Heatmapping Key Competencies STEM Students Present in PBL Environments

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Abstract

Aalborg University (AAU) uses Problem Based Learning (PBL) in which students develop professional competencies by engaging with authentic problems. All Engineering master students at AAU have had a PBL Competency profile as a compulsory exercise. The profiles are structured around the AAU PBL Competency Framework. This framework is comprised of 48 individual competencies, grouped into four categories; meta-reflective, problem-oriented, interpersonal, and structural. Students are free to choose which of these competencies they incorporate in their profile.

A total of 1095 PBL Competency profiles were reviewed across more than 50 STEM study programs, and each was evaluated for the presence or absence of each of the 48 competencies in the PBL competency framework. This study explores the relative prevalence of each competency within the profiles submitted by students, and the balance across the different categories. Further, it investigates the extent to which students made these competencies explicit, and evidence the competence.

The study reveals that the competencies are not equally represented in the competency profiles, with a subset of seven competencies comprising 40% of all reported competencies. The study further reveals that the students generally do not provide evidence to support their claims of competence.

Keywords: Active Learning, PBL, STEM, Key Competencies

1 Introduction

All degree programs at the Faculty of Engineering and Science (ENG) and The Technical Faculty of IT and Design (TECH) have included a PBL Competence Profile workshop in their 8th semester. At this workshop students engage in an active reflection process over which PBL competences they have developed and wish to communicate while searching for employment and/or internships (Velmurugan & Friedrichsen, 2023). These competences are captured in a PBL competency profile, which the students submit for feedback.

To assist students in their reflective process they are provided with the AAU PBL competency framework (Holgaard et al, 2020). This framework is a catalogue of different PBL competences divided in four areas: problem-oriented, interpersonal, structural, and metareflective competences (figure 1). Each of these areas have 12 competences embedded in them, and the students are encouraged to include competences from all areas in their profile. Students are also provided written guidance for preparing their competency profiles (Holgaard & Kolmos, 2021). Students are encouraged to consider the categories of competency in developing their profiles but are not formally required to present a profile that is balanced across the four categories. On average, students include between eight and nine of these competencies in their profile.

Analysing what competences students claim and how they do so may provide valuable insights for teachers and curriculum development: Knowing what competences students claim the most provides us with an improved understanding of their self-awareness and potentials for growth. On the other hand, knowing what they do not claim provides us with insights that may help suggest adjustments to the use of the AAU Competence Framework and the teaching itself. We are particularly interested in the relative prevalence of the different competencies (and competency categories), particularly whether there are any competencies that are universally reported, and if there are any that are universally overlooked by the students.

