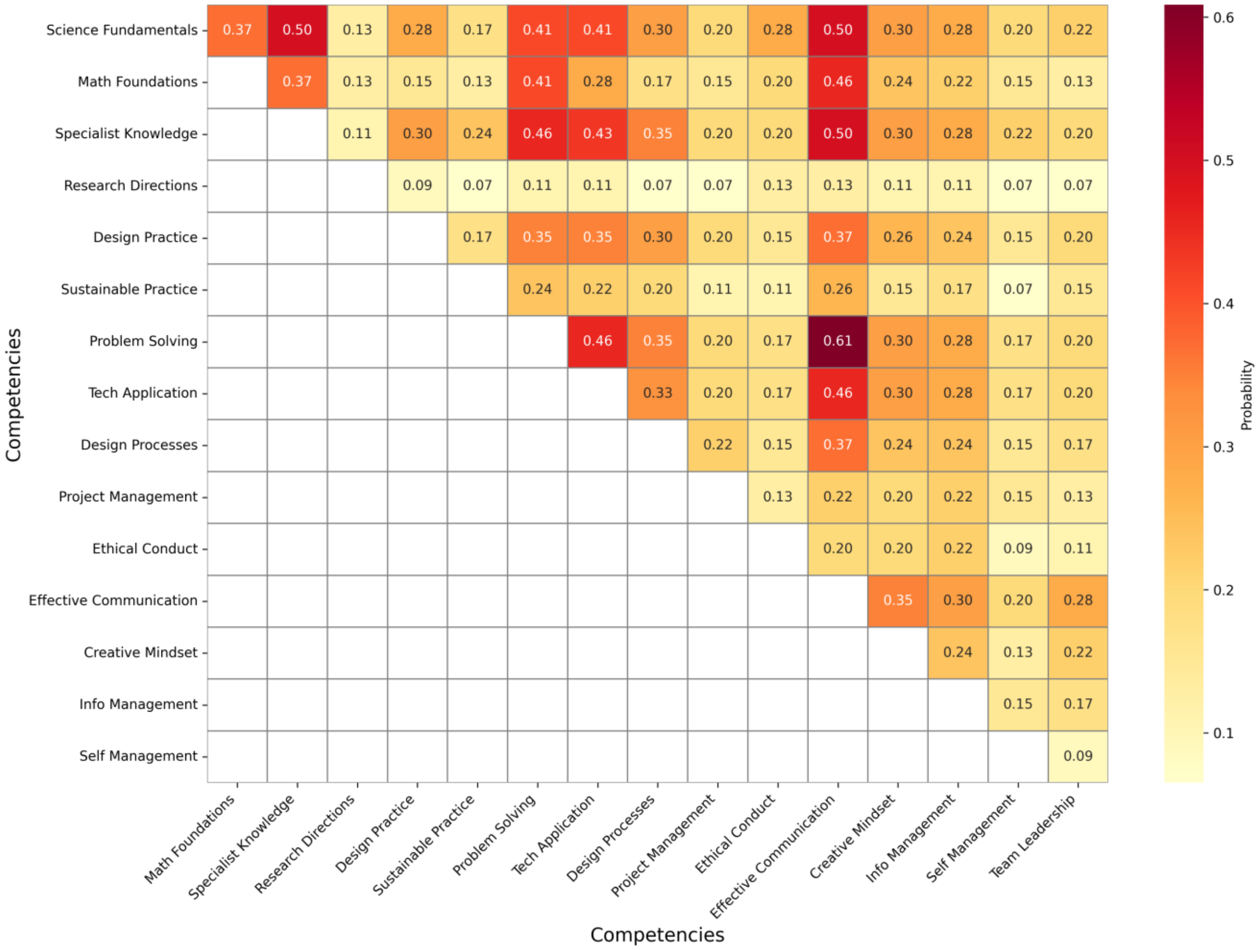

Figure 5: Competency co-occurrence heatmap.

The co-occurrence heatmap shows that competency domains, are not independent and often occur at the same time. For instance, knowledge and application of core concepts often go well together and application and presentation go well together. Application of knowledge in authentic, real-world settings would overlap with professionalism. Part of this occurs because assessment design within courses is somewhat formulaic e.g. a foundational knowledge quiz will often be paired with an application exercise and a group project will often be paired with a presentation. The findings of this study thus reinforce the importance of taking a programmatic lens on assessment design to drive professional competences (van der Vleuten & Schuwirth, 2005).

Conclusion

Considering the implementation challenges of transitioning from a traditional to a competency-based program, we presented a set of visualisations as a tool to facilitate buy-in from course convenors in designing and implementing competency-based education within an engineering degree. These visualisations allow for course convenors and program leaders to have a bird's eye view of competencies scaffolding within a degree whilst contextualising the course they teach within this degree. The visualisations are very helpful as conversation starters in terms of identifying at which stage in the program and which courses are better suited for scaffolding competencies. They also enable academics and course convenors to understand what type of assessment to choose to drive a set of learning outcomes within the context of a specific degree.

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