INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED23
24-28 JULY 2023, BORDEAUX, FRANCE

# A DATA DRIVEN TOOL TO SUPPORT DESIGN TEAM COMPOSITION MEASURING SKILLS DIVERSITY

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## ABSTRACT

Team composition in Project Based Learning is the first task for the class and has a great impact on the learning experience. Anyway, little space is dedicated in literature about team composition, considering their personal inclinations towards design tasks.

For these reasons we propose a tool that aims to map the design skills of students to optimise team composition. The tool is based on a questionnaire grounded in the design theory and aims at measuring the willingness of students at performing certain design tasks. The results of the questionnaires are analysed using Principal Component Analysis to normalise each students' answers to the whole class, and to show the distribution of students in the space of engineering design skills.

We present the design process of the tool, and a first experimentation on two classes of master's degree students in Management Engineering and Data Science, testing the tool on a total of 72 students. The results are promising and demonstrate the robusteness of the questionnaire and of the analytical method. Also, we propose next steps for our research activity, calling for other researchers to test our method in different contexts.

**Keywords**: Teamwork, Design education, Research methodologies and methods, Data Analysis, Design Team Composition

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**Cite this article:** Chiarello, F., Spada, I., Barandoni, S., Giordano, V., Fantoni, G. (2023) 'A Data Driven Tool to Support Design Team Composition Measuring Skills Diversity', in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.10

# 1 INTRODUCTION

Project Based Learning is a pedagogical approach designed to involve students in solving real-world problems (Blumenfeld et al., 1991). This approach is becoming one of the most favoured models in engineering design education, as learners can apply their strong engineering technical background to real-world problems while developing a critical design-thinking mindset (Dym et al., 2005).

Such learning activities are typically realized in teams, also enhancing interaction and communication among peers. Teams are groups of two or more individuals working together towards a common objective (Baker and Salas, 1997). The composition of the team is a challenging task, both for managers in the workplace and for educators in schools and universities. Indeed, the interaction among team members affects the execution of the assigned tasks and the quality of the obtained results (Stewart, 2006). Scholars are widely studying how group dynamics and team composition can influence the activities of the teams and their effectiveness in reaching the expected goals in working contexts (e.g., Hackman 1987).

However, little space is dedicated in the literature about team composition in education settings, as the complexity of education, and design tasks are sometimes underestimated (Todd et al., 2004). The composition of teams of students in Project Based Learning is one of the first design tasks for the class and has a great impact on the learning experience of the students and in general on the overall course. In some cases, students can autonomously decide on their teammates (Karagozoglu, 2017), in others teachers can decide on team composition based on various factors, e.g., the academic performance of students (Karimi and Manteufel, 2020). Usually, the choice revolves around the idea of increasing diversity to boost team performance. The dimensions on which this diversity is evaluated include surface-level composition variables (such as age, background, and gender) with a questionnaire, or deep-level composition variables (e.g., personality and attitude) with psychological tests (Dym et al., 2005).

Anyway, these tools suffer from the following drawbacks: (1) they do not rely straight on Engineering Design Theories, but they are derived from other disciplines (e.g., psychometrics); (2) they do not examine directly the design skills of the respondent but measure them indirectly (e.g., academic ratings, educational background, personality); (3) they measure the reaching of the learning outcomes focusing on the performance in the project, and not on the pedagogical process (i.e., how much the student is involved in the project and the learning outcome is reached towards the project).; (4) the output of state-of-the-art tools has the perspective of the single learner without considering the whole context of the team or the class.

For these reasons, we propose a method that aims to map the design skills of students (the learning outcomes of the course) to optimise team composition. The method is based on a questionnaire grounded in the design thinking theory (Brown, 2008). It aims at measuring the willingness of students at performing certain design tasks namely ideate, plan, communicate, collaborate and measure (Dym et al., 2005) which are the main learning outcomes of the course. The measure of willingness is obtained by asking students their preferences towards students' daily life activities, following the theories on enjoying and learning (Michaelsen and Sweet, 2008; Admiraal el at., 2011). The link between design thinking tasks and students' daily life activities has been done by creating a relations matrix. The results of the questionnaires are analysed using Principal Component Analysis (PCA) (Wold et al. 1987), to normalise each student's answers to the whole class, and to show the distribution of students in the space of engineering design skills.

