Measurement and Practice of Transversal Competencies in Engineering Education

Evaluation of Perceptions and Stimulation of Reflections of industry, lecturers and students

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MEASUREMENT AND PRACTICE OF TRANSVERSAL COMPETENCIES IN ENGINEERING EDUCATION

Evaluation of Perceptions and Stimulation of Reflections of industry, lecturers and students

MARIANA LEANDRO CRUZ

Measurement and Practice of Transversal Competencies in Engineering Education

Evaluation of Perceptions and Stimulation of Reflections of industry, lecturers and students

Propositions

accompanying the dissertation

Measurement and Development of Transversal Competencies in Engineering Education
Providing criteria to help to qualify and reduce the gap with industry

by

Mariana Leandro Cruz

1. Engineering researchers and educators use many types of measurement methods (e.g. questionnaires, observations) but they lack measurement standards when it comes to measuring, evaluating and assessing transversal competencies. (this thesis, chapter 2)
2. It is time to move on from using “numbered” Likert scales. More objective instruments that provide definitions of transversal competencies and criteria with descriptive levels, as well as validity and reliability properties, should be the new norm in engineering education. (this thesis, chapters 3 & 4)
3. Transversal competencies are best practised with plug-and-play activities that include active participation, engagement, rules, reflection, risk-taking, cooperation among team members and competition among teams. (this thesis, chapters 5 & 6)
4. Evaluating the effectiveness of teaching interventions immediately after they are implemented is not enough. The improvement of students’ transversal competencies will be benefited when engineering educators explore the retention of students’ transversal competencies after longer periods. (this thesis, chapter 6)
5. The current research funding system hinders the performance of longitudinal studies in engineering education research.
6. Engineers are not educated to use mixed-method research and because of that, they tend to be attached to a positivistic position towards knowledge and over-use quantitative research.
7. The current system of assessment of university teaching staff does not give incentives for good teaching hence the teaching of transversal competencies is over-ridden by the teaching of technical subjects with which university lecturers are more familiar.
8. Remote teaching is not an obstacle to the teaching and learning of transversal competencies in engineering education. The lack of educators’ willingness and competence are.
9. Having children makes you more organised and efficient in your work.
10. PhD research is like the biathlon, you can speed up the pace but if you miss the targets, you will be disappointed by the final result.

These propositions are regarded as opposable and defendable, and have been approved as such by the promotors Prof. dr. M. J. de Vries and Dr. ir. G. N. Saunders-Smits.

Measurement and Practice of Transversal Competencies in Engineering Education

Evaluation of Perceptions and Stimulation of Reflections of industry, lecturers and students

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus, Prof. dr. ir. T.H.J.J. van der Hagen,
chair of the Board for Doctorates
to be defended publicly on
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by

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SUMMARY

The engineering industry has changed in the last decades with the increasing complexity of technology, the global mobility of the engineering profession, the concern with sustainability and social responsibility, and the need for innovation and creativity. This shift has caused employability issues that include both the lack of engineering graduates available for recruitment and graduates equipped with the necessary set of transversal competencies.

One of the efforts to produce engineering graduates ready for the labour market was the emphasis on transversal competencies. They have been highlighted in the Boeing list of “Desired Attributes of Engineer” and by the accreditation bodies in the United States of America and Europe. The focus shifted from only technical competencies to including also the transversal competencies in the field of engineering education around the world. Although engineering curricula have expanded curricular and pedagogical arrangements to include transversal competencies to prepare graduates for employment, there is still a gap between what engineering education provides to students and what employers desire from engineering graduates. Employer’s feel students lack transversal competencies such as communication, interpersonal, management and team working skills.

The emphasis on the inclusion of transversal competencies has triggered the need for instruments that could measure and assess these competencies or their perceptions, or even to trigger reflection on these competencies. However measuring transversal competencies or their perceptions is considered difficult because of the lack of consensus on the transversal competency definitions between engineering educators, government bodies and employers, the overwhelming lists of transversal competencies created by universities and non-academic establishments with different terminologies and without collaborations between these parties, and finally the nature of transversal competencies which often are intertwined with the technical competencies and can also be acquired outside of the curriculum.

The research presented in this thesis contributes to the measurement of perceptions of transversal competencies, and practice and reflection on transversal competencies in the field of engineering education. This work is part of the PREFER (Professional Roles and Employability of Future EngineeRs) project, which was a European project that started in 2017 to reduce the transversal competency gap in the field of engineering and to increase the employability of future engineers.

The research design of this thesis consisted of three studies. The first study was a systematic review that was carried out to investigate what methods have been used in engineering education between 2000 and 2017 to measure transversal competencies (communication, lifelong learning, innovation/creativity and teamwork) and perceptions of competencies, and their limitations and benefits. In this review, 99 studies published in three databases (Scopus, Web of Science and ERIC) were identified. For each study, the purpose, the corresponding methods, the criteria used to establish the competencies, and validity and reliability properties were evaluated.

This analysis identified that the methods used over the past years to measure communication, innovation/creativity, lifelong learning and teamwork or their perceptions were questionnaires, rubrics, tests, observations, interviews, portfolios,

and reflections. Of these methods, questionnaires and rubrics were the most used. It was also found that many measurement methods lack competency definitions and criteria, and evidence of validity and reliability properties, i.e. they were not rigorously designed and implemented to measure transversal competencies or their perceptions, or the research data did not indicate that the methods could be used to measure the transversal competencies or their perceptions. These showed a clear need for establishing professional standards when measuring transversal competencies. The limitations of the methods found in the systematic review informed the second study of this thesis.

This second study investigated the characteristics of an instrument that measures perceptions of transversal competencies in engineering education. To do so, the *COMPetency Instrument* (COMπ) is presented to overcome some of the limitations identified in the systematic literature review: lack of competency definitions, full lists of competencies and descriptive levels. Although these individual characteristics are not new in the literature, this instrument combines them into a holistic instrument that is used in different contexts. COMπ was based on the existing transversal competency model of Siemens, the Netherlands, a partner in the PREFER project. It consisted of five domains or holistic competencies (entrepreneurial, innovation, teamwork, communication and lifelong learning) and 36 nuanced competencies with the corresponding definitions and four descriptive mastery levels.

COMπ was first used to determine the transversal competency levels that bachelor and master students should possess at graduation according to European industry and subsequently, to study the extent to which the transversal competency levels indicated by the industry were covered in the bachelor and master programmes of a representative engineering department of the Delft University of Technology (TU Delft), both formally reported in the course learning outcomes and according to the perception of lecturers. Next, COMπ was used to identify what educational practises and methods were used by the lecturers to reach the transversal competencies required by the industry.

The main findings were that COMπ as a whole or parts of the instrument can be used to determine desired industry mastery levels, to map transversal competencies course learning outcomes in formal course documentation and even to trigger lecturers to reflect on the competency levels their students reach in their courses as well as the teaching practices they use to achieve them. Other results were that *actively seeking learning*, *strengths and weaknesses awareness*, *problem solving* required the highest mastery levels for bachelor and master graduates according to industry and were considered by the industry the most important competencies for MSc graduates. In this research, a gap was also found between the formal and perceived curriculum, i.e., discrepancies in the transversal competency learning outcomes reported on formal documentation compared to those reported by the lecturers in their courses. These findings indicate that educators should develop coherent and consistent learning outcomes which adequately report the transversal competencies that students are expected to be taught.

COMπ was also used to investigate the transversal competency level perceptions of engineering students using a sample of 1087 aerospace engineering bachelor and master students from TU Delft. The data of this sample of first- and second-year bachelor and first-year master students were used to further test the validity and reliability of COMπ through exploratory factor analysis and confirmatory factor analysis, and Cronbach's alpha, respectively.

The exploratory factor analysis performed on the initial COMπ of five scales with 36 items resulted in a model, still composed of five scales, but with 25 items and with some differences in each scale. This model showed a good fit in the confirmatory factor analysis and the scales demonstrated reliable Cronbach's alpha values. The new COMπ is composed of a first domain, *communication competencies*, that is defined by oral communication and the ability and confidence to express information to different audiences; a second domain, *innovation competencies*, that is characterized by items that lead to the generation of ideas and solutions; a third domain, *entrepreneurial competencies*, that includes items related to finances, markets and business opportunities; a fourth domain, *lifelong learning competencies*, that is characterized by self-management, in terms of professional needs, strengths and weaknesses, stick to timeframes and search for continuous improvement autonomously, and the last domain, *teamwork competencies*, is defined by the ability to work in groups respecting cultural differences and disciplines of knowledge, listening attentively and managing issues.

The results showed also that COMπ triggered students to reflect on their transversal competency levels. It was found that students perceived they are most competent in teamwork and lifelong learning competencies and less competent in entrepreneurial competencies.

The third study of this thesis investigated the characteristics of a game based-learning practice that stimulates engineering students to practise and reflect on their communication competencies. This game was created as part of the deliverables of the PREFER project that aimed to develop curriculum activities that stimulate engineering students' transversal competencies. This game focused on communication competencies because they are considered essential for engineering graduates.

Although there are successful interventions in engineering education to develop communication competencies, the focus is often mainly on oral presentation and written reports delivered at the end of technical assignments. In this research, a new game-based learning practice, called *Chinese Whispers with a Twist*, was created to help engineering students practice and reflect on students' communication competencies including describing information in a short time, listening skills, and ask and respond to questions. The teaching material for this activity can be found at the OpenCourseWare Website of TU Delft: https://ocw.tudelft.nl/transversal-skills/communicating-is-more-than-just-talking-chinese-whispers-with-a-twist/.

This activity was implemented at five different European engineering universities (TU Delft - The Netherlands, KU Leuven - Belgium, TU Dublin - Ireland, IST - University of Lisbon, and University of Minho - Portugal) to 393 students. The characteristics that make this activity effective were explored in a case study using a mixed-method approach that investigated how students evaluate their communication competencies and areas for improvement in the game based-learning activity, how these competencies correlate with their performance in the activity, and finally, the communication competencies that engineering students become aware of or experience in the game based-learning activity. The findings of the scoring rubric and the questionnaire used showed that this activity is effective for engineering students to practice and reflect on their communication competencies because the activity is engaging and set by rules. Students actively participated during the activity, reflected on their effective and ineffective communication competencies and the existing communication barriers and styles. They gained awareness and experienced communication in teams and cooperated with different people.

The effectiveness of this activity to practice and trigger reflection on communication competencies and what competencies engineering students gained from the activity was not only studied immediately after the activity took place but also one year after its implementation. This was studied in an exploratory study with semi-structured interviews conducted with nine students who participated in the activity at TU Delft. The findings showed that students remembered and benefited from the activity. This exploratory study also indicated that this activity is effective to retain students' transversal competencies because it provides active learning, engagement, rules, risk-taking, cooperation and competition, and it can be plugged and played in any engineering context.

In conclusion, three main contributions are made to engineering education in this research. The first contribution is with COMπ, an innovative instrument that brings the individual characteristics (nuanced competencies with definitions and descriptive levels) together into one holistic instrument that can be used as a whole or in parts to measure the transversal competencies required for engineering graduates according to industry, to trigger lecturers to (self-)assess the levels of transversal competencies that students practice in their courses, and to stimulate students to reflect on their transversal competency levels.

The second contribution is with the *Chinese Whispers with a Twist* activity, a new game based-learning practice that stimulates engineering students to practise and reflect on their communication competencies that include active participation, engagement, rules, reflection, risk-taking, cooperation among team members, competition among teams and is plugged and played in any engineering context. It is recommended that educators should design engaging interventions and allow students to actively participate and reflect on their transversal competencies, collaborate with team members, follow rules but give space for taking risks and competing with other teams. Preferably, these interventions should be developed as plug-and-play in any course and engineering curriculum context.

The third contribution stems from the retention study of students' transversal competencies. Although it was only an exploratory study with a small and convenient sample, this research indicated that the field of engineering education should go beyond the evaluation of the teaching interventions and what transversal competencies engineering students gain from those interventions immediately after they take place, and evaluate the retention of students' transversal competencies over long periods, which are fundamental to understand how teaching practices shape students' competencies in the period after their participation.

SAMENVATTING

De technische industrie is de afgelopen decennia veranderd door de toenemende complexiteit van technologie, de wereldwijde mobiliteit van het ingenieursberoep, de bezorgdheid over duurzaamheid en sociale verantwoordelijkheid, en de behoefte aan innovatie en creativiteit. Deze verschuiving heeft tot inzetbaarheidsproblemen geleid, waaronder het gebrek aan afgestudeerden in de techniek die beschikbaar zijn voor aanwerving en afgestudeerden die over de nodige transversale competenties beschikken.

Een van de inspanningen om afgestudeerden in de ingenieurswetenschappen klaar te maken voor de arbeidsmarkt, was de nadruk op de transversale competenties. Ze zijn gemarkeerd in de Boeing-lijst van "Desired Attributes of Engineer" en door de accreditatie-instanties in de Verenigde Staten van Amerika en Europa. De focus verschoof van alleen technische competenties naar het opnemen van ook de transversale competenties op het gebied van technisch onderwijs over de hele wereld. Hoewel technische curricula de curriculaire en pedagogische regelingen reeds hebben uitgebreid met transversale competenties om afgestudeerden voor te bereiden op tewerkstelling, is er nog steeds een kloof tussen wat technisch onderwijs aan studenten biedt en wat werkgevers verlangen van afgestudeerden in ingenieurswetenschappen. Volgens de werkgevers missen de studenten transversale competenties zoals communicatie, interpersoonlijke, management- en teamvaardigheden.

De nadruk op het opnemen van transversale competenties heeft geleid tot de behoefte aan instrumenten die deze competenties of hun percepties kunnen meten en beoordelen, of zelfs aanzetten tot reflectie over deze competenties. Het meten van transversale competenties of hun percepties wordt echter als moeilijk beschouwd vanwege het gebrek aan consensus over de transversale competentiedefinities tussen ingenieursopleiders, overheidsinstanties en werkgevers, de overweldigende lijsten van transversale competenties die zijn opgesteld door universiteiten en niet-academische instellingen met verschillende terminologieën en zonder samenwerking tussen deze partijen, en ten slotte de aard van transversale competenties die vaak verweven zijn met de technische competenties en ook buiten het curriculum verworven kunnen worden.

Het onderzoek dat in dit proefschrift wordt gepresenteerd, draagt bij aan het meten van percepties van transversale competenties, en de praktijk en reflectie op transversale competenties op het gebied van technisch onderwijs. Dit werk maakt deel uit van het PREFER-project (Professional Roles and Employability of Future EngineeRs), een Europees project dat in 2017 van start ging om de transversale competentiekloof op het gebied van engineering te verkleinen en de inzetbaarheid van toekomstige ingenieurs te vergroten.

De onderzoeksopzet van dit proefschrift bestond uit drie studies. De eerste studie was een systematische review die werd uitgevoerd om te onderzoeken welke methoden zijn gebruikt in het ingenieursonderwijs tussen 2000 en 2017 om transversale competenties (communicatie, levenslang leren, innovatie/creativiteit en teamwork) en percepties van competenties, en hun beperkingen en voordelen. In dit overzicht zijn 99 studies geïdentificeerd die gepubliceerd zijn in drie databases (Scopus, Web of Science en ERIC). Voor elk onderzoek werden het doel, de

bijbehorende methoden, de criteria die werden gebruikt om de competenties vast te stellen, en validiteits- en betrouwbaarheidseigenschappen geëvalueerd.

Uit deze analyse bleek dat de methoden die de afgelopen jaren zijn gebruikt om communicatie, innovatie/creativiteit, levenslang leren en teamwerk of hun percepties te meten, bestonden uit vragenlijsten, rubrieken, tests, observaties, interviews, portfolio's en reflecties. Van deze methoden werden vragenlijsten en rubrieken het meest gebruikt. Er werd ook vastgesteld dat veel meetmethoden competentiedefinities en criteria, en bewijs van validiteits- en betrouwbaarheidseigenschappen missen, d.w.z. ze waren niet strikt ontworpen en geïmplementeerd om transversale competenties of hun percepties te meten, of de onderzoeksgegevens gaven niet aan dat de methoden konden worden gebruikt om de transversale competenties of hun percepties te meten. Hieruit bleek een duidelijke behoefte aan het opstellen van professionele standaarden bij het meten van transversale competenties. De beperkingen gevonden in de systematische review vormden de basis voor de tweede studie van dit proefschrift. De beperkingen van de methoden die in de systematische review werden gevonden, vormden de basis voor de tweede studie van dit proefschrift.

Deze tweede studie onderzocht de kenmerken van een valide instrument dat percepties van transversale competenties in het ingenieursonderwijs meet. Om dit te doen, wordt het COMPetency Instrument (COMπ) gepresenteerd om enkele van de beperkingen die in het systematische literatuuronderzoek zijn geïdentificeerd te overwinnen: gebrek aan competentiedefinities, volledige lijsten van competenties en beschrijvende niveaus. Hoewel deze individuele kenmerken niet nieuw zijn in de literatuur, combineert dit instrument ze tot een holistisch instrument dat in verschillende contexten wordt gebruikt. COMπ was gebaseerd op het bestaande transversale competentiemodel van Siemens, Nederland, een partner in het PREFER-project. Het bestond uit vijf domeinen of holistische competenties (ondernemerschap, innovatie, teamwerk, communicatie en levenslang leren) en 36 genuanceerde competenties met bijbehorende definities en vier beschrijvende beheersingsniveaus.

COMπ werd eerst gebruikt om de transversale competentieniveaus te bepalen die bachelor- en masterstudenten bij hun afstuderen zouden moeten bezitten volgens de Europese industrie en vervolgens om te bestuderen in hoeverre de transversale competentieniveaus die door de industrie werden aangegeven, werden behandelden de bachelor- en masterprogramma's van een representatieve afdeling ingeneurswetenschappen van de Technische Universiteit Delft (TU Delft), zowel formeel gerapporteerd in de leerdoelen van de cursus als volgens de beleving van docenten. Vervolgens werd COMπ gebruikt om te bepalen welke onderwijspraktijken en -methoden door de docenten werden gebruikt om de transversale competenties te bereiken die de industrie nodig heeft.

De belangrijkste bevindingen waren dat COMπ als geheel of delen van het instrument geschikt is om de gewenste beheersingsniveaus van de industrie te bepalen, om leerdoelen van transversale competenties in kaart te brengen in formele cursusdocumentatie en zelfs om docenten ertoe aan te zetten na te denken over de competentieniveaus die hun studenten bereiken in hun cursussen en de onderwijspraktijken die ze gebruiken om ze te bereiken. Andere resultaten waren dat het actief zoeken naar leren, bewustwording van sterke en zwakke punten, probleemoplossing de hoogste beheersingsniveaus vereiste voor bachelor- en master-afgestudeerden volgens de industrie en door de industrie werden beschouwd als de belangrijkste competenties voor MSc-afgestudeerden. In dit onderzoek werd ook een kloof gevonden tussen het formele en gepercipieerde curriculum, d.w.z. discrepanties in de transversale competentie leerdoelen gerapporteerd informele documentatie in vergelijking met die gerapporteerd door de docenten in hun cursussen. Deze bevindingen geven aan dat docenten coherente en consistente leerdoelen moeten ontwikkelen die de transversale competenties die studenten geacht worden onderwezen te worden, adequaat weergeven.

COMπ werd ook gebruikt om de transversale percepties van het competentieniveau van ingenieursstudenten te onderzoeken met behulp van een steekproef van 1087 bachelor- en masterstudenten luchtvaart- en ruimtevaarttechniek van de TU Delft. De gegevens van deze steekproef van eerste- en tweedejaars bachelor- en eerstejaars masterstudenten werden gebruikt om de validiteit en betrouwbaarheid van COMπ verder te testen door middel van exploratieve factoranalyse en bevestigende factoranalyse, en Cronbach's alpha, respectievelijk.

De verkennende factoranalyse uitgevoerd op de initiële COMπ van vijf schalen met 36 items resulteerde in een model, nog steeds samengesteld uit vijf schalen, maar met 25 items en met enkele verschillen in elke schaal. Dit model bleek goed te passen in de bevestigende factoranalyse en de schalen lieten betrouwbare Cronbachs alfa-waarden zien. Het nieuwe COMπ is samengesteld uit een eerste domein, communicatieve competenties, dit wordt bepaald door mondelinge communicatie en het vermogen en vertrouwen om informatie te uiten aan verschillende doelgroepen; een tweede domein, innovatiecompetenties, dit wordt gekenmerkt door items die leiden tot het genereren van ideeën en oplossingen; een derde domein, ondernemerscompetenties, dit omvat items die verband houden met financiën, markten en zakelijke kansen; een vierde domein, competenties voor een leven lang leren, dit wordt gekenmerkt door zelfmanagement, in termen van professionele behoeften, sterke en zwakke punten, vasthouden aan tijdschema's en zelfstandig zoeken naar continue verbetering, en het laatste domein, teamworkcompetenties, wordt gedefinieerd door het vermogen om werk in groepen met respect voor culturele verschillen en kennisdisciplines, luister aandachtig en beheer problemen.

De resultaten toonden ook aan dat COMπ studenten aanzette om na te denken over hun transversale competentieniveaus. Er werd vastgesteld dat studenten ervaren dat ze het meest bekwaam zijn in teamwerk en levenslang leren en minder bekwaam zijn in ondernemerscompetenties.

De derde studie van dit proefschrift onderzocht de kenmerken van een spel gebaseerde leerpraktijk die ingenieursstudenten stimuleert om te oefenen en na te denken over hun communicatieve competenties. Deze game is gemaakt als onderdeel van de resultaten van het PREFER-project dat tot doel had curriculumactiviteiten te ontwikkelen die de transversale competenties van technische studenten stimuleren. Deze game was gericht op communicatiecompetenties omdat ze essentieel worden geacht voor afgestudeerden in de techniek.

Hoewel er succesvolle interventies zijn in het technisch onderwijs om communicatieve competenties te ontwikkelen, ligt de focus vaak vooral op mondelinge presentaties en schriftelijke rapporten die aan het einde van technische opdrachten worden afgeleverd. In dit onderzoek is een nieuwe spel gebaseerde leerpraktijk gecreëerd, genaamd Chinese Whispers with a Twist, om ingenieursstudenten te helpen oefenen en reflecteren op de communicatieve competenties van studenten, waaronder het in korte tijd beschrijven van informatie, luistervaardigheden en het stellen en beantwoorden van vragen. . Het lesmateriaal voor deze activiteit is te vinden op de OpenCourseWare Website van de TU Delft: https://ocw.tudelft.nl/transversal-skills/communicating-is-more-than-just-talking-chinese-whispers-with-a-twist/.

Deze activiteit werd uitgevoerd aan vijf verschillende Europese technische universiteiten (TU Delft - Nederland, KU Leuven - België, TU Dublin - Ierland, IST - Universiteit van Lissabon en Universiteit van Minho - Portugal) met 393 studenten. De kenmerken die deze activiteit effectief maken, werden onderzocht in een casestudy met behulp van een gemengde methode die onderzocht hoe studenten hun communicatieve competenties en verbeterpunten in de spel gebaseerde leeractiviteit evalueren, hoe deze competenties correleren met hun prestaties in de activiteit, en ten slotte de communicatieve competenties waarvan ingenieursstudenten zich bewust worden van of ervaring opdoen in de spel gebaseerde leeractiviteit. De bevindingen van de scoringsrubriek en de gebruikte vragenlijst toonden aan dat deze activiteit effectief is voor ingenieursstudenten om hun communicatieve competenties te oefenen en erover na te denken, omdat de activiteit boeiend is en door regels wordt bepaald. Studenten namen actief deel tijdens de activiteit, reflecterend op hun effectieve en ondoelmatige communicatieve competenties en de bestaande communicatiebarrières en -stijlen. Ze kregen bewustwording en ervaarden communicatie in teams en werkten samen met verschillende mensen.

De doeltreffendheid van deze activiteit om te oefenen en reflectie aan te wakkeren over communicatiecompetenties en welke transversale competenties ingenieursstudenten van de activiteit leerden, werd niet alleen onmiddellijk na de activiteit bestudeerd, maar ook een jaar na de implementatie ervan. Dit is onderzocht in een verkennend onderzoek met semigestructureerde interviews afgenomen met negen studenten die aan de activiteit aan de TU Delft hebben deelgenomen. De bevindingen toonden aan dat studenten zich de activiteit herinnerden en er baat bij hadden.

Deze verkennende studie gaf ook aan dat deze activiteit effectief is om de transversale competenties van studenten te behouden, omdat het actief leren, betrokkenheid, regels, het nemen van risico's, samenwerking en competitie biedt, en het kan worden aangesloten en gespeeld in elke technische context.

Concluderend worden in dit onderzoek drie belangrijke bijdragen geleverd aan het technisch onderwijs. De eerste bijdrage is met COMπ, een innovatief instrument dat de individuele kenmerken (genuanceerde competenties met definities en beschrijvende niveaus) samenbrengt in één holistisch instrument dat in zijn geheel of in delen kan worden gebruikt om de transversale competenties die nodig zijn voor afgestudeerden in de ingenieurswetenschappen te meten volgens de industrie, om docenten aan te zetten tot (zelf)evaluatie van de niveaus van transversale competenties die studenten in hun cursussen oefenen, en om studenten te stimuleren om na te denken over hun transversale competentieniveaus.

De tweede bijdrage is met de Chinese Whispers with a Twist-activiteit, een nieuwe spel gebaseerde leerpraktijk die ingenieursstudenten stimuleert om hun communicatieve competenties te oefenen en erover na te denken, waaronder actieve deelname, betrokkenheid, regels, reflectie, het nemen van risico's, samenwerking tussen teams. leden, competitie tussen teams en wordt aangesloten en gespeeld in elke technische context. Het wordt aanbevolen dat docenten boeiende interventies ontwerpen en studenten in staat stellen actief deel te nemen en na te denken over hun transversale competenties, samen te werken met teamleden, regels te volgen maar ruimte te geven om risico's te nemen en te concurreren met andere teams. Deze interventies moeten bij voorkeur worden ontwikkeld als plug-and-play in elke cursus en in elke technische curriculumcontext.

De derde bijdrage komt voort uit de retentiestudie van de transversale competenties van studenten. Hoewel het slechts een verkennend onderzoek was met een kleine en handige steekproef, toonde dit onderzoek aan dat het vakgebied van technisch onderwijs verder moet gaan dan de evaluatie van de onderwijsinterventies en welke transversale competenties ingenieursstudenten uit die interventies halen onmiddellijk nadat ze hebben plaatsgevonden, en het behoud van de transversale competenties van studenten gedurende lange perioden, die fundamenteel zijn om te begrijpen hoe onderwijspraktijken de competenties van studenten vormen in de periode na hun deelname.

TABLE OF CONTENTS

“Education is not the learning of facts,
but the training of the mind to think.”

Albert Einstein

CHAPTER 1

General introduction

The thesis that lies before you is the culmination of 4 years of dedicated research in Engineering Education on the measurement of the transversal competencies perceptions of the industry, lecturers and students, and the practice of a set of these competencies by engineering students. All research was carried out between 2017 and 2020. In this first chapter, the research topic is introduced in the context of the evolution of Engineering Education in Higher Education, followed by a reflection on the challenges faced by the field of Engineering Education, focussing on the subfield of competencies development. Next, the context in which the research was conducted is presented as well as the perspective of the researcher. In the final part of this chapter, the objective and research question of the research are presented as well as an overview of this doctoral thesis.