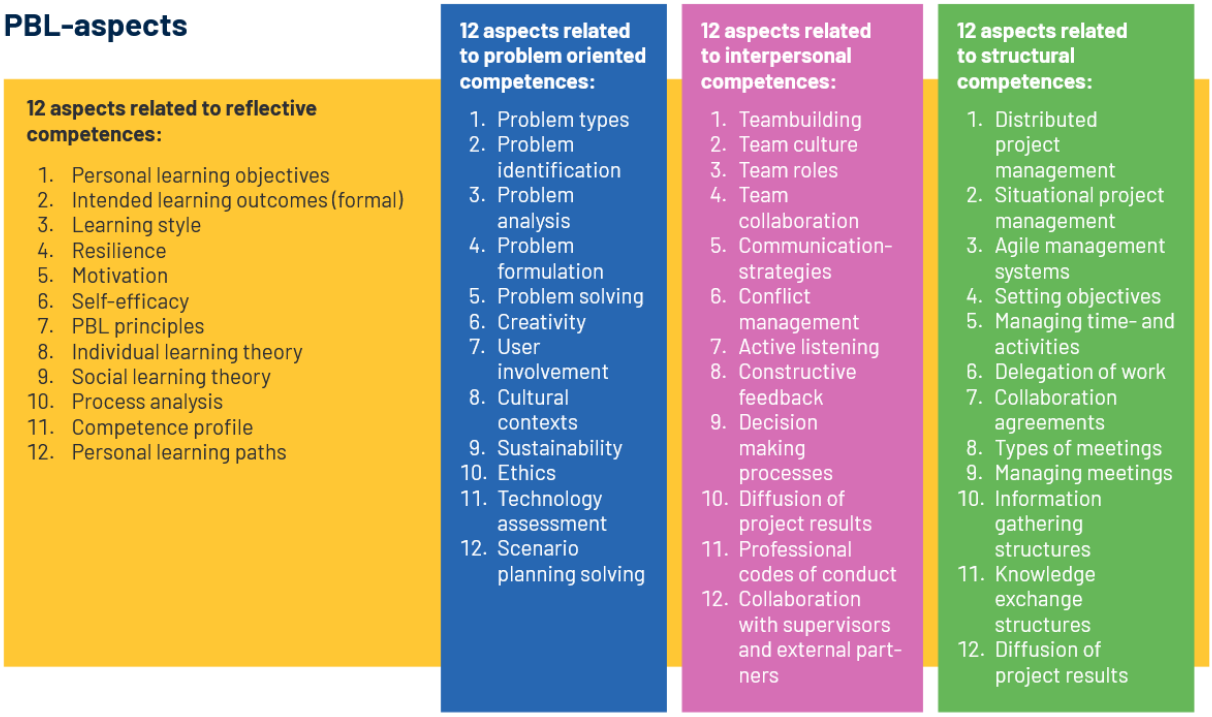

Figure 1: The PBL competency framework (Holgaard et al, 2020)

2 Theoretical underpinnings

Questions of which competences are being fostered through PBL have been discussed intensely over the years, and research for some time was focussed on demonstrating the advantages of PBL over more traditional lecture-based forms of learning (Albanese & Mitchell, 1993; Colliver, 2000;Dochy et al., 2003). This strand of research has highlighted the added value of PBL for competence development beyond mere knowledge acquisition. Subsequent studies have broken those down to communicative competences, problem-solving and teamwork, social and independent working competences (Cohen-Schotanus et al., 2008; Prince et al., 2005; Schmidt et al., 2006), however only for the domain of medical educations, and only for so-called case-based PBL, which is not the approach integrated into AAU's project-based PBL model (Kolmos et al., 2019). Moreover, recent years have shown a shift away from comparative and effectiveness-related studies and a heightened interest in understanding the interplay of PBL implementations and processes of competence development in specific domains, contexts and geographical areas with (Scholkmann, Boelt, et al., 2023; Yew & Goh, 2016).

With a more focussed view for the present study, a literature review within the engineering education context suggested that the most prevalent competences emphasized in the literature when describing PBL competences were teamwork, communication, problem-solving, navigating ambiguity, and self-directed learning (Boelt, Kolmos & Holgaard, 2022). In the review the PBL competences were clustered into four dimensions with distinct orientations towards problems, interpersonal relations, structural and managerial aspects, and meta-cognitive abilities (Boelt, Kolmos & Holgaard, 2022). These findings were used as a direct underpinning to our study, as the four dimensions are represented in the AAU Competence Framework (see Figure 1).

However, the present study must also be seen in the broader context of efforts to systematize PBL competences in frameworks and models. Here, concepts such as constructive alignment (Biggs, 1996); and theory and research on metacognitive and reflective skills development in open, active and problem based learning environments. Constructive alignment alerts us to the fact that learning outcomes – both knowledge and competence – are dependent on both the learning opportunities provided to the students and the modes of assessing these outcomes, as they signal the relevance and value of certain learning activities (Biggs & Tang, 2011; Brabrand & Dahl, 2009). Theory and research on learning in open, active and problem based learning environments has highlighted the intricate interplay between the elements of the PBL scenario, the learning processes unfolding and the resulting manifestations of competences. For example, it has been argued that a carefully crafted phase of problem-analysis and problem-formulation will enhance students' competencies to engage with complexity and uncertainty (Thomassen & Stentoft, 2020). Research on students' development of meta-cognitive competences – i.e., competences to analyse, reflect and design their learning processes – has shown that also in the Aalborg PBL model these competences not necessarily are acquired automatically (Scholkmann, Tretow-Fish, et al., 2023), but instead adjustment of educational practices will be needed to foster them (Holgaard et al., 2023). Students working with our competence framework can be seen as such an adjusted practice, and through this lens the present study enriches research on PBL competences with a facilitated approach that also focusses on reflective competences.