In this preliminary study, we present the design process of the method, and the first experimentation on two classes of master's degree students in Management Engineering (Engineers) and Data Science and Business Informatics (Computer Scientists) at the University of Pisa, testing the approach on a total of 72 students. The students did the questionnaires and used the information to create the project teams. The results report a well-balanced distribution of the design tasks (low linear correlation between the variables) and a balanced distribution of the students among the plane of the first two principal components, demonstrating the ability of the questionnaire to measure properly the skills of the whole class. Also, the results of the Engineers and the Computer Scientists show different distributions in terms of skills, respectively concentrated among managerial skills and analytical skills. We made the questionnaire and the code to analyse and visualise it available for other researchers to make experiments with it, upon request to the authors.

The paper is structured as follows. In section 2 we frame the background literature and the hypothesis of our tool. Section 3 describes the methodology to develop the questionnaire, and section 4 reports the results of the implementation of the questionnaire in two educational settings. Finally, in section 5 we draw the conclusion and point out the open question of the proposed work.

## 2 STATE OF THE ART

The proposed approach has been designed following two main assumptions: (1) team heterogeneity and diversity create value and (2) the more students enjoy the learning activity the more they learn. In the present section, we summarise the relevant literature behind each of the assumptions. We end the section revising some of the relevant works that have designed questionnaires to support team composition.

### 2.1 Team heterogeneity and diversity create value

There is a large literature on how group dynamics and team composition can influence the teams' performance (e.g., Hackman 1987). Team working is affected by many variables: the characteristics of the task to be performed, the characteristics of members, as well as the coordination mechanism among them (Neuman and Wright 1999; Singh et al., 2011). The quantitative review by Stewart (2006) classifies the design features of teams into three main clusters: group composition, (i.e., features of members - ability, personality, gender, race, age -, heterogeneity and familiarity among them, and team size), task design (i.e., work activities, structure, autonomy, coordination among members), and organizational context (i.e., leadership, support, and supervision). Bell (2007) underlines the importance of deep-level composition variables (e.g., patterns of thinking, feeling, and acting) in studying the phenomena. In this sense, the characteristics of team members cannot be limited to demographic features and technical knowledge, skills, and abilities, but also to cognitive abilities, values, and personality traits. Somech and Drach-Zahavy (2013) demonstrate that functional heterogeneity promotes team creativity, as differences in technical knowledge and social behaviour can enhance team performance. Similarly, scholars highlight that a heterogeneous team can achieve high performance with a decrease in the total effort of team members (Chen and Lim, 2017). However, also the differences must be characterised, for example, a study on cross-border R&D collaboration within multinational corporations discusses the impact on the performance of geographic diversity and different levels of technical expertise (Seo et al., 2020). Authors state that teams characterized by high geographic dispersion and various levels of technical know-how are much more sensitive to this influence, and so can achieve an amplification of the benefits of sourcing diverse knowledge. Therefore, several aspects must be considered when designing a team and finding the right combination of team members can be really a challenging task: it is necessary to find a balance between homogeneity and heterogeneity among team members in achieving a higher level of performance (Bowers et al., 2000). Anyway, to the best of our knowledge, no studies have focused on design skills when considering the parameter to evaluate teams' diversity.

### 2.2 The more students enjoy the learning activity the more they learn

Team-based learning (TBL) is a group work activity which exposes students to interact with peers and to apply course content. Group assignments are designed to boost learning and promote the development of managerial competencies (Michaelsen and Sweet, 2008). Team-based learning allows team members to feel responsible for their own learning experience, leveraging on a higher level of cognition, in contrast with the traditional transmission of knowledge by teachers; indeed, learning outcomes are typically built on the upper levels of Bloom’s taxonomy and not on recall and memorization (Hernandez, 2002). The TBL can be used in several educational contexts, among other project-based learning, where students are asked to propose original solutions to non-trivial and real problems (Blumenfeld et al., 1991). In TBL experiences students feel engaged in the learning process with energy and enthusiasm (Michaelsen and Sweet, 2008). This highlights the role of enjoyment in learning. The importance of learners’ emotions in educational activities is discussed in the literature, with some studies on the roles of emotions in group work. Some address negative conditions, e.g., anxiety (Gungor et al., 2007). Others focus on positive emotions, for example, Minkley et al. (2017) demonstrated that high enjoyment and active engagement in group work led to low stress and increase competence acquisition. Pekrun and co-authors (2002) in their review of students’ academic emotions present a taxonomy of emotions linked to learning achievement, including positive and negative