1.1. Evolution and challenges in engineering education

The field of engineering education has evolved significantly in the last decades. The earliest mentioned degrees in engineering started in Europe in 1747 at the *École des Ponts et Chaussés* and in 1795 at the *École Polytechnique* (France) based on the military needs to have well-trained engineers, followed by Germany in 1765 with the Freiberg School of Mines (Saunders-Smits 2008). In the Netherlands, in Delft, the first engineering school was a military academy that trained officers in engineering skills, which started in 1814 and would eventually become a civilian engineering institute, that is now known as Delft University of Technology. In the United States of America (USA), the first engineering colleges appeared from 1817 and 1845 (Saunders-Smits 2008). During this period in the USA, education in the field of engineering was considered practical and applied to society and industry needs (Seely 1999).

Almost three-quarters of a century later, from 1920 to 1950, the field of engineering and the education of engineers underwent a change from a focus on practice to theory (Seely 1999). Mathematics became a powerful tool to solve engineering problems rather than the practical experience of engineers. After World War II, there was a boom in engineering research, PhD degrees in engineering were introduced and classes of science and mathematics within engineering degrees intensified (Seely 1999). More engineering degrees were created, which enabled the development of theory and emphasis on science, mathematics and physics. The overemphasis of science in this period led to the turnover from the practical engineer to the theoretical engineer (Seely 1999).

From the 1990s, engineering education encountered another set of major challenges that have redirected engineering educators to combine theory and practice again (Seely 1999, Hadgraft and Kolmos 2020). The first challenge was the fragile world economy (Shuman, Besterfield-Sacre et al. 2005) that stimulated countries to work on their economic competitiveness. The second challenge was the globalisation of the engineering profession that was characterised by the mobility of engineers in the workplace (Shuman, Besterfield-Sacre et al. 2005, Spinks, Silburn et al. 2006, Lucena, Downey et al. 2008). The third challenge was the societal areas of need, including poverty, hunger, energy, water and sanitation, health and climate change around the world, as listed in the 17 Sustainable Development Goals of the United Nations (UNESCO 2017). Another major challenge that became prevalent is the intensely increased role of technology comprising corporate downsizing, outsourcing of engineering services, the globalization of manufacturing and service delivery (Shuman, Besterfield-Sacre et al. 2005), automation, the Internet of Things, artificial intelligence and augmented realities (Hadgraft and Kolmos 2020). This leads to the final challenge faced by engineering educators: the employability of engineering graduates (Spinks, Silburn et al. 2006, Hadgraft and Kolmos 2020), which is characterised by an increasing concern on the readiness of engineering graduates and how engineering education can help provide future engineers prepared for the labour market.

This thesis will focus on this last challenge: the employability of future engineers. Employability in the context of this thesis is defined as work-readiness, i.e., the comprehensive set of skills, knowledge, attitudes and commercial understanding that graduates need to have, to contribute to their employers' goals when they enter the labour market, combined with their longer-term career prospect, i.e. the capacity to move self-sufficiently on the labour market and continuously learn throughout life (Mason, Williams et al. 2009).

Employers have expressed two concerns: the lack of qualified graduates available for their existing vacancies in engineering (Spinks, Silburn et al. 2006) and the transversal competency gap of the available engineering graduates (Markes 2006, Spinks, Silburn et al. 2006). In this thesis, transversal competencies are defined as *"skills, values and attitudes that are required for learners' holistic development and for learners to become capable of adapting to change"* (Care and Luo 2016) and technical competencies as *"competencies specific to a subject or content, relevant to a particular discipline"* (Cassidy 2006). Transversal competencies are also known in the literature as employability skills (Markes 2006), generic skills (Bennett, Dunne et al. 2000), key competencies (Organisation for Economic Co-operation Development 2005), non-technical skills (Knobbs and Grayson 2012), non-traditional skills (Crawley, Malmqvist et al. 2007), professional skills (Shuman, Besterfield-Sacre et al. 2005), soft skills (Whitmore and Fry 1974), transferable skills (Kemp and Seagraves 1995), and 21st-century skills (Council 2013) but the term used throughout this thesis will be transversal competencies. The choice for using "transversal" is because the author feels that these competencies apply across all engineering disciplines and are beyond disciplinary knowledge. The choice for using "competencies" is to include a more holistic term that encompasses a set of competencies or sub-competencies. In this thesis, five main transversal competencies will be addressed and called "domains" in the following chapters because of their holistic nature.

1.2. Emphasis on transversal competencies worldwide

The lack of graduates' readiness for the labour market is one of the reasons that triggered the emphasis on teaching transversal competencies to engineering students. One of the first highlighting the need for transversal competencies in engineering education was McMasters and Matsch (1996) in the Boeing list of "Desired Attributes of an Engineer". The Boeing call was one of the factors that pushed and informed accreditation bodies to add transversal competencies as additional accreditation criteria. The accreditation body for engineering degrees in the USA, ABET, implemented the ABET engineering criteria that focused not only on technical competencies but also on transversal competencies (Shuman, Besterfield-Sacre et al. 2005). The accreditation shift from the detailed procedural specifications and curriculum content to learning outcomes occurred to respond to economic competitiveness, issues with graduate readiness to labour market shown by major corporations, changes in international norms in curriculum design and the evolution of national and international quality frameworks (Prados, Peterson et al. 2005, Lucena, Downey et al. 2008).

In Europe, to accommodate the diversity of individual, academic and labour market needs, and allow mobility between nations, its Higher Education sector was integrated through the Bologna Process in 1999 (EHEA 2015) that established a European Qualification Framework (EQF) of comparable degrees of 3-4 year Bachelor's degrees (Level 6 in the EQF) and 1-2 year Master's degrees (Level 7 in the EQF), governed by common workload and learning outcomes. Desired competencies were also developed by the European network of accrediting bodies, the European Network for the Accreditation of Engineering Education (ENAEE) divided into six categories: knowledge and understanding, engineering analysis, engineering design, investigations, engineering practice and transferable skills. However, each member state of the European Higher Education Area has their autonomy over competencies and accreditation as long as European mobility is guaranteed (Lucena, Downey et al. 2008). Also, the Washington Accord, an international agreement that mutually recognises accreditation levels as equivalent, allows for each programme to determine different emphasis on transversal competencies (American Society for Engineering Education 1994, Lucena, Downey et al. 2008).

In Australia, the original undergraduate degrees were converted to degrees at the institutional level in which students acquire broad interdisciplinary knowledge and deep core disciplinary knowledge by attending breadth and core major courses, respectively. In this way, students experience different areas of specialization in the undergraduate courses, which will likely make them cope with economic, political and societal challenges (The University of Melbourne 2006).

In 2006, curriculum reformats occurred in Hong Kong to align its educational system with the rest of China, North America and Australia and guarantee graduate mobility. This national reform, known as "3+3+4", emphasises student-centred and life-long learning experiences, gives students multiple paths for learning and stimulates whole person development (Chan and Luk 2013).

The emphasis on the transversal competencies was also highlighted in many literature studies that investigated what transversal competencies engineering programmes should emphasise (Passow and Passow 2017), what transversal competencies are the most important for engineers (Scott and Yates 2002, Spinks, Silburn et al. 2006, Male, Bush et al. 2011, Passow and Passow 2012, Saunders-Smits and de Graaff 2012) and what transversal competencies graduates lack but are necessary for the workplace (Meier, Williams et al. 2000, Martin, Maytham et al. 2005, Nair, Patil et al. 2009). In the above studies, problem-solving, communication, teamwork and lifelong learning were considered very important for engineering graduates.

In summary, over the past 20 years, engineering education curriculum reforms have occurred around the globe to provide breadth and depth within the engineering curricula and make sure students acquire not only the technical competencies but also the transversal competencies necessary for complex and mobile workplaces.

1.3. Emphasis on transversal competencies in the Netherlands

The field of engineering education in the Netherlands is no exception to the changes in recent decades. The first major adjustment happened when the Bologna Declaration was implemented in the Dutch Higher Education system in 2002. The 5-year engineering degrees at Dutch research universities were split into a two-cycle system of a 3-year Bachelor and a 2-year Master of Science in Engineering degree (Westerheijden et al. 2010). More recently, a national collaboration initiative has started to join forces in the field of education, research and knowledge transfer between the three universities of technology: Delft University of Technology, Eindhoven University of Technology and University of Twente. The 3 TU Federation (3TU), consisting of the three universities of technology in the Netherlands was founded in 2007 and was renamed 4TU when Wageningen University and Research Centre, which offers degrees in Agricultural Engineering, joined the 3TU in 2016 (4TU.Federation 2017). This collaboration was formed with a common goal of providing engineering graduates that are well-trained and ready for the labour market and able to make an impact on society, and have a positive effect on the economy of the Netherlands.

In the educational aims of the 4TU, transversal competencies are considered as important as technical competencies. Both bachelor and master graduates should be competent in seven areas: competent in one or more scientific disciplines in research, in design, and co-operation and communication, have a scientific approach, possess basic intellectual skills, and take account of the temporal and social context (Meijers, van Overveld et al. 2005), with the competencies of master graduates being an extension of the competencies of bachelor graduates. That is why this thesis, carried out at the Faculty of Aerospace Engineering at Delft University of Technology in The Netherlands, emphasises the transversal competencies of engineering students.

1.4. Measurement of transversal competencies

Engineering education has not only focused on fostering the development of transversal competencies but also on their assessment and measurement (Shuman, Besterfield-Sacre et al. 2005, Badcock 2010, Markes 2006). This became important because of the need to determine the skills and knowledge of engineering students, to evaluate the course and programme effectiveness to enhance the quality of teaching and student learning, and to assess students' performance to give summative grading and/or formative feedback. However, assessment of transversal competencies is difficult because of the lack of consensus on the transversal competency definitions between engineering educators, government bodies and employers (Shuman, Besterfield-Sacr et al. 2005). There are the overwhelming lists of transversal competencies created by universities and non-academic establishments with different terminologies and without collaborations between them (Markes 2006), which make it difficult to conduct meaningful assessments, comparisons and conclusions. Another obstacle for assessment is the nature of transversal competencies as they are often intertwined with the technical competencies and can be acquired both in and outside of the technical courses (Shuman, Besterfield-Sacre et al. 2005, Badcock 2010).

The present thesis is the first to systematically review the literature on the current methods used in engineering education to measure and assess transversal competencies and their perception levels. The measurement methods found in this review showed that there was not yet a holistic instrument, which provides a list of nuanced competencies with competency definitions and descriptive levels that could be used to measure perceptions of transversal competencies of different stakeholders and also trigger reflection on these competencies. In this thesis, this holistic instrument based on an existing industry framework, kindly supplied by Siemens Nederland, is presented. The Siemens framework was used as it is a good example of how the industry assesses employees' skills and skill levels. It also fitted well into the context of the PREFER project deliverables and the accompanying timeframe. Considering Siemens is a worldwide employer of engineers and this competency framework is used to assess personal development throughout Siemens, it was deemed an appropriate starting point.

1.5. New teaching practices

A further response to the lack of qualified graduates available for the labour market was the use of new teaching practices in Higher Education (Hadgraft and Kolmos 2020). These practices emphasised "what is being learned" and not "what is being taught", i.e., the greatest importance is learning not teaching (Mills and Treagust 2003). Among these new practices are:

1) *Student-centred learning* practices in which students are responsible for the direction of their learning (Prince and Felder 2006, Hadgraft and Kolmos 2020) such as active learning (Felder and Brent 2003, Prince and Felder 2006), problem/project-based learning (Mills and Treagust 2003, Jonassen, Strobel et al. 2006, Prince and Felder 2006, de Graaff and Kolmos 2007), inquiry-based learning (Prince and Felder 2006) and game-based learning (Bodnar and Clark 2017, Hosseini, Hartt et al. 2019, Qian and Clark 2016).

2) *Contextual, practice-related learning* practices in which elements of the curriculum can be related to work situations (Hadgraft and Kolmos 2020) including internships and industry projects (Chan, Zhao 2017, Karunaratne and Perera 2019, Maelah 2012, Zhou, Kolmos et al. 2012).

3) *Digital and online learning* practices that use technology for learning (Hadgraft and Kolmos 2020), for example, blended learning (Boelens, De Wever et al. 2017, Rasheed, Kamsin et al. 2020) and MOOCs (Sanchez-Gordon and Luján-Mora 2018, Sezgin, Sevim Cirak et al. 2020).

These three practices are not distinctive independent approaches.

These new teaching practices have demonstrated positive influences on students' learning, achievements, attitudes (Johnson 1998, Johnson and Johnson 1998), retention, engagement (Hosseini, Hartt et al. 2019, Prince 2004, Strobel and Van Barneveld 2009), motivation (Hosseini, Hartt et al. 2019, Zhou, Kolmos et al. 2012) and transversal competencies (Beagon, Niall et al. 2019, Bodnar and Clark 2017, Karunaratne and Perera 2019, Maelah 2012, Qian and Clark 2016, Terenzini, Cabrera et al. 2001, Woods, Hrymak et al. 1997).

1.6. PREFER project

Although the emphasis on transversal competencies and new teaching practices exists within engineering education, there is still a gap between what engineering education provides to students and what employers desire from engineering graduates (Meier, Williams et al. 2000, Mills and Treagust 2003, Nair, Patil et al. 2009, Trevelyan 2010). These studies showed that employer's feel students lack transversal competencies such as communication, interpersonal, management and team working skills (Meier, Williams et al. 2000, Mills and Treagust 2003, Nair, Patil et al. 2009, Trevelyan 2010). Therefore, a European project started in 2017 to reduce the transversal competency gap in the field of engineering and to increase the employability of future engineers. This project was called PREFER (Professional Roles and Employability of Future EngineeRs) and was funded by the Erasmus+ programme of the European Union (grant agreement 575778-EPP-1-2016-1-BE-EPPKA2-KA). The research presented in this thesis is part of the PREFER project.

The PREFER project spanned three countries, Belgium Ireland and the Netherlands with a consortium consisting of:

1) Three universities – KU Leuven (Belgium), Delft University of Technology – TU Delft (The Netherlands) and Technological University Dublin – TU Dublin (Ireland) whose similarities in terms of the country size and consequently its organisation, and the common interest to develop the field of engineering education as well as previous experience on it, made for an ideal match.
2) Three industry partners – Engie (Belgium), Siemens (the Netherlands) and ESB (Ireland) - to establish connections with the engineering labour market.
3) A test development partner - BDO, Belgium, to assist in the development of reliable and valid competency and preference tests.
4) The three national professional bodies of engineers in each respective country – IE-net (Belgium), het Koninklijk Instituut voor Ingenieurs - KIvI (The Netherlands) and Engineers Ireland, to represent the future engineers.
5) One employer federation – AGORIA (Belgium) to connect higher education institutions with engineering employers.
5) Two European networking associations – SEFI, the European Society for Engineering Education and FEANI, the European Federation of Professional Engineers joined to help with the knowledge dissemination of the project.

The PREFER project had three main goals: first, the development of a Professional Role Framework that describes three different roles for starting engineers: *Operational Excellence* (focused on optimisation), *Product Leadership* (focused on innovation) and *Customer Intimacy* (focused on tailored client solutions) and the necessary transversal competencies for each role (Craps, Pinxten et al. 2021). Second, the development of two tests, a motivation test (PREFER Explore) that students and young engineers can use to discover their preferred role (Carthy, Pinxten et al. 2019) and a competency alignment test (PREFER Match) that helps students to get feedback on their competency alignment with their preferred engineering professional role based on their vocational interests and competence indicators (Pinxten, Carthy et al. 2019). Last, the creation of innovative curriculum elements that stimulate the development and practice of transversal competencies necessary for the engineering professional roles. This last part of the project was carried out for a large part by the author of this thesis. A case study detailing the implementation of one of these elements, focusing on communication competencies, is described and analysed in *Chapter 5* of this thesis, and further explored in *Chapter 6*. This element is a student-centred learning practice, more specifically an innovative game-based learning activity implemented in a single course over five institutions. This intervention was created to stimulate engineering students from multiple engineering backgrounds to practise and reflect on their communication competencies. Although previous studies describe learning activities for students that are designed to stimulate practice and reflection on a wide range of transversal competencies, the work in this thesis is new because it assesses also the effectiveness of this activity to practice and trigger reflection on communication competencies one year after its implementation as well as the retention of students' transversal competencies.

All final products and other information about the PREFER project can be found on the official website of the project[1].

1.7. The researcher

The researcher of this thesis holds a Master Degree in Biomedical Engineering from the *Instituto Superior Técnico* – University of Lisbon (Portugal). The lack of practice and instruction on transversal competencies experienced during her studies in Portugal motivated the researcher to look abroad for education focusing more on engineering practice and transversal competencies. Thanks to the Bologna Agreement, the researcher studied half a year at Delft University of Technology and another half a year at Erasmus Medical Centre (The Netherlands). The practical experience acquired in the Netherlands has motivated the researcher to become an engineering education researcher and join the PREFER project with the desire to better prepare engineering students like her for the labour market.

1.8. Thesis scope, research questions and outline

This thesis focuses on the measurement and development of transversal competencies in engineering education with two main aims: to provide an instrument that measures perceptions of transversal competencies as well as triggers reflection on these competencies, and a game-based activity that stimulates engineering students to practice and reflect on their communication competencies. The main research question investigated in this thesis is:

What are the characteristics to measure perceptions of transversal competencies and stimulate the practice and reflection on transversal competencies in engineering education?

A schematic summary of the chapters and how they relate to the aims and main sub-research questions of this thesis is presented in Figure 1.

[1] www.preferproject.eu

Chapter 1 General introduction			
Aim 1	Measurement of perceptions of transversal competencies	Systematic review	**Chapter 2** What are the methods used over the past 20 years that measure the following transversal competencies: communication, innovation/creativity, lifelong learning and teamwork, or their perceptions?
		Instrument creation and evaluation	**Chapter 3 and 4** What are the characteristics of a valid instrument that measures perceptions of transversal competencies in engineering education?
Aim 2	Practice of transversal competencies	Activity creation and evaluation	**Chapter 5 and 6** What are the characteristics of a game based-learning practice that stimulates engineering students to practise and trigger reflect on their communication competencies?
Chapter 7 Conclusions, reflections and recommendations			

Figure 1 - Overview of the aims, chapters and research questions present in this thesis.

Chapter 2 presents a systematic review of the literature on the methods used in engineering education to measure the following transversal competencies: communication, innovation/creativity, teamwork and lifelong learning and their perceptions. The limitations and benefits of the measurement methods found in this review: as the absence of competency definitions and descriptive levels and the lack of validity and reliability properties indicating that the methods can be used to measure transversal competencies or their perceptions, showed that there was not yet an instrument that combines these characteristics and is used to measure perceptions of transversal competencies by different stakeholders. This instrument, which is based on an industry framework, is described in *Chapter 3*. In this chapter, the instrument is used to explore both the industry perspective on what transversal competency levels engineering graduates should hold at Bachelor and Master graduation, and the lecturers' perspectives on what transversal competencies engineering students acquire or practise in the courses of the Bachelor and Aerospace Structures and Materials Master of the Aerospace Engineering faculty at Delft University of Technology. In *Chapter 4*, the validity and reliability of the instrument are tested through exploratory and confirmatory factor analysis on a sample of Bachelor and Master aerospace engineering students, who used the instrument to indicate their transversal competency level perceptions.

In parallel with the studies conducted in chapters 2, 3 and 4, a game-based learning activity was created as part of the aim of the PREFER project to develop new curriculum elements that stimulate engineering students' transversal competencies. This game-based activity focused on practising and triggering reflection on communication competencies and was implemented in five European engineering universities. Although this game was created independently from the studies of the previous chapters, the results obtained in previous chapters 3 and 4 indicated the need to stimulate engineering students to practice and reflect on their communication skills. In chapters 3 and 4, the results indicated that industry perceives that communication competencies are still important for engineering graduates, lecturers felt that they did not practice much some of these competencies in their courses such as writing and pitching skills, and engineering students perceived that they were less competent in pitching skills.

The characteristics that make the game-based activity effective to practice and trigger reflection on communication competencies are investigated immediately after students' participation using a mixed-methods approach in *Chapter 5*. In *Chapter 6*, the effectiveness of this activity to practice and trigger reflection on communication competencies one year after its implementation and the retention of students' transversal competencies are explored with semi-structured interviews conducted with a small cohort of participating students. *Chapter 7* outlines the conclusions evidenced in this research and presents recommendations for engineering education researchers and educators.

This thesis is presented as a portfolio of journal articles. The work presented in chapters 2 to 6 has previously been published as independent journal articles. The author has tried to delete overlaps in the chapters, expanded the description of the methodology used and added more information, especially in the introduction and conclusion of the chapters, to provide a coherent flow between chapters. Where necessary ethical approval was sought and obtained for the studies in each chapter from the Institutional Review Board of the Delft University of Technology. All participants: industry representatives, lecturers and students consented to be part of the research. They were informed that their participation was voluntary and that the analysis would be conducted anonymously.

“Great things are done by a series of small things brought together”

Vincent Van Gogh

CHAPTER 2

Evaluation of methods used to measure and assess transversal competencies and their perceptions in engineering education: a systematic review

This chapter is based on the published article:

Leandro Cruz, M., Saunders-Smits, G. N., and Groen, P. (2019). Evaluation of competency methods in engineering education: a systematic review. *European Journal of Engineering Education*. 45(5), 729-757. DOI: 10.1080/03043797.2019.1671810.

2.1. Introduction

Over the last 20 years, accreditation boards and educational stakeholders worldwide have emphasised the importance of integrating transversal competencies in engineering education curricula to prepare students for the engineering labour market (American Society for Engineering Education 1994, Engineering Accreditation Commission 2000, UNESCO 2010).

The growing emphasis on transversal competencies in engineering education has triggered the need to create robust methods that measure transversal competencies (Shuman, Besterfield-Sacre et al. 2005). However, assessing students' level of mastery in transversal competencies is difficult, caused by a lack of consensus on the definition of the transversal competencies between the different engineering education communities, government bodies, and employers, and by what behaviours would exhibit mastery (Shuman, Besterfield-Sacre et al. 2005). In addition, it is also difficult to assess transversal competencies independently, because they are often intertwined with the technical competencies (Shuman, Besterfield-Sacre et al. 2005; Badcock, Pattison et al. 2010). These issues have hindered the development of the competency measurement process.

The focus of this chapter is to review the current literature on the methods used to measure and assess transversal competencies and their perceptions in engineering education. This review aims to highlight the importance of measuring transversal competencies and their perceptions, and how the current literature in engineering education measures these. This review was limited to engineering education to present an instrument that combines characteristics that the current existing instruments in engineering education do not have yet. Four holistic transversal competencies: communication, teamwork, innovation/creativity and lifelong learning were studied. This selection was motivated by the fact that these competencies are present in the lists of transversal competencies highlighted by the industry (McMasters and Matsch 1996, Bartram 2005), accreditation bodies (American Society for Engineering Education 1994, Commission 2000, ENAEE 2008), engineering education communities (Badran 2007, Crawley, J. et al. 2007, Cropley 2015), and in the instrument that will be used in the following two chapters of this thesis.

The following research questions were addressed in this review:

(1) What are the methods used to measure the competencies: communication, innovation/creativity, lifelong learning and teamwork or perceptions of their competencies?

(2) Are validity and reliability measured in the studies considered, and if so, which techniques are used?

(3) What is the purpose of the measurement used in the study?

(4) Which criteria are used to assess these competencies or their perceptions?

2.2. Background literature

This section provides the reader with the motivation for the selected transversal competencies in this chapter. This selection has been carried out using scientific and industry literature and within the confines and scope of the PREFER project.

As stated earlier, the need to focus on transversal competencies in the engineering curricula was highlighted in 1996 by McMasters and Matsch (1996) in the Boeing list of "Desired Attributes of an Engineer". This list required engineers to have *good communication skills*: *written, verbal, graphic, listening*, *ability to think both critically and creatively*, *curiosity and a desire to learn - for life*, and *profound understanding of the importance of teamwork* (McMasters and Matsch 1996).

Further emphasis on competencies such as communication, working in teams, and lifelong learning was given by the new ABET Engineering Criteria which came into effect in 2000 (Engineering Accreditation Commission 2000) and the Washington Accord (American Society for Engineering Education 1994). Similarly, in Europe after the Bologna Process, which started in 1999, the European Network for Accreditation of Engineering Education (ENAEE) has set these three competencies as an important part of engineering programmes.

A resulting engineering education initiative, called CDIO (Conceive, Design, Implement and Operate), which started in 1997 at MIT and is now a worldwide initiative, has developed a list of competencies that include *creative thinking*, *curiosity and lifelong learning*, *multidisciplinary teamwork*, and *communication* (Crawley et al. 2007).

In summary, the research in this chapter will be limited to the competencies of communication, teamwork and lifelong learning, as the comparison of the competencies present in all the previously mentioned literature that showed agreement on the importance of these three competencies.

A fourth transversal competency, innovation/creativity, was added within the framework of the PREFER project and was taken from the list of "Great Eight Competencies" (Bartram 2005), a validated tool available and used in this project. This competency was found to be important based on the outcomes of a large industry consultation by another PREFER project partner (Craps, Pinxten et al. 2018). Considering the challenges of technology in the future, this competency is acknowledged essential for engineering students not only by the PREFER project but also by the wider engineering education community (Badran 2007; Crawley et al. 2007; Cropley 2015; Kamp 2016).

Also, this review was limited to these competencies because they were four out of five holistic competencies present in the instrument that will be presented in the next chapters. The fifth competency (entrepreneurial competency) was not included in this chapter because there was already a literature review on the evaluation of the assessment methods in engineering entrepreneurship education (Purzer, Fila et al 2016). These reviews were used to inform the researcher on the state-of-the-art of these holistic competencies in engineering education, and how they were defined and encompassed other competencies. This was conducted to support the inclusion of the competencies of the instrument that will be used in this thesis.

Since this instrument is intended to be used in engineering education, this review was limited to this field to find the limitations and benefits of the existing instruments, and compare to the characteristics that the instrument present in this thesis can bring new to engineering education.

2.3. Methods

This section describes the data collection methods used to carry out the systematic review (summarised in Figure 2) and reports on the characteristics of the studies found.

Identification

Keywords
"communication" OR "innovation" OR "creativity" OR "lifelong learning" OR "life-long learning" OR "teamwork" OR "collaboration" AND "measure" OR "assess" OR "method" OR "evaluate" AND "engineering"

Database	Fields searched	Controlled terms (After applying keywords)	Studies
ERIC	Subject/title/abstract	Educational level: Higher education	332
Scopus	Title/abstract/keywords	Language: English Subject area: Engineering	391
Web of science	Topic	Language: English Research area: Engineering	349

Studies identified through databases (n=1072)

Screening

Duplicate studies removed (n = 85)

Studies screened (n = 987)

Studies excluded for not meeting the criteria (n = 877):
- Criteria 1: Performed on engineering students (n = 546)
- Criteria 2: Looked at communication, innovation/creativity, lifelong learning or teamwork (n = 331)
- Criteria 3: Reported on measurement methods (n = 7)
- Criteria 4: Reported aims and research questions, description of data and answers to research questions (n = 4)

Synthesis

Studies included for synthesis (n = 99) measuring:
- Communication (CM, n = 23)
- Lifelong Learning (LLL, n = 19)
- Innovation/Creativity (IC, n = 17)
- Teamwork (TW, n = 16)
- Combination of CM & TW (n = 8)
- Combination of CM & LLL & TW (n = 5)
- Combination of CM & LLL (n = 2)
- Combination of CM & IC (n = 2)
- Combination of TW & IC (n = 2)
- Combination of CM & TW & IC (n = 2)
- Combination of CM & LLL & TW & IC (n = 2)
- Combination of LLL & TW (n = 1)

Figure 2 - PRISMA flow diagram of the systematic review process.