Previous studies on PBL competence development and comparison frequently have relied on self-reported competence gains, which have been shown to be limited in their robustness and validity (Khaled et al., 2014). Alternative measure such as essay-based, scenario-based and mixed method approaches have therefore been explored and recommended in recent years (Davis et al., 2023; Routhe et al., 2023; Scholkmann et al., 2018). By applying at methodology that combines self-report in form of reflective texts with a scaled coding, the present study expands PBL competence research in this direction.

3 Method

The dataset for this analysis is 1095 PBL competency profiles submitted in the Spring 2024 semester. Each of these profiles were evaluated by a marker, and the presence of each competency was rated on a four point scale, depending on whether the competence was explicit and evidenced (Table 1):

Table 1: Evaluation rubric for competencies

Rating	Implying
Absent (0):	This competency is not addressed in the assignment.
Implicit (1):	This competency is addressed in the assignment but is not explicitly named.
Asserted (2):	This competency is explicitly addressed and named within the assignment, but is only asserted, and is not supported by an example of previous experience.
Evidenced (3):	This competency is explicitly addressed within the assignment and is supported by an example from previous experience.

The resulting dataset has scores for each of the 48 competencies for each of the 1095 participants.

The key limitation of this study is that the competency profiles are ultimately self-reported data, and the choice of competencies to include is ultimately made by the students according to their own priorities. Students make decisions about which competences to include in their profiles, which are space limited to two pages. As such it is possible that students have also developed other competencies that were omitted from the profile in favour of competences that were seen to be more important, or were more preferred, or had better examples to include within the narrative. While this limitation may affect the ability to draw

conclusions regarding an individual student, the size of the dataset allows for conclusions to be draw in the aggregate.

A further potential limitation is the phrasing of competences within the AAU competence framework that has been interpreted differently by students and markers. Also, some students did not explicitly use the labels from the AAU Competence Framework when writing their competences profiles, therefore increasing the reliance on the interpretation of the marker in this analysis.

4 Finding one: Claims are clustered in a small subset of competencies

Across the 1095 PBL competency profiles there were a total of 9,444 instances in which a competency was evaluated as Asserted or evidenced. Combined these two categories were considered to represent the total number of competencies that were "claimed" by the students. These claims are displayed in Figure 2, which represents the proportion of all competency profiles in which each competency was claimed by students.

It is immediately apparent from Figure 2 that the competencies are not equally prevalent across the students' profiles. Four competencies each appear in more than half of all competency profiles, with a further three appearing in more than a third. These seven competencies alone represent 40.6% of all competency claims across the entire dataset.

Furthermore, the distribution of the areas is skewed so that reflected competences (shown in yellow) are extraordinarily little claimed, whereas the problem-oriented competences are heavy in the top. Most of the interpersonal competences are loaded in the high end of the occurrence. The structural competences are more evenly distributed but not often chosen except for *Managing time and activities*.

These most prevalent competencies represent the classic PBL story: *Problem solving, Management of time and activities, Problem identification, Team collaboration, Problem analysis, Conflict management* and *Collaboration with external partners.* These competencies are a key part of the intended graduate attributes of AAU; moreover, these are the competencies that are tacitly reinforced throughout the recurring projects in the curriculum as these are required activities throughout. Conversely, there also are specific competencies that are emphasised within the curriculum and the vision of the institution but nonetheless are not prevalent within the dataset. *Ethics* in particular was only claimed 8.4% of students as a competency in their profile.

The imbalance between the four categories of competencies becomes even clearer when considered in the aggregate (Figure 3). While *Problem Related competencies* and *Interpersonal competencies* each represent around a third of all claims, *Structural competencies* and *Reflective competencies* are under-represented in the students' reports. While students are prompted to be balanced in their profiles, it is clear that not all of the categories are equally prevalent in their responses.