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emotions and different perspectives (prospective, retrospective, and social domain). Building on these theories, Tibubos et al. (2019) examine the relationship between learning-related emotions and the acquisition of moderation competence, demonstrating that "certain teaching behaviours may enhance enjoyment and reduce boredom which has effects on subjective (perceived moderation competence) and performance indicators (grades in a practical moderation exam as determined by examiner ratings) in the context of a university course to foster communication competence in students". Admiraal and co-authors (2011) address the psychological theories of flow in game-based learning, demonstrating that stimuli for concentration, interest, and enjoyment in learning activities, supported by expertise, professional-like skills, and innovative thinking, can enhance the learning experience.

### 2.3 Questionnaires for team composition

Questionnaire can be a valuable tool to support team composition and obtain quantitative evidence on the heterogeneity of teams. For example, Morgeson et al. (2005) examine the relations between social skills, personality, know-how and team effectiveness. They propose a questionnaire to map individual characteristics and support the Human Resources manager during the hiring process for selecting employees based on their possible efficacy in team working. The questionnaire included the following items: situational questions and past behaviour questions to address listening skills, speaking skills, social perceptiveness, coordination skills, service orientation, time management skills, cooperation, and stress tolerance; the test on Big Five personality characteristics (Mount et al., 1998); the test on Teamwork-Knowledge-Skills-Abilities (Stevens and Campion 1994); personality types of learners (Shen et al., 2007); and finally, several specific questions to address technical know-how. Taggar (2002) proposes a questionnaire to examine individual team member characteristics, domain knowledge, and behavioural indicators to examine the relations between individual creativity and group creativity. The questionnaire included individual variables based on the Five-factor-model traits revised by the NEO Personality Inventor (Costa and McCrae, 1992), the Wonderlic Personnel Test (Wonderlic et al., 1992) and behavioural items defined for the specific case.

## 3 METHODOLOGY

The objective of the proposed approach is to support the class in the definition of team composition. The methodology involves a questionnaire grounded in the design thinking theory, to collect information about each participant, and then to analyse the resulting data using Principal Component Analysis (PCA). Figure 1 presents the flowchart of the methodology.

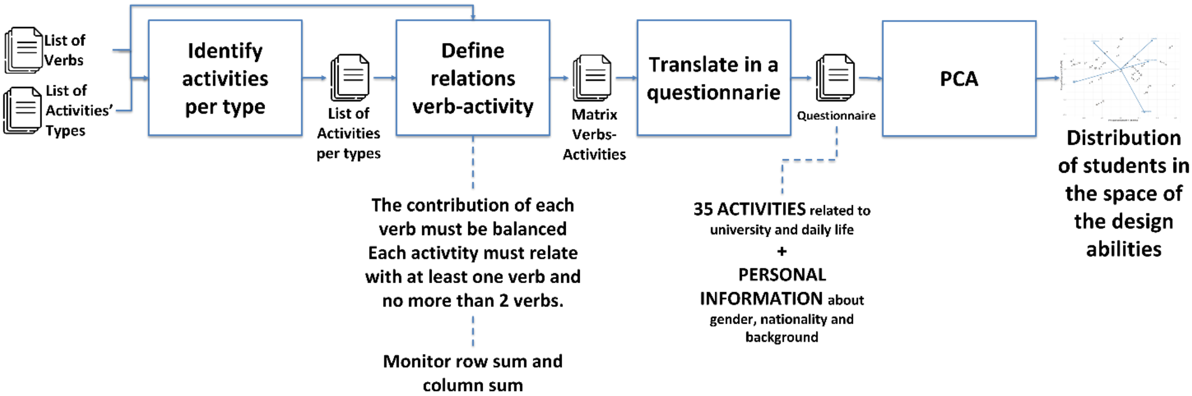


*Figure 1. Flowchart of the methodology designed to build balanced teams from a pool of participants to a design project.*

The input for the methodology is a list of design thinking tasks (in the form of verbs) that are the main learning outcomes of the course, and a list of students' daily life activities.