2.3.1. Data collection

This review has been carried out based on the methods outlined in the practical guide on the systematic review of Petticrew and Robert (2006). Following this method, first, the research questions were framed, as stated in section *2.1. Introduction*. Next, the databases were chosen and the research terms defined. The research was carried out in October 2017 using three databases: ERIC (education indexes), Scopus (science, technology, medicine, social sciences, and art and humanities indexes), and Web of Science (sciences, arts, and humanities indexes). The following keywords: *communication*, *innovation*, *creativity*, *lifelong learning*, *life-long learning*, *teamwork*, or *collaboration*, in combination with *measure*, *assess*, *method* or *evaluate* and *engineering* were used in each of the three databases. In addition, controlled library terms (see the PRISMA diagram in Figure 2) were used after applying the keywords to filter the relevant studies. The research was limited to English language studies in peer-reviewed literature, scientific journals, and conference proceedings from 2000 to 2017. The choice of the year 2000 as the starting point reflects the introduction of the ABET criteria for engineering programmes in that year (Shuman, Besterfield-Sacre, and McGourty 2005). Within these parameters, 332, 391, and 349 studies were identified in Scopus, Web of Science, and ERIC, respectively. From these studies, eighty-five duplicates were removed, resulting in 987 studies to be considered.

The third step of the method was to formulate the inclusion and exclusion criteria. To be included, the study:

- Was performed on engineering students in higher, tertiary and post-secondary education. Studies on primary and secondary education, training of practising engineers, and non-engineering programmes were excluded.
- Looked at at least one of the selected competencies: communication, innovation/creativity, lifelong learning and teamwork.
- Reported on methods used to measure students' performances (i.e., grading and feedback), to evaluate the course and programme outcomes, and to measure students' abilities in non-related courses.
- Reported its aims and research questions, contained an adequate description of the data (country, participants, etc.), and provided answers to the research questions.

The author examined the titles and abstract content of the studies found against the first two criteria. Then, the author scanned the full texts (110 studies) against the last two requirements. Studies that did not fulfil the criteria were removed from this research. From this analysis, 99 suitable studies were identified and managed using an *EndNote*™ citation database.

To answer the research questions, data about the measurement criteria, the methods used to measure each competency or their perceptions, and the purpose of the measurement (1- students' performance for formative and summative assessment, 2 - evaluation of course/programme effectiveness and 3 - characterisation of students' abilities) were extracted. In addition, the author screened the studies to search for the use of the main types of validity and reliability measurements, as recommended by Cohen, Manion, and Morrison (2007): content validity, construct validity, reliability as stability, reliability as equivalence and reliability as internal consistency. These data were recorded on a data sheet.

2.3.2. Study characteristics

When looking at the characteristics of the studies, only 17% of them were published between 2000–2009, compared to 83% published between 2010–2017 (Figure 3). The analysis of the geographical spread of the studies shows that the most studies (64%) on competency measurement originated in North America, followed by Europe (19%), South America (7%), Asia (5%), Australia (3%), and Africa (1%). Moreover, 75% of the studies looked at only one competency (see Figure 2). Only 2% of the studies (Moalosi, Molokwane et al. 2012; Narayanan 2013) looked at all four competencies. Communication was the competency that was most frequently studied (44% of the studies), followed by teamwork (36%), lifelong learning (29%) and innovation/creativity (25%).

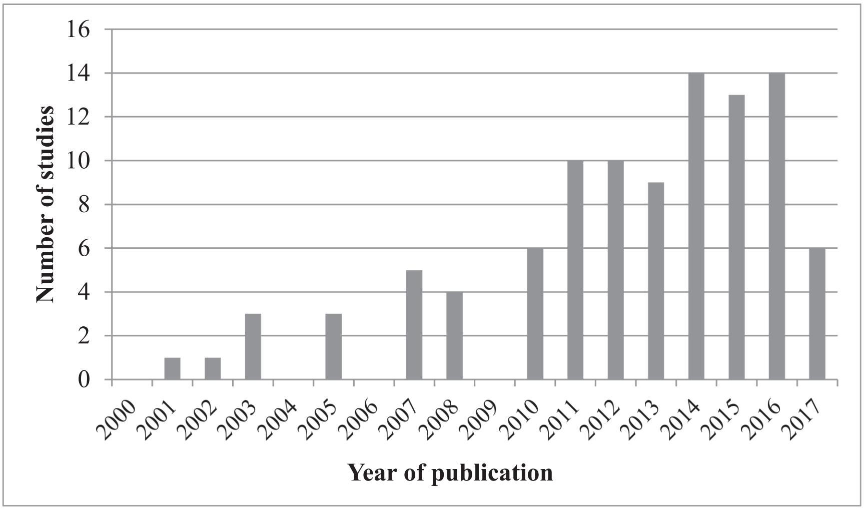

Figure 3 – Number of published studies (n = 99) that studied communication, innovation/creativity, lifelong learning or teamwork competencies from 2000 to 2017 (October).

2.4. Results

The findings of the systematic review are structured to address the research questions. Firstly, the type of methods used in the studies to measure competencies or their perceptions is described, as well as their advantages and disadvantages. Secondly, valid and reliable methods found in the literature studies are presented. Valid and reliable methods in the context of this thesis mean that they are rigorously designed and implemented to measure transversal competencies or their perceptions, and that the research data indicates that the methods can be used or are successful to measure the transversal competencies or their perceptions. Finally, the methods are reported per research purpose and per competency according to their advantages and disadvantages, and the validity and reliability of the measurement methods described.

2.4.1. Type of methods

In the studies analysed, seven different methods used to measure and assess transversal competencies or their perceptions were found: questionnaires, rubrics, tests, observations, interviews, portfolios, and reflections. Questionnaires and rubrics were the most common (75%) methods reported.

Questionnaires, which gather information from respondents through a set of written questions, were used in the form of self-assessment, where students assessed their perceptions about their skills (Strauss and Terenzini 2005; Garcia Garcia et al. 2014) and attitudes (Douglas et al. 2014), or peer assessment, where students assessed each other (Zhang 2012). Questionnaires are easier to develop (compared to interviews and observations, which are difficult to plan, collect, analyse and present) and require shorter time administration (Douglas et al. 2014). An issue observed was that the majority of the questionnaires used Likert scale questions without competency definitions or criteria. In the case of measuring transversal competencies or their perceived competencies, it is a requirement that the definitions of the competencies are provided so that evaluators or assessors are informed about what they are measuring. When the purpose is to measure changes in student competency levels, administering questionnaires at one point in time is not enough because they ignore the effect of social and process changes. To take into account this effect, some studies used pre- and post-questionnaires (Waychal 2014; Gerhart and Carpenter 2014; Ngaile, Wang, and Gau 2015), administered at the beginning and end of the programme or course.

Rubrics, scoring methods with or without detailed descriptions of levels of performance, were used by faculty (Gerlick et al. 2011) or industry representatives (Hotaling et al. 2012) to assess written reports and oral presentations, designs projects, and capstone courses. Rubrics with detailed descriptions of levels of performance homogenised and guided the assessors (Flateby and Fehr 2008; Scharf 2014; Eichelman, Clark et al. 2015) because they increased inter-rater reliability and minimised subjectivity of the competency measurement process (Fila and Purzer 2012).

Tests, in the form of written and proof of concept tests, besides questionnaires and rubrics, were frequently used to measure innovation/creativity. Similar to questionnaires, they were administrated to measure skills or abilities, either after the course (Charyton, Jagacinski et al. 2008; Charyton et al. 2011) or before and after the course (Shields 2007; Robbins and Kegley 2010). As with questionnaires, the use of pre- and post-test were used to measure transversal competency changes or improvements.

Observations, which intended to observe student behaviour, were used as a stand-alone methodology to measure students' behaviour by teaching assistants (Sheridan, Evans, and Reeve 2014) or peer-students (Pazos, Micari, and Light 2010), but also in combination with other methodologies, e.g., interviews (Dohaney et al. 2015). As a good practice, most of the observations were carried out using frameworks or rubrics to guide the measurement.

Interviews, in which an interviewer asks questions to an individual or group of interviewees, were also used as a stand-alone (Dolan et al. 2011), but mostly in combination with other instruments such as questionnaires (Barnes, Dyrenfurth et al. 2012; Dunai et al. 2015; Eichelman, Clark, and Bodnar 2015). Both observations and interviews are time-consuming for assessors and they require training, however in the case of observations they can provide authentic student behaviour and attitudes, and interviews should allow depth and flexibility of student responses. An alternative to common observations used by Besterfield-Sacre et al. (2007) is work sampling observations. This type of observation takes place in floating-length intervals instead of full-time observation. This method, used to measure teamwork in four different learning environments, reported improvement in the cost-effectiveness of the observation method.

The least used methods were *portfolios* (Martínez-Mediano and Lord 2012; Wu, Huang, and Shadiev 2016) and *reflections* (Bursic, Shuman, and Besterfield-Sacre 2011). The *portfolios* consisted of a compilation of deliverables developed by students as part of their coursework, that shows meaningful learning. The data of portfolios were coded to demonstrate students' recognition of the need for and ability to engage in lifelong learning (Wu, Huang, and Shadiev 2016) and to measure the influence of a Moodle learning platform on students' creativity (Martínez-Mediano and Lord 2012). *Reflections* included students reflecting on and describing their competency learning of a competency. Portfolios and reflections, as well as observations, were used to support the results obtained by other methods, such as tests, rubrics and questionnaires. It is suspected that the low frequency found of these methods can likely be explained by the relatively large amount of time and work required by faculty members to use these instruments. The use of multiple methods was also reported in other studies present in the review. This is discussed in more detail in the next sections.

2.4.2. Validity and reliability

More than half of the methods presented in the 99 studies did not describe the theoretical background or research behind their metric designs. Only 39 studies (32 measurement methods) went beyond that and reported validity and reliability properties (Appendix E). Of these studies, 7 measured communication or perceptions of communication, 6 lifelong learning or perceptions of lifelong learning, 6 teamwork or perceptions of teamwork, and 9 measured innovation/creativity or perceptions of innovation/creativity. Only 4 methods measured more than one competency: communication and innovation/creativity (Hernandez-Linares et al. 2015), communication and teamwork (Immekus et al. 2005; Fini and Mellat-Parast 2012), and communication, lifelong learning and teamwork (Strauss and Terenzini 2005).

In some studies, some techniques were used to demonstrate validity, i.e. the rigour of the research method to measure transversal competencies or their perceptions: a review of items or content from previous literature; review of experts and students' opinions about the content of the assessment; correlations between tests which intend to measure the same construct; use of control and experimental groups; confirmatory and factor analyses; and testing of the method as a pilot study. Reliability properties relied on internal consistency and inter-rater reliability. On the other hand, validity and reliability measurements were overlooked in other studies, i.e., they did not define the content being measured which immediately violated the definition of content validity.

It was also found that methods that presented reliable and valid measurements in previous studies were reused, such as Modified Strategies for Learning Questionnaire (Lord et al. 2011; Amelink et al. 2013), Abreaction Test for Evaluating Creativity (Clemente, Vieira, and Tschimmel 2016), Critical Thinking Assessment (Vila-Parrish et al. 2016), Index of Learning Styles (Waychal 2014), Torrance Test of Creativity Thinking (Shields 2007; Robbins and Kegley 2010; Wu, Huang, and Shadiev 2016), Lifelong Learning Scale (Kirby et al. 2010; Chen, Lord, and McGaughey 2013), and Self-Assessment of Problem Solving Strategies (Douglas et al. 2014). The convenience of using existing valid methods will be discussed later on.

2.4.3. Methods per assessment purpose

The research in this chapter intended to find out how the type of method could be related to the purpose of the measurement. This is important when creating or choosing a method because the design of a method may not be appropriate for a different purpose. For this reason, the distribution of the methods per measurement purpose was listed in Table 1 and the frequencies were analysed to verify what type of methods were more widespread per measurement purpose.

Table 1 – Distribution of methods with measurement purpose (1- to evaluate the course and programme effectiveness to enhance the quality of teaching and the student learning experience, 2- to assess students' performance to give summative grading at the end of courses and/or formative feedback to students, and 3- to measure students' abilities to characterise students populations.) and competencies (CM - communication, LLL - lifelong learning, TW - teamwork, IC - innovation/creativity, and > C - more than one competency).

		Questionnaires	Rubrics	Tests	Observations	Interviews	Multiple methods
(1) Evaluate course and programme effectiveness	CM	4	5	-	-	-	3
	LLL	1	5	-	-	-	4
	TW	5	-	1	-	-	2
	IC	3	1	4	-	-	4
	>C	7	1	-	-	-	5
	Total	**20**	**12**	**5**	**-**	**-**	**18**
(2) Assess students' performance	CM	-	4	-	-	-	-
	LLL	1	3	-	-	-	-
	TW	2	1	-	3	1	1
	IC	-	2	-	-	-	-
	>C	-	6	-	-	-	2
	Total	**3**	**16**	**-**	**3**	**1**	**3**
(3) Measure student abilities	CM	1	-	1	-	-	1
	LLL	3	-	1	-	-	1
	TW	-	-	-	-	-	-
	IC	-	-	1	-	-	-
	>C	2	-	-	-	-	-
	Total	**6**	**-**	**3**	**-**	**-**	**2**
Combination of (1) and (2)	CM	-	1	-	-	-	3
	LLL	-	-	-	-	-	-
	TW	-	-	-	-	-	-
	IC	-	-	-	-	-	2
	>C	-	-	-	-	-	1
	Total	**-**	**1**	**-**	**-**	**-**	**6**
Total		**29**	**29**	**8**	**3**	**1**	**29**

More than half of the studies reported on methods that were used to evaluate the course and programme effectiveness to enhance the quality of teaching and student learning. The most frequent (63%) method used for this purpose was questionnaires. They were used to ask students about how the course prepares them for a competency (Baral et al. 2014; Gerhart and Carpenter 2014).

Questionnaires asking students to indicate whether they perceived the course is effective should be rigorously designed, e.g., with competency definitions to make sure that students are less biased in the assessment. However, combining questionnaires with other methods such as portfolios (Martínez-Mediano and Lord 2012), interviews (Dunai et al. 2015) and observations (Blanco, López-Forniés, and Zarazaga-Soria 2017) can show that the courses stimulate the development of competencies in students. For example, in the study of Martínez-Mediano and Lord (2012), the use of portfolios confirmed the results of the questionnaire that the intervention had improved students' ability in lifelong learning. Similarly, a combination of interviews conducted by an external researcher and questionnaires given to students indicated that project-based learning promoted teamwork competencies (Dunai et al. 2015).

The second most frequent purpose (26%) was to assess students' performance to give summative grading and formative feedback. The former is used to provide student grades at the end of the curricular activity to certify students' achievements, and the latter is used to provide feedback to improve students' learning (Biggs 2003). Few studies (only 7% of the studies) which reported formative feedback were found. The results show that rubrics were the most frequent (62%) method used to grade students (Fila and Purzer 2012) and to provide formative feedback to students (Ahmed 2017). Rubrics used checklists developed based on student learning outcomes, which allowed assessors to grade students, and to provide them tailored feedback (Fila and Purzer 2012).

The third form of measurement (11%) was aimed at measuring students' abilities to characterise student populations. More than half of these methods were questionnaires. For example, Strauss and Terenzini (2005) aimed at assessing a large population of 4558 graduating seniors in seven engineering fields in more than one competency (e.g., communication, lifelong learning and teamwork) on a five-point Likert scale. Moreover, Chen, Lord, and McGaughey (2013) conducted a cross-sectional study with 356 engineering students of five different fields and major. In this study, students were asked to evaluate their abilities for lifelong learning. Self-perception questionnaires were considered an adequate strategy (Strauss and Terenzini 2005; Chen, Lord, and McGaughey 2013) when the aim was to evaluate a large population, and competencies were defined and the method was rigorously designed to answer the research questions.

Within the three purposes (assess student learning, evaluate course/programme effectiveness and characterise student abilities), a limited number of studies used qualitative methods (e.g., observations, interviews, portfolios and reflections). This limitation will be addressed in the discussion.

2.4.4. Measurement methods per competency

A summary of the criteria found per competency is reported below, as well as a definition formulated for each competency based on the studies included. In addition, the measurement methods, which referred to validity properties (e.g. content and convergent validity), found in the studies are reported per competency. This information may assist assessment developers in the development of their competency assessment and evaluation schemes.

a. Competency definition and measurement criteria

As stated by Shuman, Besterfield-Sacre, and McGourty (2005), the lack of consensus on the definitions of the competencies creates difficulties in their measurement process. For this reason, there was interest to investigate how the studies define the competencies under study. A lack of competency definitions in the studies was found. Of all of them, only 17 studies explicitly define the competencies they were studying. Lack of definitions bias understanding when performing the measurement, and prejudice the replication of the studies. Since competency terms have various meanings depending on the context, it is problematic to assume that the competencies have the same synonym and do not warrant a definition.

For the studies that were not providing any definition for the competencies, it was decided to investigate the criteria that were used to provide clarity and measure these competencies. Although 5% of the studies did not provide any criteria to establish the competencies, using only a Likert scale to rate the self-perceived level of the competencies undefined, such as in Moalosi, Molokwane, and Mothibedi (2012), the analysis of the 99 studies disclosed several criteria used to measure the attainment levels in the four competencies. The criteria found for each competency, their definition and the corresponding studies are listed in Appendixes A, B, C and D, respectively. In the analysis of the results, no distinction on the purpose of the studies is made, as the primary interest is to evaluate the criteria used to measure the attainment levels of competencies.

b. Communication (Appendix A)

Among the 44 studies that measured attainment levels in communication, 31 evaluated oral communication and 24 written communication. Sixteen studies reported on both *oral and written communication*. Out of the 31 studies which looked at *oral communication*, 16 considered it as a single criterion without sub-division. The same was found for *written communication* (15 out of 24 studies).

A few studies which look at other communication criteria than oral and written communication were found. These criteria included *self-confidence* (4), *achieve/convey ideas* (3), *self-exposure* (2), *listening* (2), *reading* (1), and *client interaction* (1). These criteria suggest that communication for engineers is more than just oral and written communication (Wilkins, Bernstein, and Bekki 2015). It also involves listening actively, carrying general conversations, showing understanding using opinions or reactions to what is discussed, and self-exposure to conversations to interact with others and to create networking.

Based on the criteria listed above and the definitions found in studies such as Immekus et al. (2005) and Wilkins, Bernstein, and Bekki (2015), the author proposes to use the following definition of communication: communication is *'the ability to show understanding and to carry technical/non-technical written/oral presentations and discussions depending on the audience where the feedback loop of giving and receiving opinions, advises and reactions is constant'*.

Valid methods measuring communication were found (Appendix E). Eichelman, Clark, and Bodnar (2015) and Galván-Sánchez et al. (2017) used rubrics to measure student performances in demonstrating written and oral communication, respectively. Also, Frank et al. (2015) has measured students' performance on written communication using two valid methods (the VALUE rubric the CLA+).

Wilkins, Bernstein, and Bekki (2015), on the other hand, validated a test that measures not only student self-perceived knowledge in communication skills (such as active listening, assertive self-expression, and receiving and responding to feedback), and their confidence to use these skills, but also their ability to apply these communication skills.

c. Lifelong Learning (Appendix B)

The top five most frequently used criteria for lifelong learning competency were found to be *self-reflection* (17 studies), *locating and scrutinizing information* (16), *willingness, motivation and curiosity to learn* (11), *creating a learning plan* (10), and *self-monitoring* (6).

Based on the definitions present in the studies (Coşkun and Demirel 2010; Martínez-Mediano and Lord 2012) and the criteria found, the author defines lifelong learning as *'the intentional and active personal and professional learning that should take place in all stages of life, and various contexts to improve knowledge, skills and attitudes'*.

When it comes to reporting validity, one point in time self-assessment methods (Coşkun and Demirel 2010; Douglas et al. 2014) reported on content and construct validity. On the other hand, EPSA (Ater Kranov et al. 2008; Ater Kranov et al. 2011; Ater Kranov et al. 2013; Schmeckpeper et al. 2014), another method that reports on content, construct and criterion validity, goes beyond self-assessment and measures student performance on lifelong learning competencies during a specific task.

d. Teamwork (Appendix C)

For teamwork, criteria such as *interacting with others* (18 studies), *manage team responsibility* (15), *team relationship* (15), *communicating between group members/others* (9), and *contribution of ideas/solutions/work* (9) were found to be the top 5 most frequently used criteria. Criteria such as *problem-solving and decision making* (8), and *encourage the group to contribute* (7) were also often named. Therefore, based on these criteria and the definitions present in the studies (Immekus et al. 2005; Valdes-Vasquez and Clevenger 2015), the author defines teamwork as *'an interactive process between a group of individuals who are interdependent and actively work together using their knowledge and skills to achieve common purposes and outcomes which could not be achieved independently'*.

Examples of valid methods present in this review that measure teamwork were rubrics used to assess students' teamwork in capstone courses, in which the correlation between faculty and teaching assistant assessor was shown (Gerlick et al. 2011). In Bringardner et al. (2016), both pre- and post-questionnaires were carried out to consider the effect of social and process changes in the measurement of student teamwork competency. Finally, Besterfield-Sacre et al. (2007) provided a valid behavioural observation method which, however more time and resource consuming, proved that teamwork was accomplished.

e. Innovation/creativity (Appendix D)

From the 24 studies which looked at innovation/creativity, 7 studies referred to innovation and 17 studies reported creativity. The low number of papers studying innovation may be an indication that only a small number of curriculum elements go beyond the design process and also focus on the idea or solution implementation step; as a consequence, measuring creativity levels is often deemed enough. Both innovation and creativity measurement criteria were found to focus mainly on *flexibility* (15 studies), *originality* (13), *fluency* (7), *elaboration* (7), *connection* (4), and *scaling information* (4).

Based on the criteria and definitions found in the studies (Fila and Purzer 2012; Amelink et al. 2013), the author proposes the following definition: Innovation/Creativity is *'the ability to generate ideas and move from their design to their implementation, thereby creating solutions, products and services for existing or future needs'*.

For innovation/creativity, some valid methods were reused from previous studies. For instance, the Torrance Test of Creativity Thinking, which is validated in many studies (Shields 2007; Robbins and Kegley 2010; Wu, Huang, and Shadiev 2016), but requires trained assessors and is very costly. Other valid methods reported on are the Index of Learning Styles that measures innovation based on student preferences on a sensing/intuition scale (Waychal 2014), and the Modified Strategies for Learning Questionnaire that measures the perceptions of student learning behaviours in innovation skills (Amelink et al. 2013). More objective methods that measured student performance in demonstrating innovation rather than self-perceived are the Abreaction Test for Evaluating Creativity used in Clemente, Vieira, and Tschimmel (2016) and the VALUE rubric used in Vila-Parrish et al. (2016).

While analysing the criteria used in the studies, overlaps in the four competencies studied were found. This is not part of the scope of this chapter, so this will not be further analysed. This finding confirms, however, the need to define the competencies under study. As the underlying criteria depend on the definition, future studies should provide both competency definitions and underlying criteria so that conflicting elements can be avoided and coherent competency measurements carried out.

2.5. Discussion

The number of studies that looked at students' transversal competencies such as communication, innovation/creativity, lifelong learning, and teamwork competencies or their perceptions has grown over the last 17 years (Figure 3). This progression is likely indicative of the importance of these competencies for engineering students' success in the labour market and the increase of their integration in engineering curricula (Passow and Passow 2017).

This systematic review shows that it has become extremely important to assess student performance in courses or programmes, to certify the level of courses and curricula, and to characterise student abilities. Based on the validity and reliability of the methods analysed, i.e. the rigorous description of the design and implementation of the research methods to measure transversal competencies or their perceptions, the time and cost of their implementation, and their practicality for a specific purpose, recommendations are given to aid educators and researchers to further measure competencies or their perceptions, in terms of the measurement methods to be used in engineering education and research, and the importance of competency definitions and validity and reliability properties. Also, principles are proposed to be applied in the creation of reliable and valid measurement methods, i.e. methods that can be used and are successful to measure transversal competencies or their perceptions.

2.5.1. Measurement methods for educators

Based on the findings of the review, instead of using methods asking students if they perceive competency improvements, methods that measure students demonstrating certain competencies would be more appropriate to grade students (Besterfield-Sacre et al. 2007). Rubrics can be used as a checklist to verify whether students demonstrate the pre-defined competencies and at which level (Fila and Purzer 2012). The inter-marker consistency should increase and the marker bias effect should reduce when rubrics are created based on the expected learning outcomes and previous observation of students' behaviour, e.g. on a specific task (Flateby and Fehr 2008; Scharf 2014; Eichelman, Clark, and Bodnar 2015). In addition, this consistency can be optimised with the use of more than one rater or grader and the standardisation of the scales according to graders' scores (Ward, Gruppen, and Regehr 2002). These techniques were proposed in Ward, Gruppen, and Regehr (2002) as alternatives to reduce the issues of the efficacy of self-assessment. However, self-assessment plays an important role in stimulating students to critically reflect on their learning and can be a useful tool to give feedback on transversal competencies (Ward, Gruppen, and Regehr 2002; Eva and Regehr 2005). Rubrics are useful to provide individual feedback to strengthen detected points in students that need improvement. However, this form of assessment was little addressed by the studies reviewed. Rubrics can also be used for large samples, as experienced by Saunders-Smits and Melkert (2011).

Alternative measurement methods that are adequate to measure student behaviour are observations. However, they are very time and resource consuming. To reduce these issues, work sampling observation as validated in Besterfield-Sacre et al. (2007) can be a very valuable method, because it reduces the amount of observation time necessary to assess students' behaviour and consequently it is less labour intensive and time-consuming. Those behavioural measurements when based on clear criteria effective tools are considered a good practice to provide summative and formative feedback. In Table 2, a set of practical guidelines for implementation in education is listed.

2.5.2. Measurement methods for researchers

For researchers who are willing to measure student competencies to evaluate courses or programmes or simply to characterise a student population, the results of the review indicate that questionnaires and tests that measure perceptions are considered adequate methods for these purposes when limited time and resources are available and large samples are present. Although self-report methods as questionnaires can be easily developed and administered compared to interviews and observations, validity and reliability properties should be present (Immekus et al. 2005), i.e. the methods need to be rigorously designed and implemented to measure perceptions of transversal competencies, and the data should indicate that the methods can be used and are successful to measure competency perceptions.

Table 2 - Guidelines for measuring transversal competencies or their perceptions.

<table>
<tr><th>For educators</th><th>For researchers</th></tr>
<tr><td colspan="2">1) Define each competency.
2) Create sub-components of competencies and define & describe each dimension or level of mastery.</td></tr>
<tr><td>3) When grading or giving feedback, use checklists with the pre-defined sub-components and levels of competencies based on the learning outcomes (Fila and Purzer 2012).
4) Standardise scales/checklists i.e., create familiarity with the levels/dimensions of the scales and rescale them based on graders' assessment scores (Ward, Gruppen, and Regehr 2002)
5) Use more than one grader (Ward, Gruppen, and Regehr 2002)
6) Analyse the level of agreement between the graders testing inter-rater reliability (Cohen, Manion, and Morrison 2007).
7) When using self or peer assessment questionnaires, ask students for aspects that they need the most and least improvement (Ward, Gruppen, and Regehr 2002)</td><td>3) When measuring learning or growth, measure student performance on a competency before and after instruction (Cohen, Manion, and Morrison 2007) or ask students for extremes: what they learn the most and the least (Ward, Gruppen, and Regehr 2002)
4) Analyse the reliability and validity properties of the measurement to evaluate whether it can be used and is successful to measure transversal competencies or their perceptions (Cohen, Manion, and Morrison 2007).
5) Use multiple methods when corroboration, elaboration, clarification and expansion of the results is needed (Creswell and Clark 2007).</td></tr>
</table>

When using questionnaires or tests to measure the perceptions of competency improvements or developments, the use of time triangulation by employing pre- and post-questionnaires (Waychal 2014; Gerhart and Carpenter 2014; Ngaile, Wang, and Gau 2015) or pre- and post-tests (Shields 2007; Robbins and Kegley 2010) is recommended to rectify the omission of social changes and processes caused by one-time assessment (Cohen, Manion, and Morrison 2007). Also, self-assessment can be done by ranking competencies where students have to identify their strengths and weaknesses, which are the extremes of the scales (Ward, Gruppen, and Regehr 2002). This method was not used in any study of this review but it is recommended because it increases the truthfulness of judging one's performance (Ward, Gruppen, and Regehr 2002; Eva and Regehr 2005).