The PBL competency framework represents a wide range of skills that can be developed within the PBL environment. What is clear from the data is that when prompted to reflect and report on their competencies within this framework, the students are focussed on only a small subset of these competencies. Their focus lies mostly with the competencies that relate to the problems they are solving, and on the interpersonal competencies they need in their teamwork environment. Reflective competencies are for the most part not emphasised by the students in the dataset.

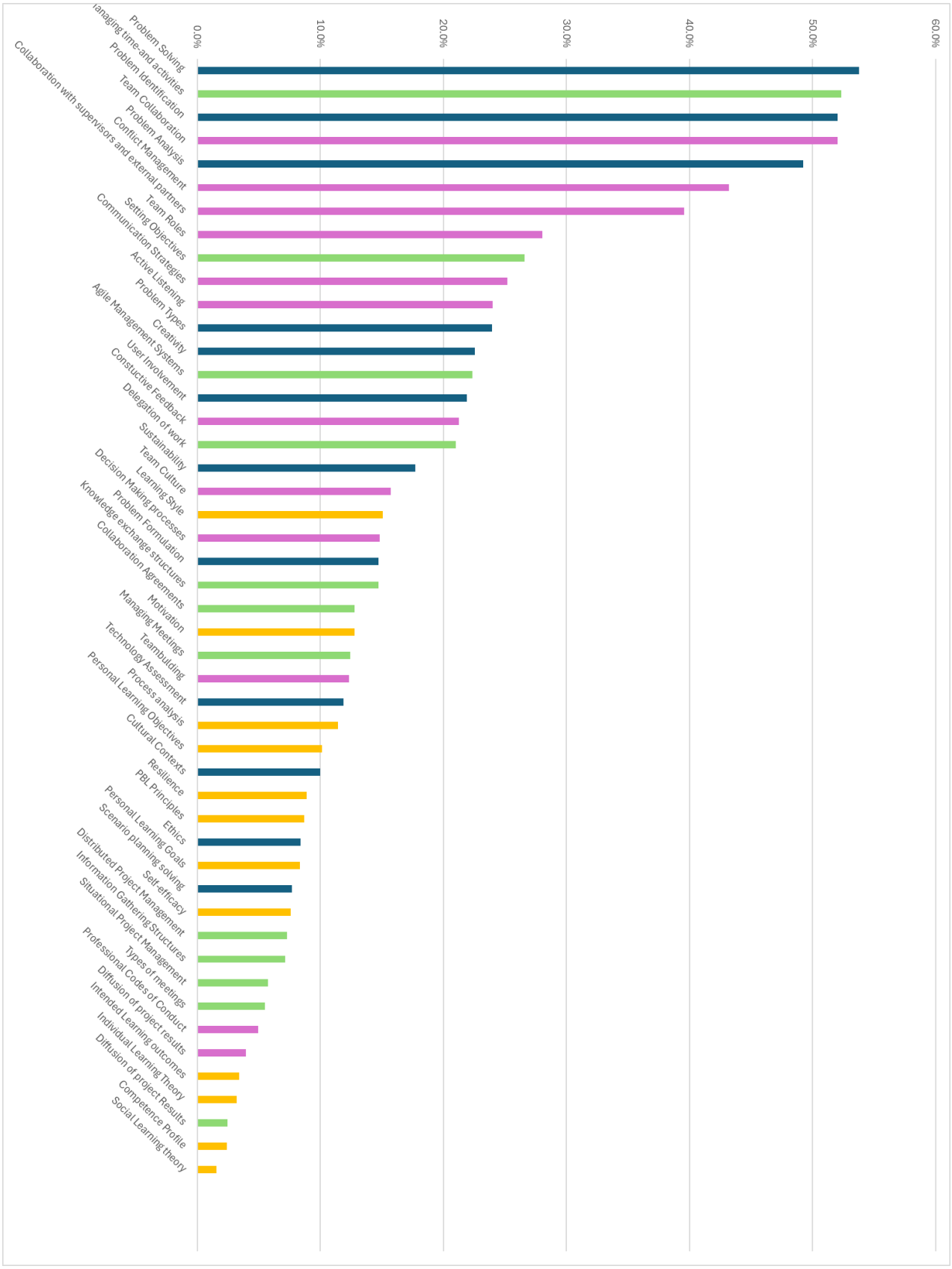

Figure 2: Competencies claimed by the students, sorted by prevalence

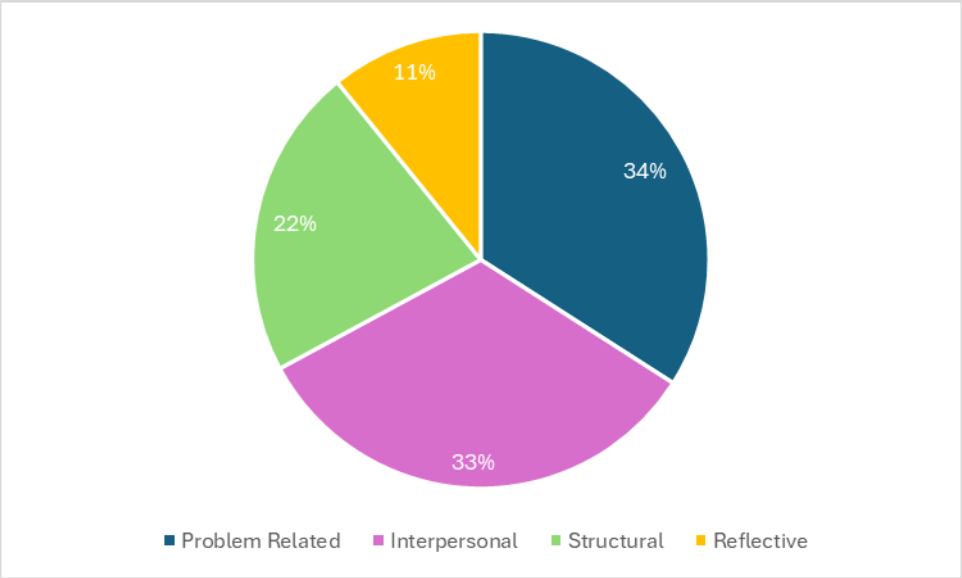

Figure 3: Relative prevalence of competencies claimed by the students, by category

5 Finding Two: Students do not support their claims with evidence

Students are instructed to provide evidence to support their competency claims within their PBL competency profile. Despite this instruction, however, only around a third (3501/9444) (37.1%) of competency claims were evaluated as evidenced by the markers (figure 4):

Figure 4 shows which competences are evidenced most. It confirms the same structure as Figure 2, with the same seven competencies appearing the most often, albeit with the rank ordering within that subset changed. Students were most likely to provide evidence regarding *Managing time and activities*, followed by *Problem solving*. The overall trend of reflective competences not being addressed continues also in this analysis.

The re-ordering between figures 2 and 4 is indicative of a difference in the proportion of competency claims that are evidenced by the students. Indeed, there is significant variation in the relative proportions between asserted and evidenced claims across the 48 competencies (figure 5):

Figure 5 shows that the competence least like to be evidenced is *Individual learning theory* (14.3%) while the most likely to be evidence is *Agile Management Systems* (64.7%). For the most commonly appearing seven competencies, the proportions for which evidence is provided range from 34% to 48%.

Functionally, the data in figure 5 suggest that students only actually provide evidence around a third of the time when claiming to have developed a particular competence, while asserting their competence without evidence the remaining two thirds.

It is not immediately clear from the data why there is such variation in the proportion of competence claims for which evidence is provided, nor why these rates are overall so low. However, a first hypothesis could be that not all competences are equally easy to support with evidence, and not all evidence fits neatly within the page limit of a PBL competency profile. That competences such as 'Agile Management Systems' and 'User involvement' move up in comparison with Figure 2 strengthen this hypothesis since these are very tangible and method-oriented competences which have been taught as opposed to the four least-evidenced competences that all relate to learning awareness. Whether the cause of this low rates of evidence is because students cannot, will not or do not include evidence in their profiles requires further investigation.