The former includes the action verbs addressing design skills. The action verbs derive from the Bloom's Taxonomy for Learning Objectives (Churches, 2010; Krathwohl, 2002; Bloom, 1956). The skills are derived from the design thinking literature (Dym et al., 2005; Chiarello et al., 2021). We selected the action verbs and the design skills based on the Learning Outcome of the program related to Engineering Design for Data Science, addressed in the two classes of master's degree students in Management



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Engineering (Engineers) and Data Science and Business Informatics (Computer Scientists) at the University of Pisa. The list, following reported, present for each action verb the related design skills:

- Ideate: Ability to come up with new ideas and new solutions to problems
- Measure: Ability to determine the amount, quantity, or degree of something accurately and precisely
- Plan: Ability to think ahead, set a goal and organise activities to achieve them
- Communicate: Ability to express information clearly using different approaches, and to understand what others are communicating
- Collaborate: Ability to work together towards a common goal, identifying compromises and finding consensus in the team.

These verbs can be modified considering different Learning Outcomes of other design courses, leaving the rest of the method like the one described in the present paper.

The second list contains the possible types of activities that characterize the routine of university students; those are activities related to studying (or working), university daily life and private daily life. This list has been done by discussing in class with students and revising the results of this discussion to identify the best activities. The activities must be related to the five verbs previously identified and must be something that students have done in the past since they will need to express how much they enjoyed that activity. The open discussion focused on mapping the daily routine of the students. The context of the discussions were the two classes where we tested the proposed approach, which are varied in terms of students' origin (both Italian from different regions and international students), of gender, and of students' background (different bachelors' degrees). We asked students to describe their typical daily routine, framing around the actions verbs previously listed the initial questions to start the discussion. Then, we grouped the collected insights based on the settings of the described activities, identifying together with the students three main situations: (1) studying for an exam (or working), (2) university in a general perspective (e.g., classes, administrative offices, events), (3) private life. We selected the most common activities, i.e., the ones mentioned by many students in the two classes, to have a fairly wide range of activities typical of student life. We produced a list of 35 activities in total, 6 for each of the 5 verbs on average.

Then, we defined the relations between design tasks and students' daily life activities: we connected the verbs to the activities which suit them the best. An activity can in fact be connected to more than one verb. We adopted a holistic approach to define the connections, performing a discussion among the authors, who have a different background (1 Mechanical Engineer, 2 Management Engineers, 1 Data Scientist and 1 Aerospace Engineer) and experience (1 Professor, 1 Researcher, 3 PhD students), adding value to the discussion as it involves different perspectives. The criteria to decide what verbs connect to what activities was briefly formalized as follows: the activity can be linked to more than one action verb or even with all the verbs by definition, as we looked for activities starting from the action verbs themselves, however the connection must be explicit only when the main described action overlaps with the action verb (e.g., 'do brainstorming' describe the action of proposing ideas, which overlaps with 'ideate', even though brainstorming are a collaborative activity, requires communication skills to properly deliver its own ideas, are used also for planning future steps or measuring relative importance of different elements). Then, to produce a balanced distribution among the contributions of the verbs, we set two constraints: each activity should have been connected to at least one verb and to no more than two verbs; each verb should be linked to exactly 10 activities, to assure that we are able to measure that dimension but not to overestimate it. We build a matrix to assign the relations between verbs and activities as shown in Table 1.

Next, we created a questionnaire where students are asked to estimate how much they enjoy each of the 35 defined activities, through a five-point Likert scale (i.e., 1 was "I don't like at all" and 5 was "I absolutely enjoy it"). We decided to ask participants about their passions, rather than asking them about abilities; this choice is related to the theories of connections between enjoyment and learning (as discussed in section 2). In addition, we included also some questions concerning the personal information of the participants (gender, nationality, and background), as control variables of the proposed approach to be used in further studies. Through the connections between activities and verbs summarised in the matrix shown in Table 1, it was then possible to measure how much each participant is likely to like the design task (learning objective of the course) expressed through the five verbs.