The studies of this review also showed that using multiple methods helps to measure the full umbrella of criteria of one or more competencies, or their perceptions. The advantage of this is that combining different methods yield the most comprehensive information from different perspectives and a more complete understanding of the research problem (Creswell and Clark 2007). Studies in this review (Barnes, Dyrenfurth, and Newton 2012; Amelink et al. 2013; Eichelman, Clark, and Bodnar 2015) suggested that the content validity of the results of the assessment increased because the results from different methods could be compared, explained and verified, and the strengths and weaknesses of the methods could be drawn and minimised, respectively. For example, the use of rubrics alongside interviews benefit from their power: the rubric with described levels guides the assessor and reduces inconsistencies in the assessment because the measurement criteria are clear and delimited, and the interviews offer more comprehensive information about students' competency development and since interviews are more flexible richer details can be obtained (Eichelman, Clark, and Bodnar 2015). Alternatively, researchers could employ a combination of questionnaires, which are straightforward and require little administration, with observations, which provide in situ data from the situations which are taking place (Amelink et al. 2013). Guidelines for researchers to measure transversal competencies or their perceptions are listed in Table 2.

At the moment, works published on competency measurements present in literature tend to rely heavily on the course evaluation only, and longitudinal studies were not found where students were followed in their years after completion of those courses or even after graduation. In future, educational researchers could consider using, if ethical boards allow, and willing participants are found, e.g. portfolios or interviews to perform longitudinal studies by collecting data from the same group of students at different points in their life, thus following the level of competency improvement of the students during their time at their institution and ideally also after graduation in their working life.

2.5.3. Importance of definitions and validity

It is observed in some studies that there is an effort in developing valid competency measurements. Some described competencies based on literature, industry and student feedback; Others used multiple methods to improve content validity or conduct factor analyses to increase construct validity. In addition, some studies used existing validated measurement methods. Choosing existing valid and reliable instruments may form a helpful option for assessment developers and instructors to measure competencies in students. However, learning outcomes, competencies and course or programme settings should be carefully considered and compared to the conditions of the existing studies, to ensure their applicability. Re-evaluation of validity and reliability are still necessary when implemented in a new situation (Cohen, Manion, and Morrison 2007).

Although robust methods were found, some studies did not define the content being measured. Lack of consensus on the definition of the transversal competencies was a cause of difficulties in the process of competency measurement (Shuman, Besterfield-Sacre, and McGourty 2005). Likewise, the lack of definitions may hinder the measurement of competencies. In this literature review, 83% of the studies identified and included did not present a definition of the transversal competencies, and 5% did not provide any criteria to establish the competencies. What were the perceived definitions of students or instructors when using these methods without definitions or descriptions? It is possible and acceptable that the definitions of competencies determined by different entities could be different. However, it should be clear for all involved parties what the definitions of the terms used are. Only with clear definitions and descriptions can measurement of competency attainment levels be understandable and valuable.

Overall, competency level measurement would benefit from rigorous method design. The only way to ensure that the results obtained from the competency measurements are valid and can be properly interpreted is through a clear and described assessment design and by carrying out validity and reliability measurements that stated that the methods can be used to measure competencies or their perceptions. Only 39 studies had methods that consistently showed reliability and validity properties. This means that only 39 out of the 99 studies indicated that the methods could be used and were successful to measure transversal competencies or their perceptions. Validity and reliability measurements provide feedback to both researchers and educators on whether methods measure the initial proposed concept and allow them to engage in subsequent revision and improvement of the measurement methods.

2.6. Conclusion, limitations and recommendations

This systematic review set out to analyse the current literature on the methods used to measure a set of transversal competencies (communication, lifelong learning, innovation/creativity and teamwork) and their perceptions in engineering education. Measurement methods of 99 studies published between the years 2000 and 2017 were analysed. This review described the type of methods that measure the four previously mentioned competencies or their perceptions, and their advantages and disadvantages, and validity and reliability properties based on the studies analysed. From the analysis of these findings, the measurement methods per purpose and competency are presented. Additionally, a definition for each competency and its underlying criteria are reported to assist assessment developers in the design of their competency assessment and evaluation schemes.

Some limitations in the current studies that measure competencies have arisen regarding competency definitions and validity and reliability properties. The analysis showed that a large number of studies lack a clear definition of the selected competency. Based on these issues, we shed a light on the importance of providing clear definitions and underlying criteria for the competencies under study. As such, a clear definition for each competency was created.

Moreover, less than half of the studies presented evidence of validity and reliability properties that show that the methods can be used to measure competencies or their perceptions. This result shows that a clear need to set professional standards when measuring competencies are needed and that future studies should report on reliability and validity properties, or in other words that the research methods are rigorously designed and implemented to be able to measure transversal competencies or their perceptions.

Questionnaires and rubrics were the methods mostly used to measure these competencies. Both are adequate methods when properly validated with the techniques presented in this review. Questionnaires, applied in the form of pre- and post-questionnaires, are particularly useful for assessors/researchers to evaluate course or programme effectiveness and characterise students' abilities in the presence of large student populations. This review also showed the usefulness of combining methods (particularly questionnaires with interviews or observations) to increase the validity of the studies. As such, researchers are encouraged to use multiple methods when evaluating the effectiveness of courses or programmes to stimulate student competencies, and when characterising students' abilities.

On the other hand, rubrics benefit evaluators in the grading and feedback processes both for small or large populations when their scales are clearly defined according to course learning outcomes. Questionnaires that ask students for aspects that they need the most and least improvement are also good practices. Alternatives are observations, portfolios and reflections; however, they are labour intense and more time-consuming.

While there is a global concern and effort in engineering education to measure competencies in communication, teamwork, lifelong learning and innovation, and their perceptions shown in this review, engineering educators and future researchers should double their efforts to provide competency definitions and analyse the reliability and validity properties of the measurement to evaluate whether it can be used and is successful to measure transversal competencies or their perceptions. Time, energy and cost are undesirable limiting factors, but other issues such as lack of expertise and description of the design and implementation of the measurement tool must be overcome.

A potential limitation of this systematic review is that powerful papers might have been left out because alternative terms used to name the four competencies might have been excluded. The review was also limited to engineering students, three databases and the past 17 years. Also, search in course documentation was not carried out in this review and examples of rubrics and other assessment criteria might have been left out. It may be worthwhile in the future endeavours to expand the review to the fields of science, technology and mathematics, other databases and possibly look at papers before 2000. Pertinent literature may have been missed as this review was restricted to engineering education and these four competencies.

In conclusion, the findings of this review showed that there is not yet in the literature an instrument that combines individual characteristics into a holistic instrument that can be used to measure the perceptions of the transversal competencies of different stakeholders. This holistic instrument with a list of 36 nuanced competencies with definitions and descriptive levels is presented and used by the industry and lecturers in Chapter 3 and by students in Chapter 4.

"Strive for perfection in everything you do. Take the best that exists and make it better. When it does not exist, design it."

Henry Royce

CHAPTER 3

Using an industry instrument to measure perceptions and trigger reflection on transversal competencies

This chapter is based on the published article:

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3.1. Introduction

As mentioned in the first chapter of this thesis, several literature studies on the transversal competencies that students should possess to be successful in the labour market have been conducted in Europe (Spinks, Silburn et al. 2006, Saunders-Smits and de Graaff 2012), the USA (Meier, Williams et al. 2000, Brumm, Hanneman et al. 2006, Passow and Passow 2012, Passow and Passow 2017) and Australia (Scott and Yates 2002, Nair, Patil et al. 2009, Male, Bush et al. 2011) over the past decades. They all show that these competencies are deemed important for engineering graduates. However, little is reported about the specific level for each transversal competency that graduates should master for each competency before entering the labour market. By investigating the transversal competency levels required by the industry, engineering educators can learn to what extent transversal competencies should be addressed in the curriculum and, as a consequence, they can provide interventions to ensure the desired levels are reached. This way, engineering educators are preparing students for the labour market, taking into account the needs of their future employers.

Engineering curricula have expanded curricular and pedagogical arrangements to include transversal competencies to prepare graduates for employment (Winberg, Bramhall et al. 2020). There are studies (Beagon, Niall et al. 2019, Chassidim, Almog et al. 2018) that report on the introduction of certain transversal competencies in the engineering curriculum and evaluate the effectiveness of these interventions. However, few studies, if any, systematically analyse how the transversal competencies are embedded in courses and formulated in the formal learning outcomes of the courses, how the achievement of the learning outcomes by students in the course is evaluated or reported on how lecturers feel they are implementing transversal competencies in their classes.

In this chapter, a *COMPetency Instrument* (COMπ) is presented to address some of the limitations found in the previous chapter such as the absence of competency and descriptive criteria, and the lack of analysis of the validity and reliability properties, i.e. in the context of this thesis the evaluation of whether instruments can be used and are successful to measure perceptions of transversal competencies. The innovation of COMπ is that it combines these individual characteristics and is used to measure the perceptions of industry and lecturers.

COMπ is characterised by 36 defined transversal competencies with four descriptive levels of competence and is based on an existing industry competency framework. COMπ is used to investigate the perspectives of European industry on the important transversal competencies that engineering students should hold at graduation and at which level of competence. Also, to see if COMπ can be used in an educational setting, two representative curricula, a BSc and a MSc of a Dutch university of technology will be used as case studies with a focus on the extent to which the transversal competency levels indicated by the industry are covered in a representative engineering degree both formally, and in the perception of lecturers, and what educational practises and methods are used to address these competency levels. Recommendations on the use of COMπ in engineering education in the capacity as course evaluation instruments as well as (self-) assessment instrument by lecturers in assessing course design and student’s learning outcomes will be made.

The main research question of the current chapter is: *What are the characteristics of a valid instrument that measures perceptions of transversal competencies in engineering education?*

Valid in the context of this thesis means that it can be used and is successful to measure transversal competency perceptions.

This question will be the subject of this chapter and also *Chapter 4*. In the present chapter, the following sub-questions will be addressed:

(1) Using COMπ, what are the desired transversal competency levels of BSc and MSc graduates by European industry?

(2) Using COMπ, what are the most important transversal competencies European industry desires that MSc graduates should hold?

(3) Can COMπ be used to map transversal competency learning outcomes against reported learning outcomes in formal course documentation?

(4) Can COMπ be used by lecturers to map transversal competency learning outcomes in their courses?

(5) Can COMπ be used by lecturers to indicate desired practices and methods to reach the transversal competencies levels required by the industry?

To respond to these questions, COMπ as a whole, or the full list or a selection of the transversal competencies of COMπ was used. More detail about this is provided in the methods section.

3.2. Background literature

3.2.1. Employability & competency gap

As mentioned in the introduction chapter, professional bodies have shown concerns about graduate employability and readiness for the labour market (Spinks, Silburn et al. 2006, IET 2016). A study conducted by Spinks, Silburn et al. (2006) in the UK has recognised a lack of qualified graduates available for recruitment (skill shortage) and documented that those graduates available have deficiencies in their competencies (skill gap). Similar gaps were reported by the Institute for Engineering and Technology in 2016 (IET 2016). This mismatch between the competencies acquired by engineering students during their studies and those necessary for the labour market was also identified in other studies (Meier, Williams et al. 2000, Nair, Patil et al. 2009). The gap was verified in competencies like *customer expectations and satisfaction*, *commitment to doing one's best*, *listening skills*, *sharing information and cooperating with co-workers*, *team working skills*, *adapting to changing work environments*, *customer orientation and focus*, *ethical decision making and behaviour* (Meier, Williams et al. 2000), *oral and written communication skills*, *interpersonal skills with colleagues and clients*, *capacity to analyse and solve problems*, *ability to develop new or innovative ideas, directions, opportunities or improvements*, *time management skills*, *capacity for co-operation and teamwork*, *ability to apply knowledge in the workplace*, *ability to cope with work pressure and stress* and *capacity to learn new skills* (Nair, Patil et al. 2009) and *managing people* (Carvalho and Tonini 2017). Discrepancies between the transversal competencies acquired at university and the workplace were found in Brunhaver, Korte et al. (2018). In this study, young engineers reported they learned transversal competencies, such as *communication skills*, *working with people* and *time* *management skills*, more on the job than at university. These studies show that engineering universities are not meeting the needs of industry when it comes to transversal competencies.

3.2.2. Transversal competencies in engineering

As mentioned in the previous chapters, many changes occurred in engineering education around the world in the last decades and many studies have highlighted the importance of transversal competencies for the success of future engineering graduates. In the study conducted by Scott and Yates (2002), 20 graduates and 10 supervisors from different engineering fields were asked to rate the most important capabilities for the successful practice of young engineers. The top selected capabilities were: *being able to develop and contribute positively to team-based projects*, *being willing to face and learn from errors and listen openly to feedback*, *being able to organize work and manage time effectively* and *understanding own personal strengths and limitations*. Another study in Australia (Nair, Patil et al. 2009) has identified *oral and written communication*, *capacity to learn new skills*, *capacity for cooperation and teamwork* and *interpersonal skills with colleagues and clients* as the most important attributes within a list of 23 attributes according to the perspectives of 109 employers. Again, in Australia, Male, Bush et al. (2011) have focused on which competencies engineering graduates need for future work careers from the perspective of experienced engineers. Similar competencies (i.e., *communication*, *working in diverse teams* and *self-management*) to the two previous studies have emerged from the responses of 300 participants.

To orient academics in the selection of what competencies to integrate into the curriculum, Passow and Passow (2012) have investigated the importance of the ABET competencies in the professional career of alumni undergraduates in the Midwestern University's College of Engineering, USA. A top cluster that contained competencies such as *teamwork*, *communication*, *data analysis*, and *problem-solving* have emerged from the data. Two other studies in the USA have surveyed stakeholders. In the study of Meier, Williams et al. (2000) at Illinois State University, 415 business managers rated the importance of 54 competencies to engineers. Competencies including *committed to doing their best*, *customer expectations and satisfaction*, *listening skills*, *appreciating punctuality*, *timeliness and deadlines*, *planning work to complete projects on time*, *team working skills*, *complex problem solving* were considered important. The study of Brumm, Hanneman et al. (2006) on 14 competencies and 61 key actions at the Iowa State University has involved 212 employers, faculty members and students. Communication and teamwork were likewise important competencies to engineering emerging in this study. Similar results were found in the systematic review of Passow and Passow (2017). A sample of 27 studies representing practising engineers, engineering faculty members and undergraduate alumni from different countries has identified *problem solving*, *communication* and *teamwork* as the top most important competencies for engineers followed by *ethics* and *lifelong learning*.

Also, studies in Europe have been interested to understand which competencies are important for future engineers. In the UK, 444 companies were involved in a study for the Royal Academy of Engineering (Spinks et al. 2006). *Communication*, *teamwork*, *business and commercial competencies*, *creativity* and *innovation* were required by stakeholders. In Saunders-Smits and de Graaff (2012), aerospace engineers were asked to rate the importance of 12 competencies for their current jobs as engineering specialists and engineering managers. On top of the most important competencies were *problem-solving skills*, *analytical skills*, *ability to synthesise*, *written and oral communication skills*, *the ability for lifelong learning* and *the ability to work in teams* (Saunders-Smits and de Graaff 2012).

Although literature focuses on the important transversal competencies, they present issues: competencies lack definitions as evidenced in the systematic review carried out in *Chapter 2* and are contextualised to the purpose of the investigation (Carthy et al. 2019). This raises issues in the interpretation of the results, i.e., if two papers mentioned that *"communication*" is the most important transversal competency for an engineer to possess, they might not mean the same thing, as the definition of communication is subjected to a context and is conceptually dense. To solve this issue, competency definitions and descriptive criteria should be provided as mentioned in *Chapter 2* or transversal competencies should be stratified into more nuanced skills as suggested by Carthy et al. (2019). Another issue pointed out by Carthy et al. (2019) is the use of Likert scales as an equal measures scale and the use of the results as objective. For instance, what does it mean when *problem solving* is rated 4 (in a 1-5 Likert scale) and teamwork is rated 3?

In this thesis, the *COMPetency Instrument* (COMπ) is presented to address these issues. COMπ 1) defines the transversal competencies, 2) stratifies them into more nuanced competencies and 3) presents a less subjective measure as the Likert scale is replaced by a descriptive scale. Although none of these individual characteristics is new, in this thesis they are combined into one coherent holistic instrument that can be used to measure perceptions of transversal competencies of industry representatives and lecturers.

3.2.3. Development of a transversal competency instrument

COMπ is based on the existing transversal competency model of Siemens, the Netherlands, a partner in the PREFER project. This model was used as a starting point because it is used to assess employees' skills and personal development, and reduce the limiting factor to the assessment of transversal competencies highlighted by Markes (2006) that mentioned that universities and non-academic establishments create overwhelming lists of transversal competencies without collaborations between each other. In this case, the literature review of the previous chapter as well as the literature study of Purzer, Fila et al (2016) provided an overview of the five holistic transversal competencies used in the measurement methods of the academic literature which was used to compare to the list of competencies of the Siemens model, used in COMπ, to avoid possible bias resulting from a single model. Although some differences were spotted, e.g. absence of literacy skills in the Siemens' list, COMπ was used as the original instrument because it was a comprehensive list already used to assess skills throughout Siemens, a worldwide employer of engineers.

COMπ divides competencies into five domains or holistic competencies (entrepreneurial, innovation, teamwork, communication and lifelong learning) as the Siemens model (Table 3). The first domain, *entrepreneurial competencies* (7 items), consisted of competencies related to managing and leading people to achieve goals as well as awareness of markets, finances and business opportunities. The second domain, *innovation competencies* (7 items), is defined by items that lead to the generation of ideas and solutions, including thinking critically and solving problems as well as taking into consideration stakeholders and costs. The third domain, *communication competencies* (9 items), covers oral and written communication and interpersonal skills necessary to convey information and influence audiences. The fourth domain, *teamwork competencies* (8 items), is characterized by the ability to work in groups and teams related to the well-functioning of a team. The last domain, *lifelong learning competencies* (5 items), is defined by self-regulation, adapting performance and search for continuous improvement.

A rubric for each competency with three descriptive mastery levels (basic, advanced, and expert) was copied from the Siemens model and an ‘absent’ level was added as engineering students and graduates may not be as competent in skills yet as engineers in later career stages (Appendix F).

3.3. Methods

This section is divided into three phases: COMπ described in the previous section is used (1) to find out what the desired transversal competency levels and the most important transversal competencies of graduates are according to industry, (2) to map the transversal competencies in the course learning outcomes of a BSc and a MSc programme at a Dutch university of technology and (3) to investigate the transversal competency levels that lecturers perceive their students acquire in their courses and which educational practises and methods lecturers use to address the transversal competency levels.

3.3.1. Phase 1: European industry exploration

a. Questionnaire structure

The questionnaire was structured in three parts. The first part was designed to collect personal data about the participants such as name, company, job position and years of working experience, to describe the sample. The second part required participants to rate the 36 transversal competencies in the five domains of COMπ on the levels of mastery they perceive students in engineering should fulfil at BSc and MSc graduation. The last part of the questionnaire asked participants to indicate the three most important transversal competencies in the five domains that students in engineering should hold at MSc graduation. The full COMπ was provided to industry to rate the required levels for graduates, while to indicate the most important competencies industry was given only the transversal competencies of COMπ with their definitions.

Table 3 – COMπ with five domains (entrepreneurial, innovation, teamwork, communication and lifelong learning) and competency definitions.

Domain	Competencies	Definitions
Entrepreneurial	1- Technology benchmarking	Demonstrates awareness of market drivers, emerging technologies, competitions, pricing and customer needs, regulations and standards.
	2- Financial awareness	Demonstrates awareness of financial capital (funding, cash flow, taxes, wages, etc.).
	3- Business acumen	Identifies business opportunities and applies business modelling and problem solving to implement strategic responses.
	4- Negotiation skills	Demonstrates knowledge of negotiation methods and negotiates under risk, long-term and international business environments.
	5- Project management	Plans, controls and orients strategies, and instructs and coordinates people.
	6- Leadership	Provides guidance, instruction, direction, and leadership to a group and is considered charismatic among members.
	7- Risk tolerance	Withstands risk and overcomes failure learning from it.
Innovation	8- Stakeholder management	Demonstrates knowledge about stakeholders' needs, concerns, and desires.
	9- Value/cost consciousness	Demonstrates awareness of project values and costs when creating, designing, implementing and operating it.
	10- Curious for innovation	Demonstrates curiosity to identify and to explore innovative ideas/products/services which give market value.
	11- Problem solving	Identifies problems and estimates risks, evaluates the different options and weights the alternatives.
	12- Critical thinking	Considers issues, develops strategies to overcome obstacles, estimates their risk, and implement solutions.
	13- Ideation	Uses creative tools and processes, and others' advice to create functional new ideas or to improve existing ideas.
	14- Idea implementation	Implements activities which enable creative ideas to move from the design to the marketplace.
Communication	15- Presentation method	Develops presentation methods and mediums depending on topic and target group.
	16- Presentation skills	Gives a clear, organized and logical speech and answers questions adequately and with elaboration.
	17- Adaptive communication style	Communicates properly, adapting style and language to the purpose, context, and environment.
	18- Self-confidence	Possesses confidence in formal and informal settings and maintains eye contact with the audiences.
	19- English language skills	Has fluency in the English language.
	20- Listening skills	Listens and understand verbal messages, and consequently acts on what someone says or does.
	21- Writing skills	Develops a logical, accurate, detailed, and organized report/paper without grammar mistakes and with accurate references.
	22- Interrelation ability	Builds and retains formal and informal relationships or networks.
	23- Pitching skills	Conveys and persuades audiences within a short time speech (1-3 minutes).
Teamwork	24- Cross-cultural understanding	Understand cultural differences, recognizes their importance or benefit and stimulates cooperative teamwork among people of different cultures.
	25- Interdisciplinary thinking	Collaborates with team members of engineering disciplines and of other disciplines, and clients.
	26- Goal setting	Establishes goals balancing self and team interests.
	27- Collaborative goal-oriented	Demonstrates a collaborative working spirit towards common goals.
	28- Engagement in teamwork	Shares information and knowledge with team members and shows engagement with teamwork.
	29- Giving constructive feedback	Gives constructive feedback to improve team members' performance.
	30- Time management	Prioritizes, determines tasks, schedules appointments, allocates team roles and meets deadlines.
	31- Managing conflict	Manages conflicts between team members by stimulating healthy debates to reach agreements.
Lifelong Learning	32- Strengths and weaknesses awareness	Possesses awareness of strengths and weaknesses, and seeks constant self-knowledge.
	33- Professional role awareness	Possesses awareness of personal and professional needs and of professional engineering roles.
	34- Actively seeking learning	Recognizes responsibility for own learning and seeks and develops strategies and practices to increase learning.
	35- Autonomous work	Works and studies with autonomy, has responsibility for tasks, manages projects and supervises people.
	36- Extracurricular activity participation	Participates in volunteering activity or paid work (non-credit giving) which involve responsibility

b. Sample and data collection

European companies and individuals were approached to include engineers, managers and HR representatives who hire or work with graduate engineers with different working years of experience belonging to small, medium and large enterprises. They were selected as stakeholders because they best know the work performed by young engineers. Approximately 70 invitations for participation were made through the project partners' networks. A total of 28 (40%) responses from different engineering disciplines (38% of Mechanical, Aeronautical and Manufacturing Engineering, 35% of Engineering and Technology, 11.6% of Material Science, 7.7% of Chemical Engineering and Life Sciences, and 7.7% of Petrochemical & Energy) based mainly in Northern Europe were received and used.

c. Data analysis

The descriptive statistics (means and standard deviation) of the required mastery levels of BSc and MSc graduates rated by the industry for the 36 transversal competencies were calculated to answer the first sub-research question. A Wilcoxon signed-rank test was carried out to evaluate the differences between the BSc and MSc mastery levels for each transversal competency. The distinction between BSc and MSc graduates was explored as differences between the labour market entrance exist, for instance engineering students in the USA and UK are more likely to go to the labour market with a BSc degree than to continue to the MSc degree as in European countries such as the Netherlands and Portugal.

Significant differences were considered for p-values smaller than 0.05. The effect size, r, was calculated using: $r = Z/\sqrt{N}$ (Field 2009). Values of r = .10, .30, and .50 refer to a small, medium, and large effect, respectively (Field 2009).

To answer the second sub-research question, a score ranging from 3 to 1 was assigned to the top 3 of the most important transversal competencies perceived by the industry for MSc graduates within each domain and the summed values were normalised with respect to the maximum number obtained. *Critical* thinking was left out from the domain innovation by mistake, so respondents could not select it as an important competency.

3.3.2. Phase 2: Course mapping against transversal competencies

Phase 2 and 3 were conducted in the 3-year BSc aerospace engineering degree and the 2-year Aerospace Structures and Materials MSc-programme at Delft University of Technology to check whether the transversal competencies present in COMπ were included in an educational setting. Phase 2 investigated the extent to which these programmes address the 35 transversal competencies listed (the competency *non-credit activity participation* was left out because it referred to activities outside of the curriculum and did not make sense in the context of this part of the study), i.e. which transversal competencies, if any, were included as learning outcomes. To do so, the author and her co-promotor went through the study guide (Delft University of Technology) listing all BSc and MSc courses and individually analysed the stated learning outcomes against the 35 transversal competencies. During the analysis, it was assumed that a learning outcome could be interpreted as including more than one competency that was not explicitly stated. Three concrete examples are given to show how the analysis was conducted:

LO1: "Being able to reflect on personal functioning in an evaluation report: reflect on personal objectives, indicate personal strengths/weaknesses. Indicate future personal improvement, drawing conclusions for future career."

Transversal competencies included: self-knowledge awareness, professional role awareness, and writing skills.

LO2: "Present work performed in a structured way through an oral presentation to their peers and wider audience."

Transversal competencies included: quality of presentation method, presentation skills, and adaptive communication style.

LO3. "Execute the project controlling the process, effectively using the plan."

Transversal competencies included: Project management, goal setting, and time management.

Cohen's kappa was calculated to see if there was an agreement between the two researchers' judgements (McHugh 2012). There was almost perfect agreement, $k = 0.931$, $p < 0.05$.

3.3.3. Phase 3: Transversal competencies in the BSc and MSc engineering programmes according to lecturers

Because in the previous phase the course learning outcomes reported only a few transversal competencies, it was suspected a gap between the formal curriculum (i.e., *intentions as specified in curriculum documents and materials* (van den Akker, Kuiper et al. 2003)) and the perceived curriculum (i.e. *curriculum as interpreted by its users* (van den Akker, Kuiper et al. 2003)) existed. I.e., that students were practising competencies in courses that are not formally specified in the learning outcomes of the courses by the lecturers in the study guide. Hence, a questionnaire was sent out to all course instructors of both programmes to ask them which transversal competencies they think their students acquire/practise in the courses they teach and supervise and to what level. This questionnaire contained the same 35 transversal competencies as in phase 2 with the four descriptive levels (i.e. the whole COMπ minus the competency *non-credit activity participation*). Responses covered 30 out of 39 courses in the BSc degree (in total accounting for 150 ECTS with 30 ECTS of electives excluded) and 30 out of 34 courses in the MSc degree (18 mandatory and 16 elective courses accounting for 120 ECTS). Two programme components: the BSc capstone design and the MSc thesis project were analysed separately, as these are not courses but proof of mastery and most lecturers (in their role of supervisor) gave a response about the transversal competencies in these projects (25 and 30 respectively). The transversal competency levels perceived by lecturers were listed on an Excel spreadsheet and medians were extrapolated when more than one lecturer from the same course responded.