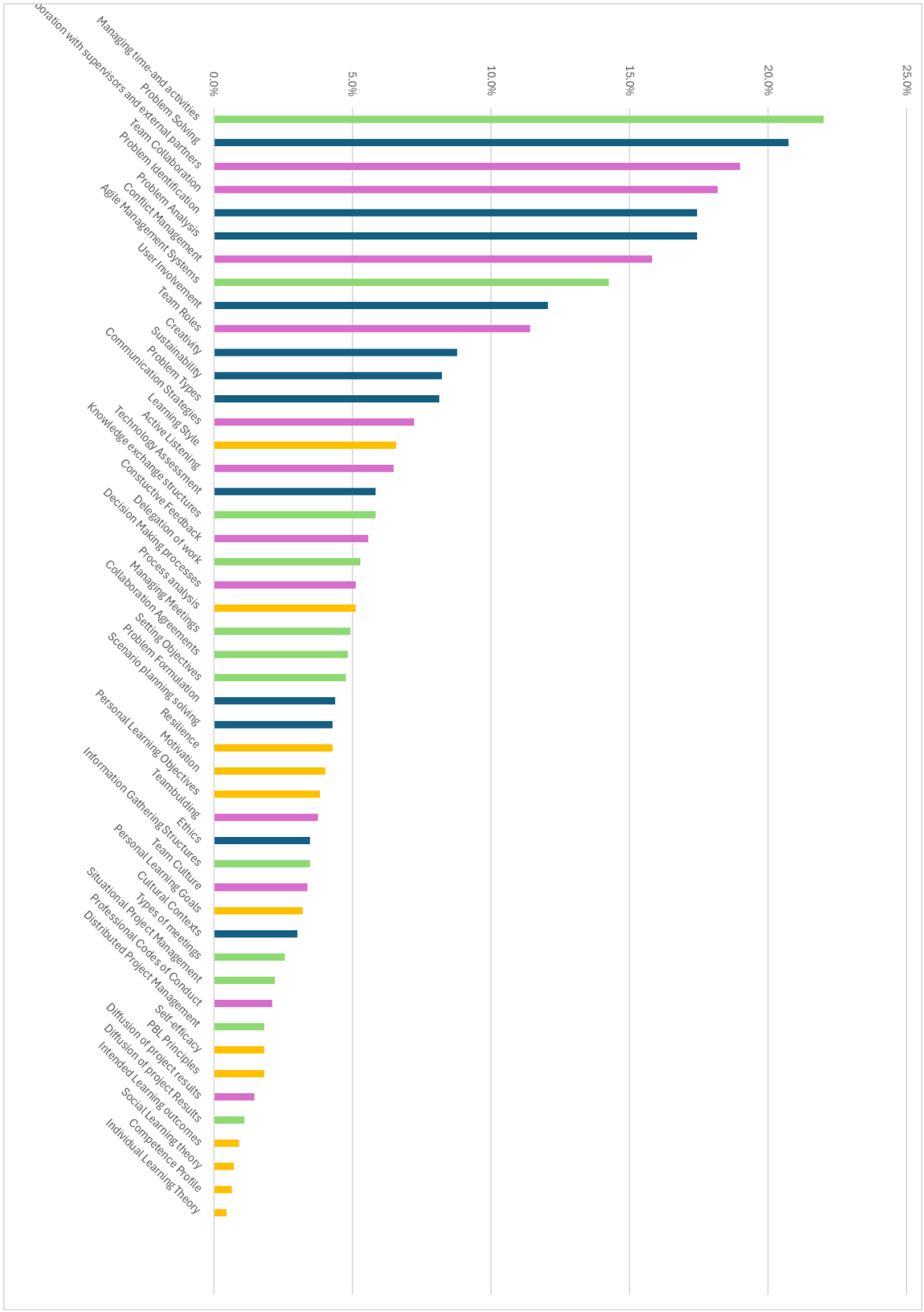

Figure 4: Competencies evidenced by the students, sorted by prevalence

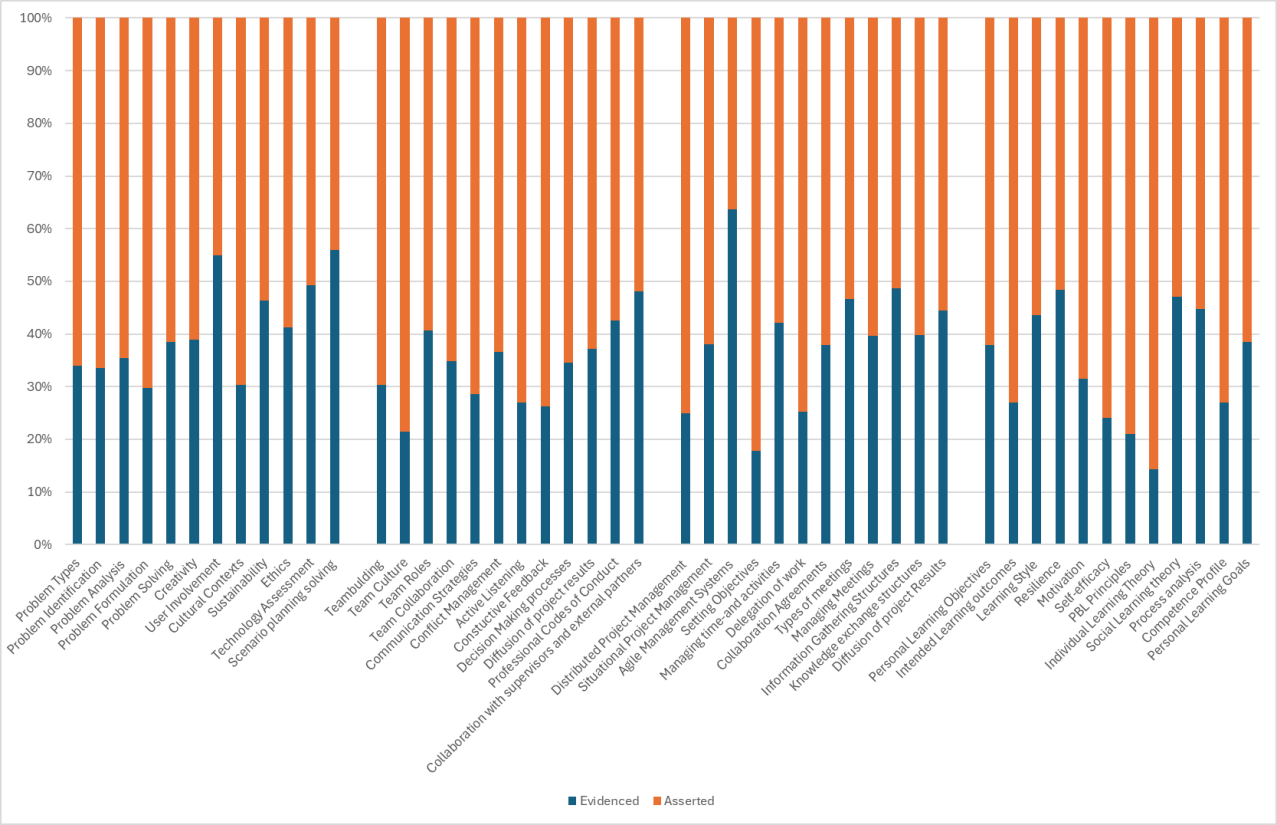

Figure 5: Proportions of asserted and evidenced competencies, grouped by category

6 Conclusion

PBL is a pedagogical approach that supports the development of a wide range of technical and professional competencies. When asked to reflect and report on their development of their competencies, however, students tended to focus upon a small subset of these competencies – those that most closely align with the overarching theme of team-based project work.

Reflective competencies in particular are not well represented in the competency profiles of the students. The lack of reflective competence further manifests when it comes to students evidencing their claims of competence. Only around a third of all competency claims presented by students are actually supported with evidence, with the majority comprising simply assertions of competence.

These results must be considered through the lens of a single, space-constrained self-reporting of competencies. While we cannot generalise from any particular students' profile, we can generalise from the aggregation of 1000+ profiles. The profiles are, in part, a reflection of how students engage with the overall curriculum, and of what they perceive as being the most important parts of that curriculum.

Overall, this analysis suggests that students are not claiming the full range of PBL competencies targeted by the PBL competency framework. Students clearly appreciate the competencies in the tacit curriculum, but are not embracing the broader curriculum. These insights will support the development of teaching approaches targeting these competencies within the curriculum as well as continued development of the PBL competency framework itself.

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