Once the answers of the participants have been collected, we have a matrix having on the rows the students and on the columns the five verbs. In other terms, we represented students' answers into



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vectors in the space of design skills. This matrix has been analysed using Principal Component Analysis (PCA) (Wold et al. 1987), obtaining the distribution of the participants' answers into the vectorial space of the design skills. PCA is a statistical method based on the normalization of a collection of data and then the computation of a covariance matrix of the dataset. These steps allow to identify a new coordinate system, which explain most of the variability of the initial dataset with fewer dimensions. Those variables are a linear combination of the original variables (eigenvectors) and they are called principal components. The first two principal components allow to represent the data in a two-dimensional space, where the data are redistributed along their maximal direction of variance. This led us to identify who is more inclined to each design skill giving to the students quantitative evidence to support them in the team composition.

*Table 1. Matrix of the relations between students' daily life activities (rows) and design tasks (columns).*

| | **Design Tasks** | | | | |
|---|---|---|---|---|---|
| **Activity** | IDEATE | COLLABORATE | PLAN | MEASURE | COMMUNICATE |
| Do brainstorming | X | | | | |
| Give alternative solution than the one proposed by the teacher | X | | | | X |
| Propose new methods in developing university projects | X | | X | | |
| Combine prior knowledge to tackle new topics | X | | | X | |
| Fantasize about not existing products | X | | | | |
| Have an artistic hobby | X | | | | |
| Improvise a recipe with the ingredients you have at home | X | | | | |
| Work in a team | | X | | | X |
| Criticize in a constructive way other's ideas | X | X | | | |
| Study with your colleagues | | X | | | |
| Share notes and materials with your colleagues | | X | | | |
| Play a squadre sport | | X | | | |
| Choose your team-mates among a group | | X | | X | |
| Participate in voluntary or extra-university activities | | X | | | |
| Plan your future exams | | | X | | |
| Tidy university notes and materials | | | X | X | |
| Use a pen and paper to take difficult decision in developing university projects | | | X | | |
| Keep an agenda | | | X | | |
| Write down your shopping list | | | X | | |
| Organize end-of-year party | | X | X | | |
| Plan your holidays | | | X | | |
| Analyse data in a quantitative way | | | X | X | |
| Search information on Google | | | | X | |
| Programming | | | | X | |
| Prove with objective data of being right on something | | | | X | X |
| Get lost in a city to discover it | X | | | X | |
| Observe everyday life with mathematical and/or physics models | | | | X | |
| Search objective data to understand the current events | | | | X | |



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| Activity | Design Tasks | | | | |
|---|---|---|---|---|---|
| | IDEATE | COLLABORATE | PLAN | MEASURE | COMMUNICATE |
| Explain a concept | | X | | | X |
| Convey data in tables and/or graphs | | | X | | X |
| Speak during a lecture in front of the classroom | X | | | | X |
| Give a presentation for university projects | | | | | X |
| Use social media | | | | | X |
| Dive into meeting new people in social contexts | | X | | | X |
| Discuss about current events with friends and/or family | | | | | X |

## 4 RESULTS

This section describes the results of the methodology applied to a case study of two classes of students of the Management Engineering and Data Science and Business Informatics master's degrees at University of Pisa. The students have been asked to work on an assignment which involved the realization of a design project, where they must follow the typical design thinking workflow (Brown, 2008) using data to make decisions towards the design process. The 72 students (36 for each class) had to create teams to collaborate on the project.

The students participated in the questionnaire, disseminated through a Google Form in the two classes for one week. Using the connection between activities and verbs summarised in Table 1, we then measured, for each student, their aptitude for each verb (e.g., students who gave high rankings to the activities "Plan your holidays", "Write down your shopping list" and "Organize end-of-year party", were considered as people with a good aptitude to the planning activities, and to the verb "Plan"). Then, we performed Principal Component Analysis using the list of answers given by each student to map each of them into a vectorial space divided into five areas, corresponding to the five verbs (i.e., Plan, Measure, Ideate, Communicate, Collaborate).