Next, the interest was to find out whether COMπ could also trigger the lecturers to reflect on concrete examples of how they perceive their students achieve the transversal competency levels. To do so, five lecturers were interviewed by the author. The criteria to select these participants were: 1) they must be lecturing both BSc and MSc courses, 2) supervise as a minimum either the capstone BSc course or the MSc thesis project, 3) work in different departments within the faculty, 4) have different levels of academic experience and academic position and 5) gender. The final sample was composed of 1 woman and 4 men among them 1 assistant, 3 associate and 1 full professor. They stemmed from 3 of the 4 different departments, lecture 2 to 7 courses each and have 9 to 33 years of academic experience.

The individual semi-structured interviews were conducted via *Skype for Business*™. The author shared a selection of transversal competencies from COMπ and the corresponding levels indicated by the lecturers in the questionnaire phase. Fourteen transversal competencies were selected in this phase: the common transversal competencies present in the top 10 highest and 5 lowest mastery levels indicated by the industry for BSc and MSc graduates (*actively seeking learning*, *strengths and weaknesses awareness, risk tolerance*, *time management*, *listening skills*, *writing skills*, *interdisciplinary thinking*, *financial awareness*, *negotiation skills*, *leadership*, *ideation* and *idea implementation*) and *problem-solving* and *critical thinking*, which are considered key transversal competencies for engineers but were only present in the top 10 highest mastery levels for MSc students. A set of questions was prepared and written in a script in advance and used to guide the interviews.

The 1-hour interviews were audio-recorded in *Skype for Business*™ and transcribed verbatim in Happyscribe. This software gives Word documents with the transcripts. However, they contain errors and inaccuracies that needed to be corrected. For this reason, the author listened to the interview recordings and confirmed the text in the Word documents and made corrections to the mistakes and deleted commas in the wrong place as well as added in the right pauses. This step took approximately four hours per transcript but it was a useful step to remember what lecturers said.

During the data analysis, the author started to work with the whole transcripts. As indicated in Creswell (2009), the author read each transcript to get the first ideas and coded each of them one by one assigning a combination of predetermined codes (used in literature e.g. open-ended problems) and emerging codes (unexpected codes that emerged from the data) to parts of the text which the author felt they revealed examples of practices or methods used by the lecturers to stimulate students' transversal competencies. During this phase, the author found out that similar practices or methods were used by the lecturers to teach more than one transversal competency. So, the author built a table that linked transversal competencies to codes for a better overview of the codes and an easier way to report similarities in the data. Because some codes seemed similar but worded differently, the author extracted the chunks of text coded from every transcript and grouped them based on similar codes. At this stage, the author checked for similarities in the chunks of text to see whether the code should be the same and whether the right words were used to describe the codes. During this process, the author went back and forth to the chunks several times to make sure that the text accurately reflected the codes. Next, the author put the themes in clusters to create the categories and gave a description to explain why they were grouped. The author checked again all the chunks of text to make sure they were allocated to the right category. Finally, the author went back to the transcripts and re-read them to check if important examples of practices/methods used by the lecturers were missing.

Quotes are provided to explain themes that emerged from the analysis. They are between quotation marks and are associated with the correspondent lecturer named L1 to L5. The interview was piloted with one lecturer, who also participated in the questionnaire and teach at BSc and MSc levels. This was done to test the questions used in the interview, as well as to see if the interview would not become too long. It also allowed the interviewer to practice interviewing. The transcript from the pilot was reviewed by the researcher and discussed with two researchers with interviewing experience. From this discussion, it was concluded that more emphasis should be given to ask for more concrete examples rather than generic opinions and follow up questions rather than leaving the subject unfinished. Reflecting on the process, the selection of a set of competencies allowed the author to manage the time of the interview and avoid a cumbersome interview. The pilot helped the researcher to become more comfortable with the script and be less nervous during the interview, as well as less passive and ask to follow up questions. The author wrote down some follow up expressions such as *"could you elaborate on that"* in the script to help her during the next interviews. Only one pilot interview was conducted mainly because of time constraints.

3.4. Results

3.4.1. European industry exploration

The transversal competency levels industry requires from BSc and MSc graduates respectively can be found in Table 4. As expected and confirmed by a Wilcoxon signed-ranked test, MSc graduates require higher competency levels compared to BSc graduates ($p < 0.01$, Table 4). Moreover, large effect sizes ($r > 0.5$ (Field 2009), Table 4) were found for all transversal competencies indicating the importance of the findings.

Comparing the ten highest means of required mastery at BSc and MSc levels to each other (grey cells in Table 4), it can be observed that they share seven transversal competencies: *strengths and weaknesses awareness*, *listening skills*, *actively seeking learning*, *interdisciplinary thinking*, *time management*, *writing skills* and *risk tolerance*. Examples of transversal competencies which were in the top 10 with the highest mastery levels for MSc graduates and not for BSc were: *problem-solving*, *critical thinking* and *presentation skills* and vice-versa not present in the highest mastery levels for MSc but present for BSc were: *engagement in teamwork*, *collaborative goal-oriented* and *English language skills*.

Furthermore, mastery levels of BSc graduates in teamwork and communication competencies are higher than the mastery levels required for BSc graduates in innovation and entrepreneurial competencies (Table 4). For MSc graduates, besides reaching the expert level in communication and teamwork, the industry also requires higher levels of mastery in innovation competencies (Table 4).

It was also intended to find out in the exploratory research which transversal competencies are deemed most important for MSc graduates according to industry. The 10 most important competencies indicated by the industry was compared to the 10 highest mastery levels required by the industry for MSc graduates (Table 5). It is observed that *problem solving*, *actively seeking learning* and s*trengths and weaknesses awareness* are present in both top 10s. Interestingly, seven transversal competencies differ from the top most important competencies and those requiring the highest levels of mastery. Master graduates are expected to possess these most important transversal competencies but not at very high levels yet at graduation. On the other hand, Master graduates need to be very competent in the transversal competencies requiring the highest levels, however, other competencies are considered more important by the industry.

3.4.2. Transversal competencies and mastery levels acquired and practised in BSc and MSc courses

a. Course mapping against transversal competencies

The mapping of the published learning outcomes of the courses in the study guide (Delft University of Technology) of each programme against the transversal competencies and mastery levels indicated that transversal competencies are rarely explicitly specified in the learning outcomes of the BSc and MSc courses of the aerospace engineering programme. Only 27 out of 61 courses (11 in BSc and 16 in MSc) reported at least one transversal competency in their learning outcomes, with 21 courses covering only 4 out of the 36 transversal competencies of COMπ. These limited results led to the investigation of a possible gap between the formal and perceived curriculum (van den Akker, Kuiper et al. 2003), where lecturers perceive that their students practise transversal competencies but do not make the transversal competencies explicit learning outcomes in their course description in the study guide. Hence, lecturers were surveyed to identify which transversal competencies they feel their students practise in each of their courses and to what level.

b. Transversal competencies in the BSc and MSc programmes according to lecturers

The suspicion about the gap between the formal and perceived curriculum (van den Akker, Kuiper et al. 2003) was confirmed by the results of the questionnaire. According to lecturers, 95% of the BSc and MSc courses addressed at least 5 transversal competencies listed. This means that lecturers feel their students practise transversal competencies in their courses even though they do not include them in the official learning outcomes.

The lecturers' perceptions of the mastery levels of the 35 transversal competencies that students practise in 30 out of 39 mandatory BSc courses, including the BSc capstone design project which is listed separately, compared to the transversal competency levels required for BSc graduates according to the industry are shown in Figure 4. For the MSc degree, the lecturers' perceptions of the mastery levels of the 35 transversal competencies that students practise in 15 mandatory and 14 elective courses and the individual Master's thesis were analysed. The transversal competency levels indicated by the lecturers for the mandatory and elective courses compared to the transversal competency levels required for MSc graduates according to the industry are shown in Figure 5.

Table 4 – Differences between BSc and MSc competency levels. z-score: z, p-value: p (significant level p < 0.01), and effect size: r. Grey cells represent the ten highest mean competency levels for BSc and MSc, respectively, and asterisks indicate the transversal competencies which require advanced levels (Median = 3).

Competencies		Wilcoxon signed-rank test								
		Median		Mean		SD		z	p	r
		BSc.	MSc.	BSc.	MSc.	BSc.	MSc.			
Entrepreneurial	Technology benchmarking	1	2	1.04	1.89	.53	.50	-4.60	< .01	.9
	Financial awareness	1	1	.58	1.36	.58	.56	-4.38	< .01	.9
	Business acumen	1	2	1.08	1.82	.63	.86	-3.88	< .01	.8
	Negotiation skills	1	1.5	.65	1.46	.69	.69	-4.30	< .01	.8
	Project management	1	2	1.31	2.25	.55	.65	-4.73	< .01	.9
	Leadership	1	2	.81	1.61	.69	.83	-4.58	< .01	.9
	Risk tolerance *	2	3	1.77	2.46	.82	.64	-3.82	< .01	.7
Innovation	Stakeholder management	1	2	1.12	1.89	.59	.57	-4.38	< .01	.9
	Value/cost consciousness	1	2	1.19	2.07	.49	.60	-4.41	< .01	.9
	Curiosity for innovation	1	2	1.38	2.14	.57	.45	-4.47	< .01	.9
	Problem solving *	2	3	1.62	2.57	.64	.57	-4.13	< .01	.8
	Critical thinking	1	2	1.46	2.43	.51	.50	-4.73	< .01	.9
	Ideation	1	2	1.04	2.07	.60	.60	-4.51	< .01	.9
	Idea implementation	1	2	.81	1.64	.63	.62	-4.38	< .01	.9
Communication	Quality of presentation method	2	2	1.68	2.21	.55	.42	-3.74	< .01	.7
	Presentation skills	1	2	1.50	2.36	.58	.62	-3.23	< .01	.6
	Adaptive communication style	2	2	1.62	2.14	.64	.45	-3.5	< .01	.7
	Self-confidence	2	2	1.54	2.11	.76	.63	-3.42	< .01	.7
	English language skills	2	2	1.73	2.18	.60	.39	-3.46	< .01	.7
	Listening skills	2	2.5	2.00	2.46	.63	.58	-3.46	< .01	.7
	Writing skills *	2	3	1.81	2.50	.69	.58	-4.12	< .01	.8
	Interconnection/ interrelation ability	1	2	1.27	2.04	.72	.43	-3.88	< .01	.8
	Pitching skills	1	2	1.35	2.00	.69	.54	-3.82	< .01	.7
Teamwork	Cross-cultural understanding	2	2	1.58	2.25	.70	.59	-4.03	< .01	0.8
	Interdisciplinary thinking *	2	3	1.96	2.71	.66	.46	-3.88	< .01	0.8
	Goal settings	2	2	1.62	2.29	.50	.46	-4.24	< .01	0.8
	Collaborative goal-oriented	2	2	1.77	2.14	.43	.45	-3.16	< .01	0.6
	Engagement in team work	2	2	1.81	2.18	.49	.48	-3.16	< .01	0.6
	Giving constructive feedback	1	2	1.58	2.11	.64	.57	-3.74	< .01	0.7
	Time management	2	2	1.85	2.32	.46	.55	-3.46	< .01	0.7
	Managing conflict	2	2	1.62	2.04	.64	.58	-3.46	< .01	0.7
Lifelong Learning	Strengths and weaknesses awareness *	2	3	2.15	2.79	.73	.50	-3.82	< .01	0.7
	Professional role awareness	1	2	1.42	2.11	.58	.69	-4.15	< .01	0.8
	Actively seeking learning *	2	3	1.88	2.64	.65	.56	-4.30	< .01	0.8
	Autonomous work	2	2	1.50	2.11	.58	.57	-4.00	< .01	0.8
	Non-credit activity participation	1	2	1.04	1.50	.72	.84	-3.36	< .01	0.7

Table 5 - Comparison of the 10 most important transversal competencies with the 10 highest mastery levels required by the industry for MSc graduates.

TOP	Importance	Mastery level
1	Actively seeking learning	Strengths and weaknesses awareness
2	Strengths and weaknesses awareness	Interdisciplinary thinking
3	Problem solving	Actively seeking learning
4	Autonomous work	Problem solving
5	Project management	Writing skills
6	Curious for innovation	Listening skills
7	Engagement in teamwork	Risk taking
8	Technology benchmarking	Critical thinking
9	Collaborative goal-oriented	Presentation skills
10	Adaptive communication style	Time management

Looking at figures 4 and 5, it is interesting to see that according to the combined opinion of the lecturers surveyed, graduates are taught to at least the level required by the industry in at least one but often more courses. This is in sharp contradiction to the low number of transversal competencies listed as official learning outcomes. It also raises questions on whether these transversal competencies that are perceived by lecturers to be practised by students are (appropriately) assessed and whether students are aware that they are being taught these transversal competencies let alone being assessed on their mastery.

What was also apparent from the questionnaire is that COMπ assisted lecturers to reflect on the level at which transversal competencies are being practised and taught in their courses. It is impossible from these findings to state whether the transversal competencies are sufficiently taught in the complete curriculum. For that much more in-depth research into curriculum content is necessary.

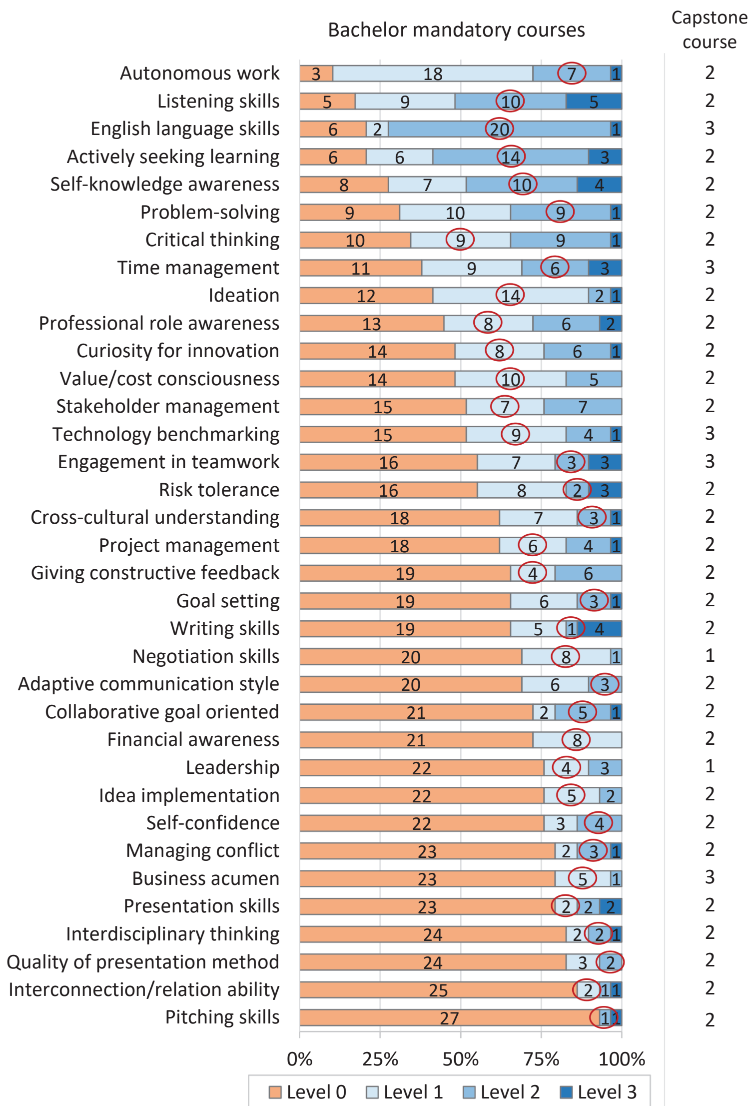

Figure 4 - Mastery levels of 35 transversal competencies that students practise perceived by lecturers in 30 of the 39 mandatory BSc courses. Circles represent the mastery levels required for BSc graduates according to industry.

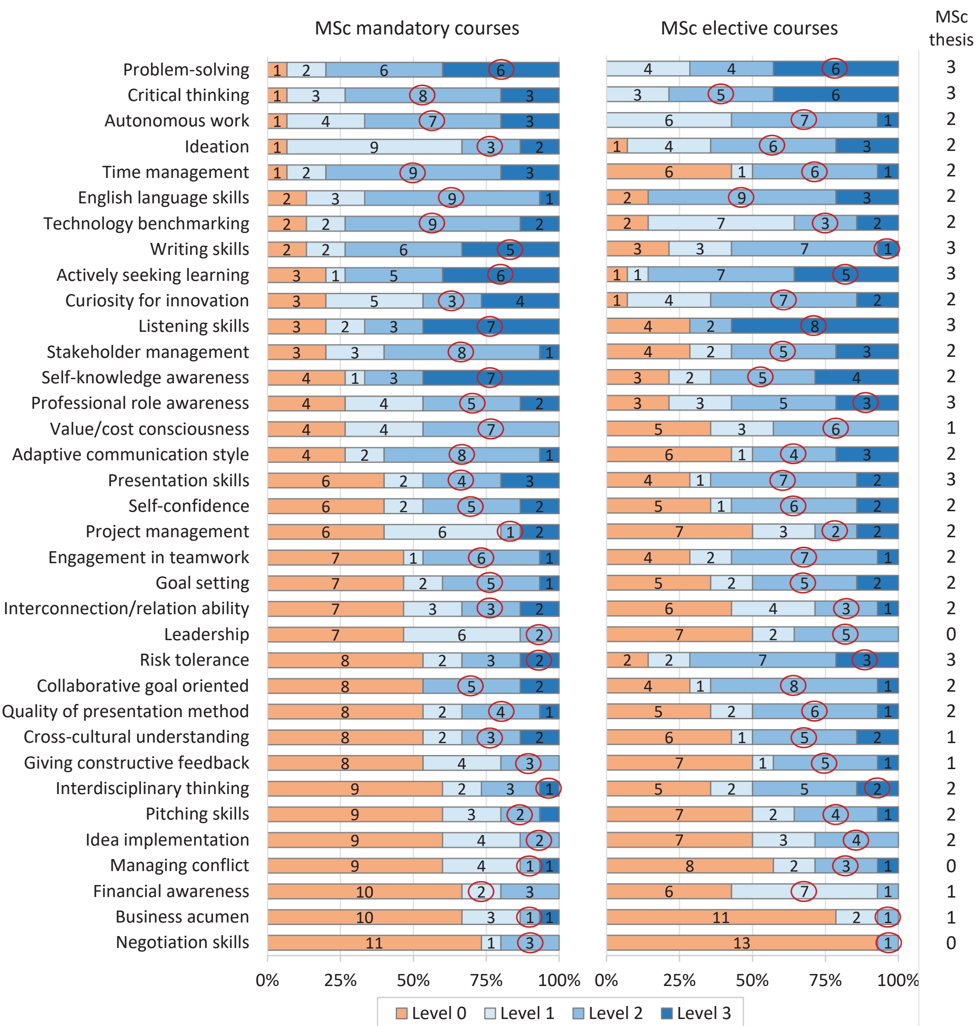

Figure 5 - Mastery levels of 35 transversal competencies that students practise perceived by lecturers in 30 (16 mandatory and 14 elective) of the 35 MSc courses. Circles represent the mastery levels required for MSc graduates according to industry.

3.4.3. Educational practises and methods to address transversal competencies

To further investigate the suitability of COMπ for lecturers to map and assess transversal competencies, five lecturers were interviewed. Four categories: (C1) problem-solving, (C2) teaching activities, (C3) coaching and (C4) student-centred activities emerged from the analysis of the interviews on the lecturers' perspectives on how students reached the levels required by the industry in the following transversal competencies: *problem-solving*, *critical thinking*, *actively seeking learning*, *strengths and weaknesses awareness*, *risk tolerance*, *time management*, *listening skills*, *writing skills*, *interdisciplinary thinking*, *financial awareness*, *negotiation skills*, *leadership*, *ideation* and *idea implementation*. The most prominent themes were grouped under one category as shown in Moreover, because of time and resources constraints, lecturers perceived that students reach the minimum level indicated by the industry in *idea implementation* (even though they did not implement the idea generated) if students prove that their idea is feasible. L5 expressed this as follows:

> *"So, the idea implementation in the DSE, once they have an idea and they've narrowed down to a concept* […] *and really check the feasibility of it. They need to do the calculations to show that it is indeed feasible that if someone would take that further into manufacturing and flying that would be feasible."*

3

Table 6. The findings of the interviews indicate that COMπ triggers lecturers to reflect on the practices and methods they use to reach the transversal competency levels that the industry required for engineering graduates.

C1 - Problem-solving: Themes in this category relate to the nature of problems lectures give to students and the process used to solve them.

Lecturers identified they used multiple types of problems from well-defined to open-ended, ill-defined and authentic real-world problems to develop the following competencies present in COMπ *problem-solving*, *critical thinking*, *ideation*, *idea implementation* and *negotiation skills*. When presented with the list of transversal competencies selected from COMπ and their levels, lecturers were encouraged to specify how these competencies are practised in their courses. They mentioned that when solving these problems with multiple possible solutions, students go through a learning cycle in which they are given a challenge (problem, scenario or case) with or without requirements to be fulfilled, they have to brainstorm and generate ideas, assess and mitigate their risks and converge to one idea which they have to justify their choices, prove its feasibility and verify and validate the results so that it can be implemented. An example of how COMπ triggers L3 to reflect on how he addresses *ideation* is:

> *"So, they reach level two because […] they find out the gaps that exist in the literature and they have to be creative to address those gaps during their thesis."*

Lecturers also identified with COMπ that students practise *strengths and weaknesses awareness* and *actively seeking learning* when students are confronted with the formulation of problems because they need to define the gaps existing in the literature and evaluate different options. L4 expresses this as:

> *"They end up doing a, taking stock of where their own gaps in skills and abilities relevant for their thesis are and they realize that they have to catch up."*

Also, in the process of problem-solving, lecturers reflected on the practice of *risk tolerance* and *financial awareness*. This is shown by L1 in the following statements:

> "*It was a bit of difficulty choosing between level two and level three, but a risk analysis, a risk assessment and risk mitigation is an integral part of the DSE. We want that in the early design phase, but also in a detailed design phase* […]. *That's why I chose more than level two.*"

> "*Well, we require them to make a cost analysis and give it some thought. Really at the minimum level. I'd say little awareness of financial capital, cash flow, etc.*"

Moreover, because of time and resources constraints, lecturers perceived that students reach the minimum level indicated by the industry in *idea implementation* (even though they did not implement the idea generated) if students prove that their idea is feasible. L5 expressed this as follows:

“So, the idea implementation in the DSE, once they have an idea and they've narrowed down to a concept […] *and really check the feasibility of it. They need to do the calculations to show that it is indeed feasible that if someone would take that further into manufacturing and flying that would be feasible.”*

Table 6 - Analysis of lecturers’ perspectives on how students reached the levels required by the industry in the following competencies of COMπ: problem-solving, critical thinking, actively seeking learning, strengths and weaknesses awareness, risk tolerance, time management, listening skills, writing skills, interdisciplinary thinking, financial awareness, negotiation skills, leadership, ideation and idea implementation.

	Categories	Themes
Lecturers ‘perspectives	C1: Problem-solving	Type of problems
		Formulate problems
		Brainstorm and generate ideas
		Assess and mitigate risk
		Develop and evaluate solutions
		Show feasibility of ideas
		Verify and validate findings
		Implement ideas
		Defend/Justify choices
		Analyse cost
	C2: Teaching activities	Lecturing
		Homework
		Reports
		Exams/tests
		Assignments
		Quizzes
		Exercises
		Interviews
	C3: Coaching	Feedback
		Asking questions
		Reflection
		Help/guidance
		Role-play
		Availability
	C4: Student-centred activities	Work independently
		Responsibility
		Interaction with people
		Mix of expertise
		Plan
		Roles
		Deadlines/milestones
		Appointments
		Tasks

However, in other courses lecturers indicated higher levels, as expressed by L5:

“Students are really implementing it and […] *from the ideation and the design phase they need to make it into a model or experiments and then get the conclusions out of it.”*

C2 - Teaching activities: this category focuses on the teaching activities lecturers recognised that they practise to address the transversal competency levels.

When presented the transversal competencies, lecturers mentioned they use lecturing to teach or create awareness of transversal competencies such as *critical thinking*, *ideation*, *financial awareness* and *writing skills*. Examples of these were:

"[We] explain a little bit the pros and cons [of the design choices] and how this goes in a design process." (L1)

"We talk about brainstorming sessions with also ideation phases, design thinking." (L1)

"I tell them, for instance, a little bit about how big aerospace projects are run, how the investments and the money within capital is needed." (L2)

"They have had previous training in written communication." (L1)

COMπ triggered also lecturers to identify homework and exams/tests as a method to develop students' *actively seeking learning*. An example of how L4 uses homework to address *actively seeking learning is*:

"They are assigned much more complicated practice problems and homework problems, and they really have to struggle and discuss with their peers about the solution approaches".

Lecturers also recognised that they use exams and tests to practise students' *time management* as reported by L4:

"To sort of facilitate that, we've tried to create some structure with the more frequent tests to create sort of a motivation to keep up with the study."

The same lecturer uses assignments to address *time management* too. In his course, students "*are on the clock*" (L4) to solve a 2-hour case study every week. Assignments also develop students' *critical thinki*ng, *problem solving*, *ideation and idea implementation* according to lecturers. L2 expresses how his students achieve *ideation* in the capstone BSc course as follows:

"In the DSE, I think it is a three because they are very creative. They have to come up with concepts. We give them an assignment where we do not have a solution. So, they have to sort out their own ideas and they have to work on that."

Lecturers were also able to reflect on other teaching activities. Lecturers use a system of peer feedback on the written reports to develop students' *writing skills*. L5 mentioned she uses anonymous live quizzes in large classes to address *listening skills*. L4 covers *negotiation skills* with teaching and practising interviewing skills.

C3 - Coaching: this category is concerned with the lecturers' role as facilitators of students' practice of transversal competencies.

Lecturers mentioned they use coaching when they have the role of supervisors in project-based courses and regular lecturing courses. They recognised that coaching helps students to acquire *problem solving* and *critical thinking* because lecturers guide how to address problems that emerge instead of giving the answers. Also, lecturers stated that they help students recognise and develop students' self-knowledge and learn from failure. In this way, they feel students practise *strengths* *and weaknesses awareness* and *risk tolerance*, respectively. L1 and L4 address these transversal competencies, respectively, as:

> "*I would just like to know what they think their strengths and weaknesses are (…) we can actually also try to work on strengthening the strengths, but also developing those weaknesses.*" (L1)

> "*The other aspect is failures. That is one I spent a lot of time coaching on because students are really upset if their hypothesis is wrong. So, you have to spend a lot of time in trying to separate them from their ego, in wanting to be right, to looking at, well, what can I actually learn from the fact that I wasn't right from the beginning. A lot of talking and sharing my own personal experience*." (L4)

Lecturers reflected that optional help sessions (sometimes also taught by teaching assistants), where students can discuss doubts about exercises, can develop students' spirit of looking for more knowledge (i.e., *active seeking learning*).

Lecturers also identified questioning as a practice to address *problem solving*, *critical thinking* and *actively seeking learning*. Lecturers ask questions to students before and after solving problems to encourage exploration of meaning, consequences and applications of solutions and to guarantee and check understanding. The following statements express how L5 addresses *critical thinking* and *listening skills*, respectively:

> "*And once we have done that step, ask them basically like, does this make sense? Or what we also do is even before we start that step is by looking at the structure, what do you think should be the answer before you actually start calculating?*"

> "*I always ask questions whether they understood, so trying to have them rephrase what I said, for instance, just to make sure.*"

When presented with the competency *interdisciplinary thinking* of COMπ, lecturers stated they use the interaction with clients (real or role-played by supervisors) in project-based courses to practise this competency.

Feedback on students' efforts, skills and learning was also identified as a practice by lecturers to develop students' *listening skills*, *actively seeking learning* and *leadership*. An example of how L4 addresses *leadership* is:

> "*After each of these activities* [case-studies] *every week we focus, we do a debrief and we focus not on their outcome, but on the process and what went wrong, where, you know, was their communication issues, was their direction issues and identify the barriers to them working as a team and discuss strategies that a leader could use to circumvent those challenges.*"

Another theme that arose from the interviews was lecturers' availability which develops students' *actively seeking learning*. L3 reflects on his own practice and mentions he creates specific timeslots e.g., at the end of the class and some hours during the weeks before the exam so that students can come and ask questions and he encourages students to ask questions by email, especially in large classes where often there is no time in the class or students feel too intimidated to ask questions in front of their peers.

C4 – Student-centred activities: This category relates to students' tasks and interaction with people when they work individually or in teams.

Lecturers mentioned that students develop *actively seeking learning* and *time management* by giving them responsibility and autonomy. This spirit of responsibility and working independently is stimulated in the assignments and exams and tests with fixed and strict deadlines to be fulfilled by the students as well as in the MSc thesis in which students need to set their own milestones because "*there are no real deadlines*" (L5). According to lecturers, *time management* is also achieved at high levels when assignments are built without a predefined plan, roles and tasks and preliminary appointments so that students have to be independent and responsible for that. L5 expresses this as follows:

> *"So, they could basically structure that themselves in terms of time management. They were able to identify the tasks because we didn't give the tasks to them. So, they need to figure out what they needed to do in order to get to the final aim. And that's what we expected. They could reach us if they wanted to. So, they could schedule an appointment with us, but they didn't use that too often. So, that's why I put it at a two rather than a three."*

When presented with competency *leadership*, most of the lecturers mentioned that students have different leadership roles and because of that they achieve different levels. Examples of these were:

> *"Not all of them [students] will take up a leadership role"* (L1)

> *"Actually, what you often see in the DSE team is, you see both level one and two, but I think the better ones can achieve two here. If you have a team of 10 students, then usually three or four will achieve level two and maybe two or three will stay at level one." (L2)*

However, L4 makes sure that all students reach the level required by the industry, as mentioned:

> *"I try and ensure that everybody within the team, at least for one of those weeks, has to take the role of the investigator in charge, the IIC, in a leadership role."*

Lecturers recognise that working in groups and working with external advisors is beneficial for students to recognise their strengths and weaknesses and thus develop *strengths and weaknesses awareness*. An example of how L3 reflects on how students achieve the highest level for *strengths and weaknesses awareness* with external advisors is:

> *"Their [external advisors] line of questioning is often different from the line of questions that we have at the university (…) they help also the students to be aware of what is what will be expected from them when they finish their studies and have to look for a job."*

Other lecturers stated that the interaction with experts should be used to look for knowledge, thus they recognised that students practise *actively seeking learning*.

Finally, lecturers indicated that students practise *interdisciplinary thinking* in teams (often arranged by lecturers) when there is the possibility to mix students from different backgrounds. In the curriculum, this happens in the capstone BSc project and in some elective courses of the MSc where students from more than one aerospace engineering track can attend. An example of L1 is:

"They have to integrate with all the aerospace disciplines and every now and also look beyond their borders and go into other fields, electrical engineering, but also management, maybe civil engineering."

3.5. Discussion

The main research question of the current chapter and *Chapter 4* was: "*What are the characteristics of a valid instrument that measures perceptions of transversal competencies in engineering education?"* To answer part of this question, COMπ was developed to address the limitations of the lack of transversal competency definitions and descriptive criteria, and validity measurements found in *Chapter 2*. COMπ is characterised by providing definitions for each transversal competency, dividing them into more nuanced competencies and presenting four descriptive scales. COMπ was then given to both industry and academic stakeholders to see if it was valid, i.e. can be used to measure perceptions transversal competencies. This will be discussed in the following sections.

3.5.1. European industry perspective

COMπ was used to find out the desired transversal competency levels of BSc and MSc graduates according to European industry. The findings showed a common agreement between the transversal competencies with highest levels for BSc and MSc graduates perceived by the industry, as seven transversal competencies: *strengths and weaknesses awareness*, *listening skills*, *actively seeking learning*, *interdisciplinary thinking*, *time management*, *writing skills* and *risk tolerance* were in the top 10 highest mastery levels for both. Nonetheless, small differences in the top transversal competencies of the highest levels exist. Transversal competencies in the top highest mastery levels of BSc graduates are perhaps expected to be mastered by the time they start the MSc degree. Hence, the emphasis shifts at the MSc level to different competencies that are possibly more advanced competencies. It seems that there is a natural order of development of competencies, i.e., students need to develop some transversal competencies first to be able to develop other competencies. For example, BSc students should reach high levels of *English language skills* to be able to successfully present their work and reach high levels for *presentation skills* required by the industry at MSc graduation.

The list of competencies of COMπ was also used to identify the most important transversal competencies for engineering graduates, which include *actively seeking learning*, *strengths and weaknesses awareness*, *problem solving*, *autonomous work*, *project management*, *curious for innovation*, *engagement in teamwork*, *technology benchmarking*, *collaborative goal-oriented* and *adaptive communication style*.

The new approach taken in this chapter, of investigating not only the important competencies for engineering graduates but also to look into the mastery levels required, makes direct comparison with previous studies in literature difficult as literature mainly focused on the most important transversal competencies. However, consistent with previous studies, *problem solving* (Meier, Williams et al. 2000, Saunders-Smits 2008, Male, Bush et al. 2011, Passow and Passow 2012, Passow and Passow 2017), *actively seeking learning* (Nair, Patil et al. 2009) and *strengths* *and weaknesses awareness* (Scott and Yates 2002) are ranked in the top of important transversal competencies and in this chapter, they were considered both the most important transversal competencies and requiring the highest levels.

Interestingly, the tops of the most important transversal competencies and the transversal competencies with the highest levels differ substantially. Transversal competencies present in both tops must be the focus of engineering institutions. Universities should expose students frequently to the transversal competencies which require high mastery levels from the start of engineering degrees so that students possess high levels when they graduate. The most important transversal competencies, not requiring high levels, should not be discarded but rather introduced at a later stage in the MSc degree where students have consolidated other transversal competencies and can be wide-open to more transversal competencies. Perhaps, they should be introduced at a later stage in the MSc degree where students have consolidated other transversal competencies and can be open to more transversal competencies. However, research needs to be conducted to investigate the potential relationships between the most important transversal competencies and the transversal competencies with the highest levels and how they complement one another.

In the research of the current chapter, *curious for innovation* and *technology benchmarking* were considered important transversal competencies. Similar findings were shown by Spinks, Silburn et al. (2006), where business and commercial competencies, creativity and innovation were requirements for future engineers according to stakeholders.

Communication as a whole (Spinks, Silburn et al. 2006, Passow and Passow 2012), or divided into sub-components such as written and oral communication (Saunders-Smits 2008, Nair, Patil et al. 2009) and listening skills (Meier, Williams et al. 2000, Scott and Yates 2002), was considered one of the essential transversal competencies for engineers' success. As described by Trevelyan (2010), young engineers spend a great part of their working time communicating in several forms such as writing, listening, having meetings and phone calls. Corroborating these findings are the fact that industry also requires high mastery levels in *listening skills*, *writing skills* and *presentation skills* for graduates, and the industry also thinks it is important that graduates can adapt their communication style.

Another competency recognised in previous studies (Meier, Williams et al. 2000, Scott and Yates 2002, Brumm, Hanneman et al. 2006, Spinks, Silburn et al. 2006, Saunders-Smits 2008, Nair, Patil et al. 2009, Male, Bush et al. 2011, Passow and Passow 2012) as very important for engineering graduates is *teamwork*. In the present chapter, *collaborative goal-oriented* was also considered a key competency and it should already be mastered during the BSc. The importance of *working in diverse teams* was identified by employers in Male, Bush et al. (2011) and in this chapter, this competency (called *interdisciplinary thinking*) was pointed out by the industry as requiring high levels for BSc and MSc graduates.

More advanced transversal competencies, such as *idea implementation*, *stakeholder management*, *leadership*, *negotiation skills*, *financial awareness* and *activity participation* were considered less important and lower levels of mastery were required. This could be an indication that less focus by the university may be given to them. Perhaps, students are not expected to develop them at university but at a later stage in their life, when they have already entered the labour market and are working as engineers.

3.5.2. Transversal competencies required by the industry addressed in the BSc and MSc programmes

The usability of COMπ was also evaluated by mapping transversal competency learning outcomes against reported learning outcomes in formal course documentation and by asking lecturers to use COMπ to indicate at which transversal competency levels they expose students to in their courses. A shorter version of COMπ with 16 transversal competencies was also used to trigger lecturers to reflect on the practices and methods they use in their courses to reach the transversal competencies required by the industry. The findings showed that COMπ was suitable to map transversal competency learning outcomes against reported learning outcomes in formal course documentation and for lecturers to map transversal competencies in their courses. When comparing the mapping of the formal transversal competency learning outcomes of each course in the BSc and MSc curricula studied to the mapping by lecturers of the transversal competencies, they feel they teach in their courses, a gap between the formal and perceived curriculum was revealed. This gap itself is not new and was identified by van den Akker, Kuiper et al. (2003). In the context of the research in this chapter, lecturers perceived students practised more transversal competencies in their courses than lecturers themselves wrote down as formal course learning outcomes. Consequences can arise when the content of the courses is not properly highlighted in the learning outcomes. First, students do not know what they can learn from each course and may not even feel they were taught a particular competency. Second, students have insufficient information to make informed decisions when they need to select courses. Third, students can legally not be assessed on the outcomes that are not listed in the study guide nor can quality control take place on whether the transversal competencies are taught to a specified level. Next, if it is unclear what transversal competencies are taught to what level in each course, it may be hard to prove to accreditation boards that the transversal competencies in question are taught to the level specified. Furthermore, not making the transversal competency learning outcomes' explicit can result in the delivery of such outcomes being dependent on the individual lecturers and consequently, there may be incoherency in terms of the range and levels achieved by students during their degree. Finally, another vulnerability here is that when courses change lecturers due to staff changes the strategic integration of transversal competencies will be difficult to achieve or monitor. It also appears from this finding that transversal competencies are taught in the engineering curriculum but not seen by teaching staff nor management as necessary to incorporate in the learning outcomes.

Improvements in the description of course learning outcomes with regards to the inclusion of transversal competencies and with that the access for students to acquiring transversal competencies is needed. Uncovering the implicit transversal competencies hidden in the learning outcomes and shifting to a practice of explicitly stating and assessing transversal competencies will need significant investment from educators. Explicitly formulated transversal competencies in the learning outcomes will also help students to develop a better lexicon for the transversal competencies they need in the labour market. This will also clarify which transversal competencies are included in the aerospace engineering programmes and to what level, which subsequently will make the assessment by accreditation boards more straightforward.

The findings of this chapter indicated that COMπ can be used to measure the perceptions of the transversal competencies that lecturers think students practice in their courses and the shorter version of COMπ of 16 competencies can be used to trigger lecturers to reflect on the practises and methods that they use to expose students to the transversal competency levels required by the industry. From a lecturer's perspective, students practise to at least the transversal competency level required by the industry in at least one course in the BSc and MSc, respectively. As our analysis was carried out at the course level and not at a curriculum level, it is not possible to state whether all transversal competencies are sufficiently taught over the whole curriculum. Also, based on the outcomes of this study it is not possible to quantify when students reach the required transversal competency levels or what level of exposure and practice to transversal competencies is needed to reach the required level. For this, further research into the curriculum and its delivery is needed. However, it is possible to make some statements with regards to practices currently employed by the lecturers to develop transversal competencies in students which were identified in the interviews: first, the use of project-based learning with assignments (Saunders-Smits, Rolling et al. 2012, Saunders-Smits, Schuurman et al. 2015) that allow students the opportunity to produce real(istic) products or services, ideally with real clients (Prince 2004) and the exposure to many different problems (open-ended, ill-structured, ambiguous and complex) throughout students' degrees. In these problems, not only the technological answers are considered but also non-engineering contextual factors/constraints such as costs, time and functionality, as it happens in real engineering life (Jonassen, Strobel et al. 2006). Second, lecturers used explicit coaching for students where they provide guidance and feedback in regular and project-based courses (Prince 2004) and challenge students with questioning. Finally, lecturers used student-centred activities to impose responsibility and autonomy of students' learning (Prince and Felder 2006). These concrete examples given by lecturers provide evidence that COMπ can trigger lecturers to self-assess the practices they use in their courses to reach the transversal competency levels.

3.6. Conclusion, limitations and future work

The research in this chapter presents COMπ that measures perceptions of transversal competencies based on an existing instrument used in industry. The main conclusion of this chapter is that COMπ combines the following characteristics: five holistic transversal competencies that are stratified into more nuanced competencies, each of these competencies has a definition and four descriptive levels, into one holistic instrument that can be used not only to measure the perspectives of industry on the required transversal competency levels for engineering graduates but to what extent these levels indicated by the industry are covered in representative engineering degrees both by looking at the stated learning outcomes of the courses and by triggering lecturers to reflect on the transversal competencies they taught in their courses. It is recommended that educators use COMπ to self-assess their course practises and assess students' learning outcomes. Also, the desired industry transversal competency levels required for engineering graduates identified using COMπ help those involved in engineering education to focus on the right transversal competencies at the level required by employers of future engineers.

An additional finding is that lecturers report that their students practise transversal competencies in their courses but that these transversal competencies are not stated in the course documented learning outcomes, indicative of a gap between the formal and the perceived curriculum. Likely, COMπ is also suitable to identify any such gaps in other engineering programmes. It is recommended that a detailed description of the taught transversal competencies in the learning outcomes of the aerospace engineering programme is a step to be taken by educators. This will facilitate students in developing an awareness of the importance of transversal competencies for their future careers, in deciding what courses are more appropriate to develop their desired competencies and to create visibility and controllability of which transversal competencies are acquired during these courses and to what level to aid educational management.

The research in the current chapter has some limitations. The industry sample was not very big, a larger sample with more industry representatives would have been desirable. Another limitation is that the same industry representatives and lecturers were asked to rate the level each competency is required or present for the BSc and MSc levels. This research approach may have biased the participants to rate higher competency levels for MSc than BSc students although the results show that the same employers indicated similar competency levels for BSc and MSc students and the same lecturers indicated higher competency levels in some BSc courses than MSc courses. Also, the approach to find the gap in the curriculum was limited to the mapping of the learning outcomes and the focus of the interviews conducted with the lecturers was on the teaching practices and methods used to achieve students' transversal competency levels and not on the assessment of the transversal competencies. Future research focusing on how to assess and evaluate the transversal competency levels that lecturers indicated their students acquire in the courses is needed to verify the constructive alignment between the learning outcomes, the teaching activities and the assessment tasks used by the lecturers. This inevitably includes a study of the transversal competencies students perceive they develop throughout their degree and compare the results of the students to the answers of the surveyed lecturers to verify the existence of differences among the formal, perceived and experiential curriculum (*i.e., learning experiences as perceived by learners* (van den Akker et al. 2003)). Alternatively, course observations to focus on the operational curriculum, *i.e., the actual process of teaching and learning or curriculum-in-action* (van den Akker et al. 2003) can be used to investigate lecturers' perspectives and thus verify the gap identified.

To conclude, the findings of this chapter indicated that COMπ is a valid instrument to measure transversal competency perceptions, i.e., it can be used as a full instrument or in shorter versions with fewer competencies to measure perceptions and trigger reflection on transversal competencies. COMπ is further evaluated on whether it can be used by engineering students to measure their perceptions of transversal competencies.

"A leader is one who knows the way,
goes the way, and shows the way."

John Maxwell

CHAPTER 4

Testing the validity and reliability of an instrument measuring engineering students' perceptions of transversal competency levels

This chapter is based on the published article:

Leandro Cruz, M., Saunders-Smits, G. N., Van den Bogaard, M. E. D., and Groen, P. (2020). Testing the validity and reliability of an instrument measuring engineering students' perceptions' of transversal competency levels. *IEEE Transactions on Education*. 64(2): 180-186. DOI: 10.1109/TE.2020.3025378.

4.1. Introduction

The purpose of the research of this chapter is to further explore the validity and test the reliability of COMπ presented in *Chapter 3*, i.e. whether COMπ can be used to measure the perceptions of students' transversal competencies. COMπ, described in *Chapter 3*, section *3.3.3. Development of a transversal competency instrument*, addresses five main domains: entrepreneurial, innovation, communication, teamwork and lifelong learning competencies, and provides definitions for each competency and mastery levels based on an existing industry competency model. The main research question presented in *Chapter 3* is answered further by validating COMπ. The sub-research questions discussed in this chapter are:

(1) What is the reliability and validity of COMπ to measure the perceptions of engineering students' transversal competencies?
(2) What are the transversal competency level perceptions of engineering BSc and MSc students?

The research presented in this chapter was carried out among aerospace engineering students of Delft University of Technology in the Netherlands. In the Dutch engineering education system, both bachelor and master graduates should be competent in seven areas, notably: competent in one or more scientific disciplines in research, in design, and cooperation and communication, have a scientific approach, possess basic intellectual skills, and take account of the temporal and social context (Meijers, van Overveld et al. 2005). ABET accreditation standards use the same criteria for technical and transversal skills across all accredited engineering programs (Engineering Accreditation Commission 2000). In both cases, transversal competencies are used interchangeably between engineering disciplines. Therefore, the outcomes of this chapter can be transferred to any engineering context including electrical engineering.

4.2. Background literature

4.2.1. Self-perception of transversal competencies

Previous studies have focused on graduates' perceptions of the most important competencies to the engineering field (Meier, Williams et al. 2000, Saunders-Smits 2008, Passow and Passow 2012) and students' perception of their competency mastery levels (Direito, Pereira et al. 2012, Chan, Zhao et al. 2017). These perceptions refer to beliefs or opinions. Research studies often use perceptions because they are easy to use and alternatives are labour intensive and not always easy to implement, especially with large samples (Cohen, Manion et al. 2007). Second, it is important for students to learn to reflect on their competency levels as part of their education (Lizzio and Wilson 2004, Pinxten, Saunders-Smits et al. 2018) as it makes students aware of their transversal competencies and mastery levels and hence students can identify weaknesses, strengths and needs (Eva and Regehr 2005), which are required for a successful student and professional careers.

Self-perceptions are also investigated in this chapter. Self-perception of competencies is the reported self-efficacy in performing competencies (Katowa-Mukwato and Banda 2016). As mentioned before, self-perceptions are frequently used in education research. However, using perceptions as a measurement has a downside.

Research (Boud 1995, Kruger and Dunning 1999, Pinxten, Saunders-Smits et al. 2018) has shown that students overestimate their competencies when asked to self-assess their abilities. However, studies in the medical field (Jones, McArdle et al. 2001, Coberly and Goldenhar 2007) demonstrated a better correlation between self-perceived and objectively measured transversal skills compared to practical skills. It stands to argue that the same applies to engineering students, as both are applied degrees and some similarities exist between the two sciences such as the required problem solving skills. Also, it has been demonstrated that students at higher degree levels, who likely have been more exposed to self-assessment during their degree, are better able to self-assess (Gehringer 2017). Therefore, self-assessment can be a reliable instrument for measurement in research studies if a mix of academic experience (i.e., students of different years of study) is present in the sample of this chapter.

Next to using self-perception for research purposes, there is also a case to be made to use self-perception as an educational tool to help students learn to self-assess. There is consensus in literature (Lizzio and Wilson 2004, Pinxten, Saunders-Smits et al. 2018) that the ability to self-assess and be self-aware is essential in the process of maturing and learning. By being able to self-assess, one can identify weaknesses, strengths and needs. Engineering students able to recognize gaps in their learning may look for learning in areas of limited competence. Also, the ability to reflect on students' strengths and weaknesses can help them to establish expectations of themselves, goals and future career needs (Eva and Regehr 2005).

Self-assessment (as a possible instrument of self-reflection) is often a requirement in both organizational and professional contexts (Boud 1990). Engineers able to recognize that they are not able to complete a task can consult and refer it to another person or recruit additional resources. In contrast, they can offer their expertise to help to solve others' problems.

In summary, students should have an awareness of their transversal competencies and mastery levels because they need to be able to identify their strengths and weaknesses in their studies and professional engineering career. To assist students in this, an instrument allowing them to reflect on their competencies would be useful.

4.2.2. Limitations of measurement instruments in engineering education

Previous studies have measured students' perceptions of their competency levels (Lizzio and Wilson 2004, Direito, Pereira et al. 2012, Chan, Zhao et al. 2017). However, these studies present some limitations. The systematic review of competency measurement methods in *Chapter 2* identified that most studies lack definitions of the competencies under study, and that absent or broad (Arnold, Loan-Clarke et al. 1999) definitions make interpretation complicated and may hinder the internal structure of the instrument. Another limiting factor of the measurements was the lack of psychometric properties in the studies, found in *Chapter 2* and Lizzio and Wilson (2004). However, as mentioned in *Chapter 2*, some studies have shown efforts in this regard. They developed lists of competencies based on industry or academic literature, conducted exploratory and confirmatory factor analyses and tested the reliability of the measurements using Cronbach's α. Chan, Zhao et al. (2017) identified these limitations and designed a questionnaire to assess the perceptions of first-year bachelor engineering students' competency levels in 38 skills based on prior academic literature. This Hong Kong-based study created a valid and reliable instrument with eight scales. However, they pointed out that their study had a limitation regarding the generalisability of the results as the instrument was only based on the perceptions of first-year students who had just started their engineering studies. As a solution, they suggested measuring the competency levels perceived by final-year students and investigate how students develop competencies during their studies.

4.2.3. An industry competency model

The research in this chapter continues with the 36-competency instrument, named COMπ, with four descriptive levels of mastery created based on the competency model developed by Siemens. In short, COMπ divides competencies into five domains (as shown in Table 3 of *Chapter 3*, section *3.3.3. Development of a transversal competency instrument*): entrepreneurial competencies (ENTREP; 7 items), innovation competencies (INOV; 7 items), communication competencies (CM; 9 items), teamwork competencies (TW; 8 items) and lifelong learning competencies (LLL; 5 items).

4.3. Methods

4.3.1. Participants and data collection

A paper-based questionnaire was administered to all first- and second-year BSc and first-year MSc students in aerospace engineering at a university of technology in the Netherlands, in the first week of the academic years 2018/19 and 2019/20. In this chapter, from here on, all first- and second-year BSc students are referred to as BSC1 and BSC2, respectively, and first-year MSc students as MSC1.

As stated earlier, within the Netherlands, the four research-based universities of technology have created a set of common learning outcomes which includes transversal competencies generic for all engineering disciplines (Meijers, van Overveld et al. 2005). As all engineering degrees (including degrees in electrical engineering and applied computer science) offered by these institutes are accredited according to these standards, the results of this sample can be seen as representative. Also, this population is well-mixed in terms of nationalities (more than half of the students are non-Dutch and stem from five different continents) and years of study (BSC1, BSC2 and MSC1), as well as gender-balanced considering the engineering field.

A total of 1087 students (72% of the total student population approached to participate) completed the questionnaire and gave consent (Table 7).

Table 7 - Information of the number of students participating in this chapter per degree (BSC1, BSC2 and MSC1), gender (female, male and other) and nationality (international and Dutch) in the years 2018 and 2019. Percentages refer to the total number of completed questionnaires (n = 1087).

Total	Complete	Gender	Nationality
BSC1 2018 (461)	BSC1 2018 (314; 28.9%)	Female (45; 4.1%) Male (267; 24.6%) Other (2; 0.2%)	International students* (162; 14.9%) Dutch (152; 14.0%)
BSC2 2019 (347)	BSC2 2019 (223; 20.5%)	Female (35; 3.2%) Male (188; 17.3%) Other (0)	International students* (127; 11.7%) Dutch (96; 8.8%)
MSC1 2018 (315)	MSC1 2018 (279; 25.7%)	Female (31; 2.9%) Male (248; 22.8%) Other (0)	International students* (124; 11.4%) Dutch (155; 14.3%)
MSC1 2019 (385)	MSC1 2019 (271; 24.9%)	Female (34; 3.1%) Male (236; 21.7%) Other (1; 0.1%)	International students* (156; 14.4%) Dutch (115; 10.5%)

* From 53 countries of which 3 are African, 7 American, 11 Asian, 2 Australia and 30 European.

4.3.2. Questionnaire design and structure

The first part of the questionnaire contained questions to collect students' data: student number, academic degree, gender and nationality. This was asked to describe the sample. Then, COMπ was given to students so that they could indicate the transversal competency levels on the 4-point descriptive Likert scale (0 - absent, 1 - basic, 2 - advanced and 3 - expert) they perceive they hold for the 36 transversal competencies. The administration time was approximately 15 minutes.

4.3.3. Data analysis

To answer the first and second research questions, respectively, the psychometric properties (reliability and validity) of the questionnaire and the descriptive statistics (mean and standard deviation of students' self-perceived scores) were calculated and analysed at factor and item level.

Before starting on the factor analyses, the dataset was randomly split into two groups. As proposed by Hair, Black et al. (2014), exploratory factor analysis (EFA) was conducted to assess the initial item structure of the competency questionnaire using the first dataset followed by confirmatory factor analysis (CFA) to examine the structure of the factors obtained in the EFA and determine the fit of the model using the second dataset.

EFA was done in *SPSS™ 25* with 544 cases. Correlation between variables and the determinant of the correlation matrix, which should be above 1E-5 to avoid multicollinearity, was investigated (Field 2009). Also, Kaiser-Meyer-Olkin (KMO) and Bartlett's tests were considered. They indicate sampling adequacy and a correlation between items significantly large, respectively. KMO values above 0.9 are considered superb and KMO values of individual variables are acceptable above 0.5 (Field 2009). Then, the factors were extracted and the eigenvalues and variance within variables were calculated. Kaiser's criterion of eigenvalues greater than 1 was assumed, because of the large sample size (> 250 according to (Field 2009)). The underlying factors were evaluated using orthogonal rotation (varimax) to avoid dependency between the factors (Field 2009) as the constructs in the initial instrument were not correlated. A cut-off score for the factor loadings of 0.4 was used. Also, factors with fewer than three items were removed (Raubenheimer 2004).

CFA was tested in *SPSS AMOS™ 25* with 543 cases. Maximum likelihood estimation was used. To assess model fit, Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA) and the ratio of χ^2 to its degrees of freedom (χ^2/df) were considered. Threshold values of CFI above 0.90, RMSEA below 0.06 and χ^2/df below 3.0 were indicative of a good model fit (Hooper, Coughlan et al. 2008). The Chi-squared statistic (χ^2) was included in the research of this chapter but not used as a model fit indicator because it is sensitive to sample size and it rejects the model for large samples (Hooper, Coughlan et al. 2008).