Figure 2 shows the results of the PCA, presenting on the left the graph for the Engineering Management course, and on the right the one for the Data Science and Business Informatics course. The figures show the reprojections of the 5 variables on the first two principal components, and how the students are positioned in this space. These results have been shown in the two classes and have been given to students together with the exact number they scored for each of the variables (i.e., their inclination towards performing the particular design thinking task). In particular, we described the results of the analysis in the two classes, discussing with students on the dimensions of the design space. We first presented the graph with numbers for each point, asking students to guess their position, then we show the graph with their names starting a discussion on their own position and on the relative positions of all the students in the class. We let students explore the graph on their own and freely decide whether to use or not the indication provided here about their inclination towards design skills to find out the best teammates.

The first evidence coming from both graphs in Figures 2 is that the 5 design thinking tasks are widespread across the plane of the first two principal components. This means that there is a low linear relation between the variables, proof of the ability of the questionnaire to measure the class attitude towards all 5 dimensions. This is proof that the designed questions can measure the different aptitudes of the students. The angles between the variables also, show the similarity between the different tasks, measured considering the answer of the students. As expected, for example, students enjoying activities related to measure (ability to determine the amount, quantity, or degree of something accurately and precisely) tend to enjoy fewer collaborative tasks (ability to work together towards a common goal, identifying compromises and finding consensus in the team). Something similar is happening in the plan (the ability to think ahead, set goals and organise activities to achieve them) and ideate (the ability to come up with new ideas and new solutions to problems).

Also, students are well distributed on the plans for both courses, showing that the questionnaire was able to measure different preferences of students in terms of design thinking-related activities. Considering this, in the left graph of Figure 2 (Engineering Management course) it is evident from the



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plot a denser section at the bottom, in correspondence to the verbs plan and communicates (managerial skills). On the other side, from the right graph of Figure 2 (Data Science and Business informatics course) emerges a greater concentration at the top of the plan, following the dimensions of measure, and on all the quantitative activities to be done in design thinking (analytical skills). This is in line with the background of the students (respectively management engineering and computer science) and with the goals of the course they are following, which aims at giving quantitative and data-driven tools for new product design in the first case and management tools for designing data-driven products in the second case. This is evidence of the fact that the tool can adapt to the actual inclinations of classes.
Also, both results show the presence of generalist students (the ones positioned in the centre of the graph) and specialist students (the ones positioned in the neighbourhoods). The first, are the ones that are showing no clear preferences towards the design tasks. This can be because the students are open to all (or none) of the tasks or to the fact that the questionnaire had low measuring power on them (i.e., the students have poor or no experience in the proposed activities). The second, are the ones that have a strong inclination towards design thinking activities (i.e., they scored higher with respect to the class, on activities that are connected in the matrix, to the specific design thinking activity). Students have been guided in creating teams that mix generalists and specialists, to maximise diversity also from this perspective.