The internal consistency of each scale was measured through Cronbach's α. Item-total correlations lower than 0.3 were pin-pointed as items that do not correlate with the overall score from the scale. Reliable scales were assumed for $\alpha > 0.70$ (Field 2009).

4.4. Results

4.4.1. Questionnaire construct validity evidence

EFA was carried out on the 36 items with varimax rotation. A KMO value of 0.89 was obtained, meaning an adequate sample size. Bartlett's test of sphericity χ^2 (630) = 4809.9, $p < 0.001$ demonstrated that correlations between items were large. In the first exploratory phase, five items were removed as two items (*English language skills* and *writing skills*) loaded to a single factor, the item *risk tolerance* had a negative loading and the other two items (*collaborative goal-oriented* and *negotiation skills*) had factor loadings below 0.4. Therefore, a second analysis was performed with 31 items. Two other items (*giving constructive feedback* and *non-credit activity participation*) were deleted as they had factor loadings below 0.4. Another item (*engagement in teamwork*) was removed in a third analysis for the same reason. In the following analysis, a sixth factor composed of three items (*leadership*, *goal settings* and *project management*) was deleted because it did not meet the reliability threshold. The final model had five factors: communication (CM; 5 items), innovation (INNOV; 5 items), entrepreneurial (ENTREP; 5 items), lifelong learning (LLL; 5 items), teamwork (TW; 5 items) competencies with eigenvalues over Kaiser's criterion of 1 and together they explained 47.4% of the variance. Their factor loadings are shown in Table 8. The total explained variance is 47.4%.

Cronbach's α was calculated for each scale to test the reliability of COMπ. Cronbach's α values ranged from 0.66 to 0.79 (Table 8). The item-total correlation ranged from 0.34 to 0.65 indicating that the items correlated with the overall score of each scale. The findings showed that five scales: CM, INNOV, ENTREP, LLL and TW demonstrated moderate to high consistency.

CFA was performed to test the factor structure of COMπ. The five-factor model obtained from the EFA presented a χ^2 = 581,5, df = 265, $p < 0.001$ and it showed good fit: χ^2/df = 2.194 (< 3.0), RMSEA = 0.047 (< 0.06) and CFI = 0.901 (> 0.90). The standardized estimates of this model ranged from 0.43 to 0.77. Therefore, the findings showed that COMπ is valid at measuring the perceptions of transversal competencies of engineering students.

Table 8 - Factor loadings derived from the EFA of 36 items and above 0.4 are shown (n = 544).

Factors and items	Rotated factor loadings/scales				
	1	2	3	4	5
Communication Competencies					
Presentation Skills	**0.75**				
Pitching Skills	**0.68**				
Presentation Method	**0.67**				
Adaptive Communication Style	**0.67**				
Self-confidence	**0.65**				
Innovation Competencies					
Ideation		**0.71**			
Curious for Innovation		**0.62**			
Critical Thinking		**0.61**			
Problem Solving		**0.61**			
Idea Implementation		**0.58**			
Entrepreneurial Competencies					
Financial Awareness			**0.71**		
Stakeholder Management			**0.68**		
Business Acumen			**0.63**		
Technology Benchmarking			**0.54**		
Value/Cost Consciousness			**0.46**		
Lifelong Learning Competencies					
Actively Seeking Learning				**0.69**	
Strengths & Weaknesses Awareness				**0.59**	
Autonomous Work				**0.57**	
Time Management				**0.56**	
Professional role awareness				**0.50**	
Teamwork Competencies					
Cross-Cultural Understanding					**0.72**
Managing Conflict					**0.63**
Listening Skills					**0.58**
Interdisciplinary Thinking					**0.58**
Interrelation Ability					**0.42**
Number of items	5	5	5	5	5
Eigenvalue	5.58	2.07	1.59	1.39	1.21
% of variance	22.30	8.30	6.38	5.56	4.82
Item-total correlation	.52-.65	.46-.53	.39-.48	.36-.49	.34-.48
Cronbach's alpha	**0.79**	**0.74**	**0.70**	**0.71**	**0.70**

4.4.2. Descriptive Statistics

The means and standard deviations for the perceptions of the combined students' competency levels for the (new) 5-factor COMπ (including the individual items) are reported in Table 9. The highest competency levels were found for teamwork and lifelong learning competencies and the lowest for entrepreneurial competencies. When looking at the item level, the five highest competency levels perceived by students were *listening skills*, *strengths and weaknesses awareness*, *cross-cultural understanding*, *actively seeking learning* and *problem solving* (marked in Table 9 with *) while the five lowest competency levels were *stakeholder management*, *business acumen*, *financial awareness*, *idea implementation* and *technology benchmarking* (marked in Table 9 with #).

Table 9- Descriptive statistics of the perceived students' competency levels of the 25-item 5-factor COMπ (n = 1087). The 5 highest and lowest competency levels perceived by students are highlighted with a * and # respectively.

Competencies	Mean	SD
Communication Competencies	***1,81***	***0,68***
Presentation Skills	1,90	0,74
Pitching Skills	1,57	0,70
Presentation Method	1,85	0,61
Adaptive Communication Style	1,82	0,58
Self-confidence	1,92	0,75
Innovation Competencies	***1,84***	***0,62***
Ideation	1,63	0,67
Curious for Innovation	2,05	0,56
Critical Thinking	2,04	0,64
Problem Solving *	2,12	0,57
Idea Implementation #	1,34	0,66
Entrepreneurial Competencies	***1,30***	***0,71***
Financial Awareness #	1,31	0,69
Stakeholder Management #	1,16	0,77
Business Acumen #	1,24	0,75
Technology Benchmarking #	1,37	0,66
Value/Cost Consciousness	1,41	0,69
Lifelong Learning Competencies	***2,10***	***0,66***
Actively Seeking Learning *	2,23	0,63
Strengths & Weaknesses Awareness *	2,48	0,63
Autonomous Work	2,07	0,60
Time Management	1,92	0,75
Professional role awareness	1,81	0,69
Teamwork Competencies	***2,13***	***0,68***
Cross-Cultural Understanding *	2,30	0,73
Managing Conflict	2,09	0,65
Listening Skills *	2,49	0,65
Interdisciplinary Thinking	2,06	0,69
Interrelation Ability	1,73	0,67

4.5. Discussion

The original competency model comprised 36 items loading to five scales (Table 3). After EFA and CFA, the model is still composed of the same five scales: CM, INNOV, ENTREP, LLL and TW. However, with fewer items and with some differences in each scale. When comparing the initial model (5 factors with 36 items) with the new model (5 factors with 25 items), the former shows redundancy in the context of the research of this chapter as 11 items were measuring more than needed and the latter robustly measures engineering students' perceptions of mastery levels.

In the new model as listed in Table 8, the first scale (CM) is defined by oral communication and ability and confidence to express information to different audiences. A scale involving oral communication and the use of influential communication is present in the study of Lizzio and Wilson (2004). The CM scale in the new model has lost four items present in the initial model. Two of them (*English language skills* and *writing skills*) were deleted as they loaded to a single factor in the first step of EFA and the other two items (*listening skills* and *interrelation ability*) loaded to the TW scale. Although listening to others was considered part of communication in the study of Lizzio and Wilson (2004), listening skills seem to fit well in the TW scale as engineers need to listen when working in teams.

The second scale (INNOV) of the new model is characterized by items that lead to the generation of ideas and solutions. Again, similarities were found between the research of this chapter and Lizzio and Wilson (2004). Both studies suggested an interaction between problem-solving and critical thinking. Although in Chan, Zhao et al. (2017) these items belonged to two distinct scales (*academic and problem-solving skills* and *critical thinking*), in their new instrument (Chan and Luk 2020), items related to the identification and solving problems and thinking critically loaded to the same scale, as in Lizzio and Wilson (2004) and this chapter. The INNOV scale of the new model compared to the initial model excluded skills such as *stakeholder management* and *value/cost-consciousness*. They load to the ENTREP scale. This finding makes sense as the ENTREP scale includes items related to finances, markets and business opportunities. Thus, the awareness of stakeholders and value and costs seem to be related to them. The ENTREP scale gains two items but loses four. Two of them (*project management* and *leadership*) loaded to an extra factor which was deleted because it showed low reliability and the other two items were deleted as *risk tolerance* showed a negative factor and *negotiation skills* seemed to be redundant due to similarities with *pitching skills*. This scale seems to be not considered in previous literature. This gives value to COMπ as it can measure items related to entrepreneurship, important for engineering roles (Craps, Pinxten et al. 2018).

The fourth scale (LLL) is characterized by self-management, in terms of professional needs, strengths and weaknesses, stick to timeframes and search for continuous improvement autonomously. In this scale, the new model has four items in common with the initial model. One item *non-credit activity participation* present in the initial model was deleted in the new model as it seemed to have issues shown by the factor loading lower than 0.4. On the other hand, in the new model, this scale has an extra item, *time management*. This item was left on this scale as it is also present in a similar scale named self-management skills of the study of Chan, Zhao et al. (2017). A scale including adaptability, self-management and self-understanding was also present in Lizzio and Wilson (2004) and the new instrument by Chan and Luk (2020).

The fifth scale (TW) in the new model is defined by the ability to work in groups respecting cultural differences and disciplines of knowledge, listening attentively and managing issues. Three items were maintained from the initial model and two other items were added. The item listening skills was discussed above. The item *interrelation ability* was considered appropriate in this scale as teamwork requires interaction and relationships between people. The four items deleted (*collaborative goal-oriented*, *engagement in teamwork* and *giving constructive feedback*) seemed to show redundancy in the initial model in the context of the research of this chapter.

The work presented in this chapter and the study carried out by Chan, Zhao et al. (2017) have similarities that show that the competency levels' perceptions of engineering students in the Netherlands and Hong Kong are alike. However, dissimilarities were also present. The scale interpersonal skills of Chan, Zhao et al. (2017) consisted of items related to interaction and communication with others, teamwork and flexibility. However, in the work of this chapter as well as in Lizzio and Wilson (2004), three distinct scales (CM, TW and LLL) were demonstrated. The reason presented by Chan, Zhao et al. (2017) for this difference between their study and Lizzio and Wilson (2004) was discipline generalizability (engineering versus behavioural science, engineering and management, respectively). Considering the results of this chapter, the reason may be the different cultural-educational backgrounds in terms of location and a student population of the three studies: 90% Asian in Chan, Zhao et al. (2017) versus Western in Lizzio and Wilson (2004) and this study (80% Australian and 84% European, respectively). This may be explained by similarities between the European and Australian systems, which have 3-year BSc programs and 2-year MSc programs combining broad interdisciplinary knowledge and deep core engineering disciplines, versus the Hong Kong system, which after the reformation in 2006 included a student holistic development approach i.e., *"a progressive process through which the intellectual, physical, professional, psychological, social and spiritual capacities of an individual can be holistically enhanced"* (HKBU 2019), that is not implemented in the degrees in Europe and Australia (Chan and Luk 2013). The fact that students are exposed to different education systems and consequently differently exposed to transversal competencies may influence the way they perceive their competency levels. Thus, more similarities between the system may mean more similarities between students' perceptions.

When looking at the outcomes of the descriptive statistics, students perceived they were most competent in teamwork and lifelong learning competencies and less competent in entrepreneurial competencies. Previous studies (Meier, Williams et al. 2000, Saunders-Smits 2008, Passow and Passow 2012) have shown that engineers highly require teamwork and lifelong learning competencies as in their careers engineers are constantly working with other people engineers and non-engineers, and these competencies need continuous development.

Looking at studies that investigated students' competency levels, Direito, Pereira et al. (2012) and Chan, Zhao et al. (2017) showed that engineering students perceived they were most competent in *listening skills*. In this chapter, this competency belonged to the TW factor and students indicated they were highly competent too. High levels for *actively seeking learning* and *problem solving* were also found in Direito, Pereira et al. (2012). In this chapter, they belonged to LLL and INNOV factors, respectively, and students also perceived high levels of competency. These three competencies are essential for future engineers who need to solve problems constantly and be attentive to the needs of people around them including colleagues but also the wider society and look continuously for opportunities to develop themselves. Although students already feel they are highly competent in these competencies, it is the role of the university to further prepare future engineers with the ability to problem solve, listen to others and actively looking for more knowledge, so that students are prepared for the real-life environment of the labour market.

As innovation is considered a key competency for future engineers by stakeholders (Spinks, Silburn et al. 2006), it is interesting to see that the INNOV factor was not among the factors that students perceived they were highly competent in. This is mainly due to that students felt they were not very competent in *ideation* and *idea implementation*. This outcome was also verified in the following studies (Lizzio and Wilson 2004, Direito, Pereira et al. 2012, Chan and Luk 2020). Another similar outcome of this chapter and Lizzio and Wilson (2004), Direito, Pereira et al. (2012) and Chan and Luk (2020) was that engineering students felt less competent in *pitching skills* and *negotiation skills*. In this chapter, the item *pitching skills* presented the lowest competency level in the CM factor. Attention to the development of students' *ideation*, *idea implementation* and *pitching skills* should be given by the university, as students felt less competent and these competencies are important for the engineering professional roles developed by Craps, Pinxten et al. (2018). Their model highlights the need for the *customer intimacy* engineer to be able to negotiate with clients and the *product leadership* engineer to develop new ideas and execute them.

Moreover, the focus of the university should not be limited to the previous competencies but also entrepreneurial competencies because first engineers are expected to become leaders of top organizations, refine markets, solve major technological problems and economic crises at national and global levels (Purzer, Fila et al. 2016), second entrepreneurial competencies were considered important for future engineers by stakeholders (Spinks, Silburn et al. 2006) and finally, students in the research of this chapter perceived they were less competent in these competencies. Although the development of entrepreneurial competencies has grown interest in engineering education (Creed, Suuberg et al. 2002), universities should continue to emphasise the development of these competencies, for instance, through inductive teaching methods with real-life problems (Prince and Felder 2006).

The transversal competency instrument, COMπ, presented in this chapter measures students' perceptions of their competency levels to overcome the limitations found in *Chapter 2* and previous studies (Chan, Zhao et al. 2017). This is done by providing descriptions for each competency and mastery levels based on an industry-based competency model. The model has been tested using a wide selection of students of different ability in self-perception skills by including students from different years of studies and different nationalities, even though only aerospace engineering students took part in this study. In doing so, the research of this chapter differs from the study of Chan, Zhao et al. (2017) that only used first-year engineering students, who have a limited understanding and experience of the engineering disciplines and transversal competencies (Karataş, Bodner et al. 2016, Pinxten, Saunders-Smits et al. 2018). Moreover, this sample included a range of different cultural pre-university education backgrounds, i.e. students from several parts of the world participated in this research.

Finally, the results of the EFA and CFA have shown that after a reduction in items, a valid and reliable 5-scale, 25 item-instrument that measures perceptions of competency levels has been achieved which can be used both for educational research and as a self-reflection instrument for students.

4.6. Conclusion, limitations and future work

The research of this chapter has provided a valid and reliable COMπ consisting of 25 transversal competencies divided over 5 scales, or in other words, engineering students were able to use COMπ to measure their perceived transversal competencies and found it a good measure to reflect on their transversal competencies. These findings indicate that COMπ can be used to research the perceived competency levels of engineering students and as a self-assessment instrument.

Although the sample included students of different nationalities, gender and years of study, it is limited to aerospace engineering students. The results indicate, however, that they can be transferred to other engineering contexts, or in other words that COMπ can be used in other contexts to measure perceptions of transversal competencies or trigger their reflection.

For future research, interviews and observations exploring the level of mastery in competencies of BSc and MSc students may yield additional outcomes on the perceptions of students' competency levels.

The similarities and differences between the research of this chapter and the studies of Lizzio and Wilson (2004) and Chan, Zhao et al. (2017) showed that there is a potential role of disciplines and cultural educational-background influencing the perceptions of students' competency levels, which can be explored further.

To conclude, the evaluation of COMπ through its application with employers, lecturers and engineering students conducted in chapters 3 and 4 indicated that COMπ:

- Was an appropriate starting instrument because it was used by the industry to assess their employee's skills, had a list of nuanced competencies with definitions and descriptive levels,
- required an absent level of competency and had some redundant competencies in its list of competencies compared to the initial industry model and
- Can be used by different stakeholders as a whole or in parts, i.e., the full instrument, or selected domains and competencies can be used to measure the stakeholder perceptions of transversal competencies or trigger their reflection depending on the competencies that need to be assessed.

"Play is the highest form of research."

Albert Einstein

CHAPTER 5

The effectiveness of an activity to practise communication competencies: A case study across five European engineering universities

This chapter is based on the published article:

Leandro Cruz, M. Sá, S., Mesquita, D., Lima, R., and Saunders-Smits, G. N. The effectiveness of an activity to practise communication competencies: A case study across five European Engineering Universities. *International Journal of Mechanical Engineering Education*. DOI: 10.1177/03064190211014458.

5.1. Introduction

In this chapter, a plug-and-play activity called *Chinese Whispers with a Twist* was created to fulfil the aim of the PREFER project of developing innovative curriculum elements that stimulate engineering students to practice transversal competencies necessary for the engineering professional roles. This activity will focus on one of the five holistic transversal competencies researched in this thesis – communication that was previously defined in *Chapter* 2, section *2.5.4. Measurement methods per competency* as "*the ability to show understanding and to carry technical/non-technical written/oral presentations and discussions depending on the audience where the feedback loop of giving and receiving opinions, advises and reactions is constant"*.

As mentioned in *Chapter 1*, this activity was created and implemented in parallel with the studies presented in chapters 2, 3 and 4. Although these and the current chapters were not performed in a sequence, the findings of chapters 3 and 4 indicated the need to stimulate engineering students to practice and reflect on their communication skills. In the following paragraphs, the reason for choosing an activity based on communication will be presented as well as the results of the previous chapters that support this choice.

The activity of this chapter focuses on communication competencies because they are important for engineering graduates according to academia (Beagon and Bowe 2018) and industry, as found in *Chapter 3* and Spinks, Silburn et al. (2006) and Passow and Passow (2012). They are considered important because they are required in an engineer's professional life. The research in *Chapter 3*, section *3.5.1. European industry exploration* indicated that communication competencies are considered important by the industry and require higher competency levels for engineering graduates. Among the most important competencies were *adaptive communication style*, while competencies requiring the highest levels of competence were *writing*, *listening* and *presentation skills*. However, engineering graduates still lack communication competencies such as *listening skills* (Meier, Williams et al. 2000) and *oral and written communication skills* (Nair, Patil et al. 2009) when entering the workforce. For this reason, the introduction of communication competencies in the engineering curricula was considered a desirable outcome by accreditation bodies such as the ABET Engineering Criteria (Commission 2000) in the USA and the European Network for Accreditation of Engineering Education (ENAEE 2008) in Europe, as well as several engineering departments (Donnell, Aller et al. 2011). However, in overcrowded curricula, to go from desire to a realisation is often difficult, as it requires finding space within a curriculum and a willingness to create and implement new activities, workshops and courses (Jennings and Ferguson 1995).

So far, practices, such as oral presentations (Berjano, Sales-Nebot et al. 2013) and written reports (Drury, Langrish et al. 2006), were introduced mostly in project-based learning courses to enhance students' communication competencies. However, communication competencies extending to informal listening and speaking are rarely addressed in the engineering curricula (Trevelyan 2019). In *Chapter 3*, section *3.5.1. Educational practises and methods to address transversal competencies*, lecturers mentioned they practised *listening skills* during their courses through feedback and asking questions to students and in *Chapter 4* section *4.5.2. Descriptive Statistics*, students felt they were highly competent in *listening skills*. However, the same picture does not apply to *pitching skills*. Students felt they had low mastery levels in *pitching skills* (*Chapter 4*, section *4.5.2. Descriptive Statistics*) and lecturers did not practise these skills as much. The same applies to the practising of *writing skills* in their courses (*Chapter 3*, section *3.5.2. b. Transversal competencies in the BSc and MSc programmes according to lecturer*s).

This activity is a game-based learning practice in which students cooperate in teams and experience other forms of communication rather than oral presentations and written reports. It intends to provide students with an opportunity to practise and reflect on effective verbal and visual communication. This includes actively listening, describing information within a time-limited, effectively asking and answering questions, and drawing images. The outcomes of this activity which was implemented in five European engineering institutions - TU Delft (The Netherlands), KU Leuven (Belgium), TU Dublin (Ireland), IST and UMinho (Portugal) and in a variety of courses and engineering degrees over one-and-a-half years are presented in this chapter.

This chapter aims to investigate what characteristics of a game-based learning activity make it effective (i.e. successful) to practise and trigger reflection on the communication competencies of students in different fields of engineering. This research does not intend to provide a full list of characteristics but only a set that was included in this particular activity.

The main research question addressed in this study is: *What are the characteristics of a game based-learning practice that stimulates engineering students to practise and trigger reflect on their communication competencies?*

To answer this question, the game characteristics that make this activity effective will be explored in a case study using a mixed-method approach that investigates how students evaluate their communication competencies and areas for improvement in the game based-learning activity, how these competencies correlate with their performance in the activity and finally the communication competencies that engineering students become aware of or experience in the game based-learning activity.

5.2. Background literature

5.2.1. Communication competencies in engineering professions

To develop students' communication competencies, it is essential to understand communication in the engineering profession. Novice engineers report that they spend 32% of their time using verbal communication with other people and 28% writing (Trevelyan 2010). Also, young engineers spend a great part of their time listening (Trevelyan 2010). In the study of Lievens (2013), engineers mentioned they spend on average 57% of their working hours on active communication such as writing e-mails and reports, making phone calls and having meetings. Lappalainen (2009) argues that, in technology sectors, engineers are constantly exchanging information between other engineering fields and society. They need to communicate effectively to show their vision, put plans into practice, and stimulate feedback mechanisms.

Regarding writing skills, differences between writing in academic and industry settings were observed (Moore and Morton 2017). At university, students are required to write the content learned in an elaborative way, while in industry, because of limitations in time due to short deadlines, communication should be brief and concise. Also, in the study of Moore and Morton (2017), engineering students are reported to have problems with adjusting their writing to their audiences and context. Often the technical and academic language is used instead of simple language. Being able to adapt one's communication style to a purpose and an audience was a key requirement indicated by the industry in *Chapter 3*, section *3.5.1. European industry exploration* and in the study of Moore and Morton (2017). Since communication is an active process of listening, adapting conversation styles, and using feedback in terms of giving and receiving opinions and responses (Wilkins, Bernstein et al. 2015), engineering curricula must not limit communication training to just giving oral presentations and writing technical reports.

5.2.2. Learning by doing

Evidence of the importance of communication competencies for engineers is clear. The next step is to study which teaching strategies exist to practise communication competencies in engineering education.

Learning by doing as a practice has been well-known for more than two thousand years. The Greek philosopher Aristotle stated that *"for the things we have to learn before we can do, we learn by doing"* (Bynum and Porter 2005) and the Chinese Philosopher Confucius mentioned that *"I hear and I forget. I see and I remember. I do and I understand"* (The Quotation Page). Active learning has gained even more attention over the past years. It is defined as a teaching and learning practice that engages students in doing things and think about what they are doing (Bonwell and Eison 1991). According to Kolb (1984), in the experiential learning theory, knowledge is generated through direct experience. Learning happens concretely and actively, through interaction between people and their environment. Kolb promotes that abstract concepts cannot be learned with traditional educational techniques (e.g., books and lectures) because they are disconnected from the experience. According to Kolb's theory (Kolb 1984), learning happens in a cycle where four modes are confronted: *concrete experience* (learners emerge themselves in the experience), *reflective observation* (learners reflect on what they experienced), *abstract conceptualisation* (learners conceptualise and draw conclusions from their experiences) and *active experimentation* (learners critically use the knowledge gained from the experience in future scenarios).

The research of this chapter will consider game-based learning as an approach to active learning. Game is *"a form of voluntary play that is structured by a set of rules, where players may make choices that can influence the actions of other players and the overall outcome"* (Bodnar, Anastasio et al. 2016) and has a feedback system in which participants draw parallels between the game and real-world scenarios (Garris, Ahlers et al. 2002). The type of games can go from live-action, board games to digital games (Bodnar, Anastasio et al. 2016, Bodnar and Clark 2017). Engineering education research (Garris, Ahlers et al. 2002) showed that games are effective to understand complex subjects, provide student engagement and increase their interest, motivation and confidence. A game element that positively impacted students' motivation is cooperation (Bodnar, Anastasio et al. 2016).

In cooperative learning, students work in small groups towards a common goal (Johnson and Johnson 1998). Students should have a role to be able to accomplish the task and the responsibility of the learning of the group is shared by all group members. In contrast, in collaborative learning students are responsible for their work and learning (Johnson and Johnson 1998). While cooperative and collaborative learning each have independent historical developments and philosophical roots, they have in common that students work in groups instead of individually (Prince 2004). Research in engineering education (Johnson, Johnson et al. 1998, Johnson and Johnson 1998) showed that cooperation improves academic achievement, interpersonal interaction and student attitude compared to students working as individuals. Cooperation was also compared to competition (Johnson, Johnson et al. 1998, Johnson and Johnson 1998) and results showed that cooperation improves interpersonal interaction, social support and self-esteem. Cooperative learning also promoted communication and teamwork compared to lectures (Terenzini, Cabrera et al. 2001). As engineers in their workplace need to think critically, solve problems and make decisions as a team, providing collaborative learning practices in engineering curricula is essential to develop transversal competencies and prepare students for their future workplace.

Game-based learning was also used to improve students' communication competencies in engineering education (Bodnar and Clark 2017). In this study, a mixed-method approach was conducted to assess students' perceptions and performance of oral and written communication skills. Findings showed that students improved their communication skills but did not perceive improvements. This study concluded that although students did not perceive an improvement in their communication skills, the use of games gave students a learning experience that stimulated communication.

However, a systematic literature review on game-based learning in engineering education has reported several limitations on game practices (Bodnar, Anastasio et al. 2016). First, the majority of studies assess students' perceptions and attitudes and do not consider the learning outcomes achieved by students. Second, issues were found with the reporting of the results in the research examined. Many studies did not provide validation evidence or procedures for instruments used. A final limitation was that in much of the research self-selected or small sample sizes were used.

This literature review showed the importance of experiential, cooperative and game-based learning to develop transversal competencies such as communication and teamwork and create students' engagement and motivation in the learning process through active learning and reflective thinking. The points highlighted in this review were incorporated in the design and research of the communication activity present in this chapter.

5.3. Communication activity: *Chinese Whispers with a Twist*

5.3.1. Learning outcomes

The communication activity was designed to achieve the following learning outcomes:

- Practice oral and visual communication through active listening, describing within a time limit, effectively asking and answering questions and drawing images.

- Trigger reflection on the use of effective oral and visual communication for engineers.

5.3.2. Design of the activity

The communication activity is based on the universal children's game, known as Chinese Whispers in the Commonwealth English world (Oxford Dictionary). This activity is called *Chinese Whispers with a Twist*[2] because instead of passing around a message and comparing it at the end as in the original game, in this version, the participants are given an image, have to pass instructions to the next person to draw it and compare the image at the end. This activity lasts one hour and allows students to practise their communication competencies by actively listening, describing information in a short time, and effectively asking and answering questions. It is performed in groups of 4-6 people and each group is divided into three subgroups, each of which has a set role (A, B and C). The rules and dynamics of this activity are shown in Figure 6. The vector image used as the drawing in the activity at all five universities is shown in Figure 7. This image was chosen so that it could be used in all university contexts. At the end of the activity, a 10 to 15-minute feedback session is held in which students are encouraged to reflect on their communication competencies and the performance of the team as a whole, as well as on how this activity can be related to a real-world engineering environment. The goal of triggering student reflection was also achieved by having students complete a questionnaire, which had not only a research function but also an educational purpose. From the experiential learning approach (Kolb 1984), we provide an activity in which students engage in an experience and actively reflect on it.