*Engineering Management course* *Data Science and Business Informatics course*

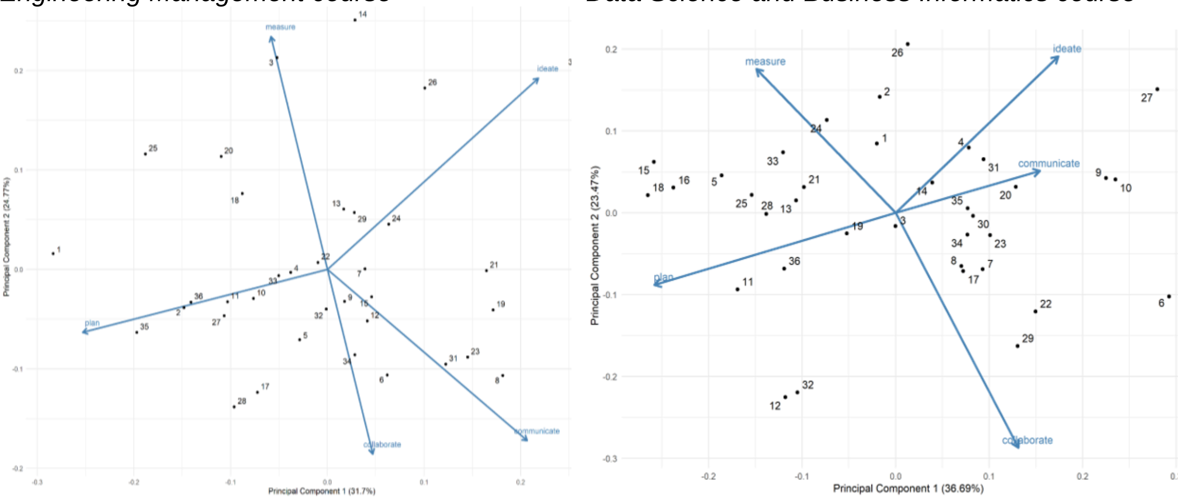


*Figure 2. Results of the PCA in the two case studies.*

## 5 CONCLUSIONS

This paper presented a tool that aims to map the design skills of students to optimise team composition. The method is based on a questionnaire grounded in the design thinking theory and aims at measuring how many students enjoy performing certain design tasks namely ideate, plan, communicate, collaborate, and measure which are the main learning outcomes of the courses where the method has been tested. The graphs have been used to propose student information to optimise team composition, based on the distribution of skills among the team. Similarly, the teachers can explore the graph resulted from the analysis of the questionnaire to decide teams' composition based on the relative positions of the students in the space of design skills.
In this preliminary paper, we have presented the design process we use and a case study of its application in two master's degree courses. The questionnaire and the code are available for other experiments both in higher education and industrial content, for the optimal creation of teams, by contacting the authors. We aim to stimulate future research on mixing Project-based learning (PBL) and Team-based learning (TBL) within the discipline of Engineering Design, to promote an educational paradigm focus on strengthening students' abilities to work in teams, pursuing quality of the team and the team working not only on the product developed. We deployed our questionnaire along the theories on enjoying and learning, therefore we structured the questionnaire on indirect questions on preferences towards design tasks, future research can address the comparison of students' responses to direct question, exploring if relevant differences exist among the two possible approaches.


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The proposed approach, still in its prototypical form, has still several limitations to be solved. First, we acknowledge the subjectivity of the proposed method for what concern the definition of the connection between the daily activities and the action verbs, moreover, we didn't track the open discussion among the authors therefore we register the lack of an interrater reliability as well as the risk that a modification of such rationale may affect the proposed results. Therefore, future research can strength this part of the proposed method in this promising stream of literature. Second, a clear measure of skills diversity must be defined, since at the present state students evaluate this information qualitatively, looking at the results of the PCA. Measures like the mean Euclidean distance between the points representing students plotted on the diagram of the first two principal components, or the area of the polygon made by the students' point on the same graph, can be possible solutions. Third, a measure of the relationship between diversity and educational performance has still to be implemented. Indeed, at the time of the analysis here presented the courses were still in progress in the two classes adopted as implementation contexts. We plan to make this measure at the end of the semester when the students will deliver their design project. To make this measure reliable we will use both the evaluation of the professor and the peer-to-peer evaluation between students. Such measure can have a twofold purpose: on one hand it can assess the ability of the questionnaire to support team composition based on the overall assessment of team performance; on the other hand, it can provide an additional indicator to the teachers for the evaluation, balancing the performance of the students and of the teams around the dimension of the design skills space. Finally, all the control variables such as age, gender or background still must be considered, to measure how much they influence the result of the questionnaire and possibly the team performances. Indeed, personal and demographic diversity in team may affect the team performance, as discussed in literature and reported in Section 2. These variables can be used both to control the distribution in the design space resulted from the PCA and provide teachers with data which can be used as guidelines for team composition addressing both personal and demographic diversity and students' distribution in the design space. The unavailability of the students' evaluation due to the courses schedule prevent us to perform in the present paper such analysis, which we aim to explore in further studies. The next iterations of our research activity will go in this direction, also be willing to collect other applications of the proposed method in other courses.

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