In line with best practices at TU Delft, the activity, with supporting materials for lecturers, has been published as OpenCourseWare[3] at the OpenCourseWare Website of TU Delft.

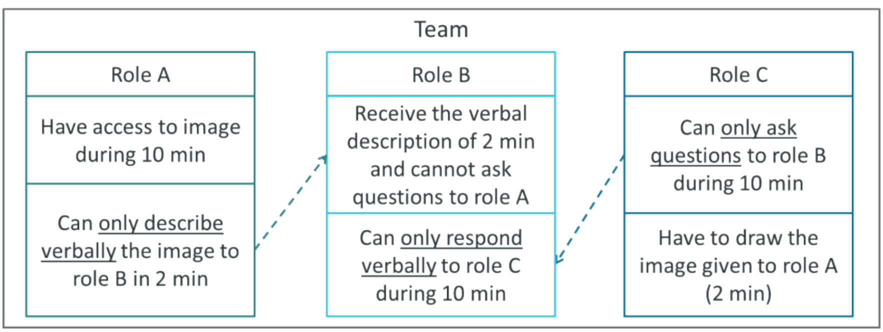

Figure 6 - Rules of the communication activity per role of each team.

[2] This name is used in this chapter to make an unambiguous reference to the game as it is the most used term in the Commonwealth English world. The researcher does not intend to create controversy due to racial stereotypes linked to the origin of the name nor to associate the Chinese language with "confusion" and "incomprehensibility". If the reader feels uncomfortable with the use of this name, please use instead *Telephone with a Twist*, based on the North American version of the game.

[3] It can be found on https://ocw.tudelft.nl/transversal-skills/communicating-is-more-than-just-talking-chinese-whispers-with-a-twist/.

Figure 7 - Image used in the activity and shown to students in role A.

5.4. Methods

5.4.1. Participants

Data were collected between March 2018 and October 2019 over five European engineering universities: TU Delft, KU Leuven, TU Dublin, IST and UMinho. The activity was implemented at the first three universities because they were part of the PREFER project and in the last two as researchers at these institutions had shown interest to implement it in their institutions after learning about its existence.

The communication activity in TU Delft was integrated into the Forensic Engineering course, an elective for Aerospace Master students in the faculty of Aerospace Engineering and was delivered to a multinational class of first-year Master students in March 2018 and May 2019.

In KU Leuven, the activity was implemented twice. First in September 2018, in a one-week summer school with international engineering Master students of KU Leuven and FH Dortmund, and second in April 2019, with Flemish Master in engineering students at different KU Leuven campuses.

The activity in TU Dublin was carried out in March 2019 with a group of first-year Bachelor students in a project-based learning course in the Civil engineering faculty.

At IST, ten lectures were given in October 2019 to first-year Master students of Computational Engineering in the course Independent Studies that focuses on communication.

Finally, at UMinho the activity took place with students in the first semester (October 2019) of the first year of the Master in Engineering Project Management.

The activity was conducted in English at TU Delft, TU Dublin, in the first implementation at KU Leuven and two lectures in IST. English was used when at least one non-native speaker was present in the activity. In the second implementation at KU Leuven, the activity was carried out in Dutch and at UMinho and IST, the activity was delivered in Portuguese.

In total 393 students participated in the activity (53 at TU Delft, 27 at KU Leuven, 6 at TU Dublin, 282 at IST and 25 at UMinho), of which 385 consented to be part of this research.

5.4.2. Data analysis

The research in this chapter took a mixed-method approach utilising the *Chinese Whispers with a Twist* as a case study to investigate what characteristics make the game-based learning exercise effective to practise and trigger reflection on the communication competencies of students of different engineering fields. The characteristics of this game-based learning activity are first analysed based on the performance of the groups using the scores given to each of the outcome drawings produced by each group during the activity. The rubric (Table 10), developed based on Stevens and Levi (2005) and the information present in the image in Figure 7, was used to score the drawings on the number, position, and colour of the objects. This way, the group performance can be quantified and comparisons made. All the drawings were scored by the researcher.

In addition, a paper-and-pencil questionnaire, delivered at the end of the activity, collected information on students' perceptions of their communication performance in the activity (*“1.1A. How good did you feel your communication skills were in this activity?*” on a 5-point Likert scale - very good, good, neither good nor bad, bad and very bad, and *“1.1B. Explain briefly why.*”), on points of improvement (*“1.2. What do you feel you can improve on?”* given a range of options [pay attention to details, listen to others, ask questions, reply to questions, describe information, write down information and other) and students could select more than one response) and on the importance of communication competencies (*“2A. Do you feel that this activity helped you to understand the importance of communication?*” on a 5-point Likert scale - strongly agree, agree, neither agree nor disagree, disagree, strongly disagree, and *“2B. Explain briefly why.*").

This study intended to investigate how effectively students performed as a group but also as individuals. The aspects that the students focused on in the rubric as a group and the aspects expressed by students individually are compared to see the effectiveness of students’ communication competencies.

In this paper, the open questions (1.1B and 2B) will be referred to as OQ1 and OQ2 from here on. Unlike OQ1, which was present for all implementations of the activity, OQ2 was added to the questionnaire only in the last three implementations (at TU Delft 2019, IST and UMinho) to gain a deeper understanding of the quantitative data. The quantitative data was originally the only method of assessment used to understand whether students gained awareness of the importance of communication competencies in the first implementations (TU Delft 2018, TU Dublin, KU Leven 2018 and 2019). The analysis of the data in such implementations suggested the need to add OQ2.

The open responses (i.e., students’ explanations) were analysed by a multidisciplinary team of researchers with backgrounds in psychology, engineering and education. A General Inductive Analysis was used, which is similar to Grounded Theory but instead of drawing a theory as in the Grounded Theory approach, it provides an understanding of how students experienced the communication activity (Thomas 2006).

Table 10 - Rubric used to compare the group outcome drawings to the image in Figure 7. One point was given to each item (objects, number, colour, position and details) of the rubric (maximum points = 43).

Objects	Amount	Colour	Position	Details
□ Tree	□ 3	□ Black	□ Middle	□ The tree on the left is the biggest (at the front) □ The tree in the middle is the smallest (at the back) □ The tree on the right is medium size (compared to the other two) □ The tree on the left has triangular tree top □ The tree in the middle has triangular tree top □ The tree on the right is circular
□ Bull/cow	□ 1	□ Black	□ Bottom right	□ Tail □ Horns □ Hear □ Head to the right
□ Fence	□ 1	□ Black	□ Bottom left	□ Horizontal alignment □ 4 horizontal wooden sticks □ 2 vertical wooden sticks
□ Grass	-	□ Black	□ Bottom	□ ¼ of the image
□ Ears of wheat	□ 2 bunches	□ Black	□ 1 bunch between the 2 trees on the left □ 1 bunch on the right	□ Each bunch has 3 ears of wheat
□ Mountain	□ 2	□ Orange and yellow	□ Background	□ Rounded mountains □ Orange on the top and yellow on the bottom
□ Sky	-	□ Orange and yellow	-	□ Orange on the top and yellow on the bottom

The analysis followed the steps described in Figure 8. The author of this thesis has started the coding process of the responses of the students. Codes were attributed to chunks of text of the responses. During this process, the author went back and forth to check the match between code and response. From all the responses 23 and 17 codes were created for OQ1 and OQ2, respectively. Then, the author searched for similarities in the codes and divided them into 2 and 3 categories for OQ1 and OQ2, respectively. The next step of the analysis was conducted by three other researchers. The author selected randomly 10 to 20 responses per OQ1 and OQ2 and gave them to the three researchers so that they could match the codes created by the author to the selected responses of the students. This step is intended to cross-check the codes created by the author. It turned out that the three researchers had difficulties matching the codes to the responses because the codes were too long and some of them were not single codes. The author and the researchers discussed the coding process in three zoom meetings. They shared previous coding experiences and how to improve the current codes. The author realised that it would have been smarter to have coded just a sample of the responses and have asked the researchers to check them at an earlier stage. However, the author gained experience in the coding process and familiarity with the responses of the students, which turned out to be useful for the reporting of the findings. The other researchers also found useful the fact that they had already codes as a starting point, as it speeded up the process. The group has decided to begin with the codes created by the author and refine them, i.e. reduce the number of words per code in a way that they could be self explicative but not too long, delete redundant codes and add missing codes. This process required three meetings because time was required to discuss and agree the new codes and test them. In the first meeting, the codes for the responses of OQ1 were discussed and then each person had to individually match those new codes to a sample of responses from OQ1. In the second meeting, researchers discussed whether the current codes for OQ1 were enough and match the responses, and revised the codes for OQ2. After the individual match of the new codes for OQ2, the researchers met the third time to discuss the match of the current codes to the responses of the students. At the end of this phase, the author and the three researchers have agreed to use 22 codes per question. After finding this agreement, the author and two researchers coded individually all the responses with the new codes. The other researcher calculated the Fleiss' kappa after this first round of coding. The researchers decided that it could be possible to find a better agreement on the codes attributed to all the responses and the first author met either with the two other researchers or with each one individually to find possible agreements. During these meetings, the researchers went through every response in which there was disagreement between the researchers, i.e. at least one code different. When this happened, the researchers explained their rationale for giving that code and when there was an agreement for adjustment, the codes were changed. This step was time-consuming but everybody gained more experience with the coding and understanding of the data. At the end of this phase, kappa Fleiss was calculated again.

Reflecting back, the author has gained a lot of experience in coding because she has learned from experienced researchers. Another interesting experience was that the author found working with people from different backgrounds very enriching, on the one hand, because she learned to see from different perspectives as people think and work differently and, on the other hand, these differences brought more insight and richness to the data analysis.

Quotes are provided to explain themes that emerged from the analysis. They are between quotation marks and have been labelled using the role, group and university of the students, e.g. 'C1.TUDublin' is a student from TU Dublin with role C of group 1. As more than one lecture was conducted for IST per day, those student codes were created as follows: 'A6.ISTTh1' is a student with role A, group 6, participating in the lecture on the first Thursday at IST.

To ensure consistency within the findings, Fleiss' kappa was calculated in R to measure agreement between the three raters (Fleiss 1971). After the first round of coding Fleiss' kappa = 0.571 and 0.630 for OQ1 and OQ2, respectively. After discussion among authors 1, 2 and 3 about their individual attribution of the codes, the Fleiss' kappa improved to 0.988 and 0.954 for OQ1 and OQ2, respectively. The agreement was not achieved when there was not a specific code to be attributed (e.g. a code regarding the outcome drawing: *"Because we got a good score"* A6.ISTTh1) or when students' responses were not well written grammatically.

	Steps	WHAT	HOW	WHO
	1	Coding of all responses of OQ1 and OQ2	Attribution of first codes to every chunk of text (23 and 17 codes were assigned to OQ1 and OQ2, respectively)	Researcher 1
	2	Identification of categories	Search for relationship in the data/codes (2 and 3 categories were created in OQ1 and OQ2, respectively)	Researcher 1
	3	Cross-checking codes	Individual match of first codes to 10-20 responses randomly selected in OQ1 and OQ2	Researchers 2-4
3x	4	Zoom meetings	Discussion about coding process and reformulation of codes (codes were reduced to few words, redundant codes deleted and missing codes added) and categories	Researchers 1-4
	5	Coding of all responses of OQ1 and OQ2	Individual attribution of new codes to every chunk of text (22 codes for both OQ1 and OQ2)	Researchers 1-3
	6	Checking reliability	Calculation of kappa	Researcher 4
2x	7	Zoom meetings	Discussion to find agreement (or not) on codes attributed to all the responses of OQ1 and OQ2	Researchers 1-3 or 1&2 or 1&3

Figure 8 - Process followed by the researchers during the qualitative data analysis of the responses students provided in open question 1 and 2 (OQ1 and OQ2).

5.5. Results

This section first presents the communication performance of students according to the group drawing scores. This is followed by reporting on the analysis of the perceptions of students, based on the quantitative and qualitative data provided in the questionnaire. Finally, it describes the benefits of the activity according to the quantitative and qualitative responses given by students in the questionnaire.

5.5.1. Students' performance

Seventy-two outcome drawings were produced by the groups over the five universities. The drawings' scores per category (objects, number, colour, position and details), as present in the rubric, are shown in Table 11. These scores give the aspects that the groups focused on during the activity and as a result, how effective each group of students performed.

The results showed that four groups: 4.TUDelft (drawing on the left in Figure 9), 1.TUDublin, 5.ISTMo3 and 2.ISTTh1 scored more than 75% of the points, meaning that the flow of communication between these participants worked effectively. These groups met most of the aspects present in the picture. They identified all the objects, number, colours, positions and even small details such as the ears of wheat. Conversely, 25 groups, as indicated by the drawing on the right in Figure 9, did not even score half of the points (Table 11), meaning that they had issues communicating with each other. They missed several aspects in the picture such as objects and their colours and number, as well as most of the details. The average groups, who met between 50% and 75% of the aspects of the picture, as shown by the example drawing in the middle of Figure 9, performed well on the identification of objects. However, some of these groups missed the colours of the objects, their number and positions, and other groups missed out on the details, as can be seen in Appendix G.

Table 11 - Drawing scores, assessed using the rubric, of the groups who score higher than 75% of the points (highlighted in bold) and less than 50%of the points. The maximum possible score was 43 points (with Mo - Monday, Tu - Tuesday, We - Wednesday, Th - Thursday and Fr - Friday).

University	**Year**	**Group ID**	**Rubric Scores**					
			Objects	**Number**	**Colour**	**Position**	**Details**	**Group Total**
TU Delft	2018	4	7	4	7	7	11	**36**
IST	2019	5 Mo3	7	5	7	7	9	**35**
IST	2019	2 Th1	7	5	7	5	11	**35**
TU Dublin	2019	1	7	4	7	6	9	**33**
IST	2019	2 Mo2	6	3	0	3	9	21
IST	2019	2 Mo3	5	3	4	2	7	21
IST	2019	5 Mo2	6	3	0	3	8	20
IST	2019	3 Mo3	5	4	3	5	3	20
IST	2019	3 Fr1	5	4	3	4	4	20
IST	2019	3 Th1	5	4	0	4	7	20
IST	2019	2 Tu2	5	3	4	3	5	20
IST	2019	2 Tu1	5	3	2	3	7	20
IST	2019	4 Th3	4	3	2	3	8	20
IST	2019	5 Mo1	6	2	3	3	5	19
IST	2019	4 Th1	5	3	4	1	6	19
IST	2019	1 Mo4	6	3	1	3	4	17
UMinho	2019	6	5	3	1	3	5	17
IST	2019	4 Tu1	5	3	0	2	7	17
UMinho	2019	5	4	4	0	3	6	17
KU Leuven	2018	2	4	3	1	4	5	17
IST	2019	6 Mo3	4	2	2	2	7	17
KU Leuven	2018	3	3	3	3	3	5	17
IST	2019	4 Mo2	5	2	0	4	5	16
IST	2019	4 Th2	4	3	1	2	6	16
UMinho	2019	1	6	4	0	4	7	15
IST	2019	5 Tu1	6	2	4	1	2	15
UMinho	2019	3	5	2	1	1	6	15
IST	2019	1 Mo2	3	2	0	3	6	14
UMinho	2019	4	4	2	0	1	5	12
Rubric Total			7	5	7	7	17	43

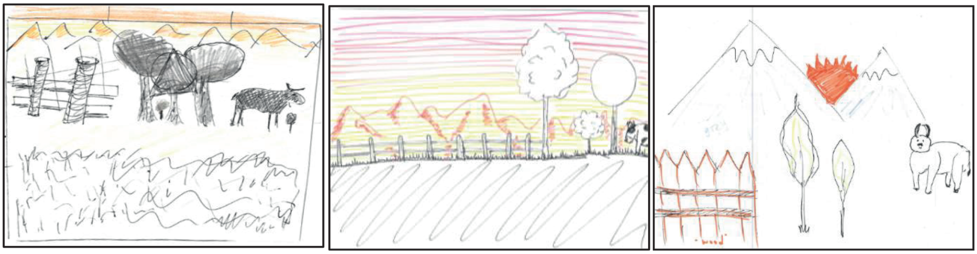

Figure 9 - Drawings of groups who score higher than 75% (left), between 50% and 75% (middle) and lower than 50% (right) of the points of the rubric.

5.5.2. Students' perceived performance

a. Communication competencies

Looking at students' perceptions of their performance in the communication competencies during the activity (Figure 10), 14% of the students mentioned they felt they were *very good* communicators and 63.1% of the students reported they felt they were *good* communicators. A small percentage of students, 20.5 and 2.3% perceived they were *neither good nor bad* or *bad* communicators, respectively.

To further investigate students' performance during the activity, students were asked to explain their perceptions of their communication competencies performance (OQ1). Two categories emerged from the qualitative data analysis of OQ1: C1) effective communication competencies and C2) ineffective communication competencies. The themes and the number of times students mentioned them are present in Table 12.

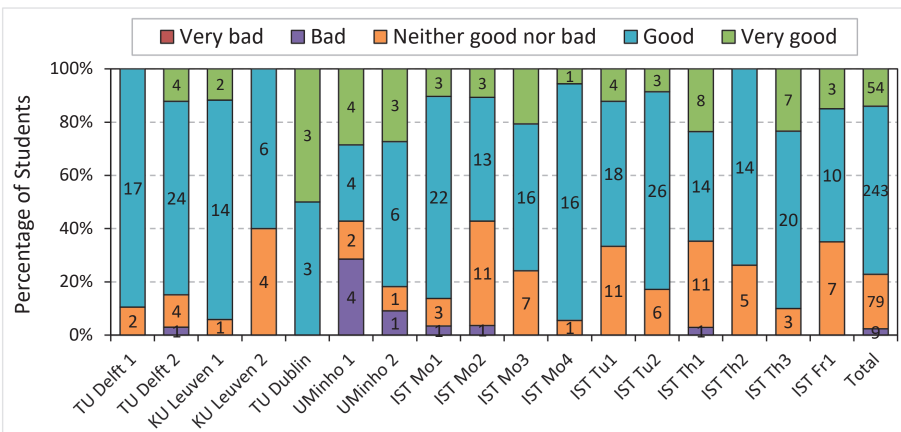

Figure 10 – Students' perceptions (n = 385) on their communication competencies on a 5-point Likert scale (very good, good, neither good nor bad, bad, and very bad).

Table 12 - Themes attributed to students' responses to OQ1 of the questionnaire (n = 385). # Students is the number of students who mentioned each theme.

Themes	# Students	
	Effective (+)	Ineffective (-)
Conveying/explaining/answering	167	36
Asking questions	48	28
Details	46	82
Planning/strategy	44	13
Listening	20	3
Managing	20	34
Taking notes	11	6
Noise	11	27
Observing	8	1
Participating	3	2
Remembering	2	16

The two categories and their associated themes are used to summarise how students perceived their communication competencies performance. Most students provided balanced experiences of effective and ineffective communication competencies during the activity. Since effective and ineffective experiences were reported by students for the same themes, they will be presented together.

(In)Effective communication competencies: Themes in these categories focused on the ineffective and effective communication competencies perceived by students and how that hinders or benefits their performance during the activity.

Conveying/explaining/answering+

Almost half of the students perceived they were effective communicators in the activity when they provided clear explanations and responses to the questions posed and conveyed the message to their peers. Examples that expressed these were:

"Everything was explained accurately." (A4.TUDelft2018)

"I tried to convey information as efficiently as possible by visual (charades) and descriptive (talking) means." (A1.TUDublin)

"I answered all questions with details known to me, without expanding into aspects not specifically asked for." (B1.KULeuven2018)

Conveying/explaining/answering-

This theme was not the most selected theme under the category *of ineffective communication competencies*, contrary to its opposite above. However, many students recognised they could have explained and answered better, be clearer and more coherent. Students also mentioned difficulties to convey, explain and respond to questions because they were disorganised and rushed, did not gather nor receive enough information, did not know how much information to provide and because time was limited. Also in this theme are comments in which students expressed that they did not describe or answer with detail. Examples of these were:

"Did not explain clearly the information to role C." (B5.ISTMo1)

"I could've responded more specific and detailed." (B4.ISTFr1)

> *"Because I was ineffective in explaining everything, I had seen in 2 minutes."* [T] *(A2.ISTMo2)*

<u>*Asking questions+*</u>

This was the second most referred to the theme under the category of *effective communication competencies*. Students mentioned what kind of questions they posed. They go from specific, in-depth and detailed to open and broad questions. Other adjectives students used were good, relevant, clear, useful and right questions. Students also stated how they formulated questions. They either asked a lot of questions, with a specific structure or asked questions based on the answers given. Examples in this theme were:

> *"Asked both in-depth and broad, general questions"* (C1.KULeuven2018)

> *"As C, I went straight to the point and started by "what did A describe to you?". After that, I asked questions like sizes, colours and relative positions."* (C2.ISTMo3)

> *"We overloaded the B's with open questions in a structured manner, getting a ton of information."* (C5.TUDelft2019)

<u>*Asking questions-*</u>

Issues with asking questions were identified by many students in the questionnaire. Some students mentioned they did not ask enough questions or that they asked questions that were too specific or too general. Students also stated they were not able to ask questions because they were nervous and limited by the time constraints. Examples provided by students were:

> *"I asked very specific and straightforward questions, instead of asking something broader."* [T] (C1.UMinho)

> *"I should have asked more specific questions"* (C5.ISTTu1)

> *"Because I was nervous, I didn't know how to ask the right questions."* [T] (C3.UMinho)

<u>*Details+*</u>

This theme contained all the comments under *effective communication competencies* that students stated the word *detail* or similar words to that effect. They mentioned that they wrote down details, paid attention to them, explained with enough detail, received detailed information and ask and answered with detail. Examples of these were:

> *"I focused on the details."* (B1.ISTTu1)

> *"I explained the details as much as I could."* [T] (A2.UMinho)

> *"I pay attention to details and transmit this information to others."* (A5.ISTMo1)

<u>*Details-*</u>

This theme was the most referred to under the category *of ineffective communication competencies*. As in the theme "*Details+*", every time details were mentioned in a negative context, it was considered in this theme. Several students in this theme stated they were able to describe information, answered and

[T] Sentences translated from Portuguese to English.

responded to questions effectively, however, they mentioned they forgot, mixed up, and missed details. In contrast, other students mentioned specifically that they did not describe some details, ask what details to draw, respond with detailed answers nor paid attention to details. Also, in this theme comments of students can be found that express the causes for not being able to communicate the details. The causes listed were time constraints, wrong focus, and large amounts of information received. Examples given by students in this theme were:

> *"We could communicate the most important aspects of the image but forgot to mention some details."* (A3.ISTMo1)

> *"When trying to get a lot of information given by my colleagues, I was not able to pay much attention to details."*[T] (B1.ISTMo2)

> *"I tried to communicate with detail in the simplest way possible but wasn't fast enough so some details were missing from my explanation."* (A4.ISTMo1)

<u>*Planning/strategy+*</u>

Under this theme, comments were found that showed that students had plans and strategies during the activity to describe, listen, ask, respond and draw the image. Some students only mentioned they were organised and had a structure in place. Others stated specifically their strategies, as seen in the following examples:

> *"We had a good strategy going from left to right and bottom to top. One person speaking."* (A6.TUDelft2019)

> *"We have grouped the information in different categories (trees, background, etc.)"* (B7.ISTTh3)

> *"We were able to divide tasks and prepare what we were going to say."* (A5.ISTMo3)

<u>*Planning/strategy-*</u>

On the other hand, some students stated that they lack planning and organisation during the activity. Most students stated these issues as a point for improvement. They realised they should have been more organised when taking notes and describing the image, planned what to say in the short time and to have a strategy of how to ask questions. Students' responses showing these issues were:

> *"More organization was enough. We both tried to speak, repeating many things and leaving others."*[T] (A4.ISTTh2)

> *"I could have asked more questions and not assume as much, and try to begin from left to right."* (C3.ISTTh1)

> *"Next time I would take this into account in the organization of the notes and in the way, I pass information."* (A1.ISTMo2)

<u>*Listening+*</u>

In this theme, comments of students that referred to listen, receive, pay attention, focus, capture and catch information were considered. Students mentioned they were able to receive the information described, listen to the questions posed and pay attention to details. One student also mentioned the importance of listening and show interest in the contribution of their colleagues. Examples in this theme were:

> *"I listened to both A's descriptions and C's questions attentively."* (B2.ISTMo3)

“Listened for most details” (B1.TUDublin)

“Listening to my colleague so that it is not just from my viewpoint” [T] (A2.UMinho)

Listening-

In contrast, three students reported encountering problems when listening either because of teamwork or because of time management issues. Examples provided by students were:

“Didn't listen/take into account the suggestion of another team player "C".” (2C.KULueven2018)

“It was hard to listen while in a hurry.” (5B.ISTTu1)

“When we started, we realized we only had 1:15 minutes left so we had to rush a bit, and we ended up causing group B to mishear "vaca" as "barra".” (5A.ISTMo2)

Managing+

This theme referred to time management during the activity. Few students perceived that time was not a limitation to complete their tasks during the activity and others were more specific, saying they were efficient using their communication competencies. Examples in this theme were:

“There was enough time for it.” (B1.ISTTu2)

“Fast and effective communication.” [T] (B2.ISTTh1)

“We managed to tell most of it in two minutes.” (A6.TUDelft2019).

Managing-

Students mentioned *“Managing-”* more frequently than “*Managing+”* which means that more students found that managing the limited time of the activity harder. Due to time constraints, students stated they forgot information, could not take all the notes nor listen attentively and were not able to describe things clearly, because they were either too fast or too slow, focused too much on details, or failed to mention them all. Students expressed time management issues as follows:

“Passing all the information was difficult in 2 minutes.” [T] (A2.ISTTu1)

“Time constraint makes you forget the simplest questions.” (C2.TUDelft2019)

“We spent too much time in discussing detail on a particular part of the sketch and that resulted in explaining badly in a rushed manner the other elements." (A4.ISTMo1)

Taking notes+

Most students in this theme mentioned that they took notes to be able to transmit the information they saw. Few of them also took notes while listening to the description of the image. Students expressed these as follows:

“I think I wrote down all the right details.” (A2.TUDelft2018)

“Everything that was in our notes was successfully passed to group B.” [T] (A5.ISTTh3)

“When listening, I tried to balance sheer memory and note-taking.” (B1.ISTTu1)

Taking notes-

Under this theme, students recognised they should have taken notes and not only memorised the information received. Also, students who took notes mentioned they were slow or did not take the right notes. Examples given by the students were:

"I should have written the details rather than memorize everything." (3B.ISTTh3)

"I couldn't write down all the information I got." (3B.ISTTu1)

"Because the notes I had taken weren't very helpful." (5B.ISTMo1)

Noise+

Comments in this theme referred to the understanding and interpretation of information. Some students stated their colleagues understood what they described and asked. Other students realised that they understood the information they received. Examples in this theme were:

"For my part, everything I described was well interpreted." [T] (A6.ISTMo4)

"I managed to make myself understood in the questions I asked and I understood everything I was told." [T] (C1.ISTFr1)

"I didn't start drawing until I understood exactly what and where everything in the picture is." (C1.TUDublin)

Noise-

More students have identified this theme than *"Noise+"*. Comments here were references to barriers in students' communication, such as the assumptions they made and their lack of understanding. Students mentioned that their predefined ideas made them wonder about what to and how much to describe, what kind of questions to ask, and how detailed they should have answered. Another barrier pointed out by students was the lack of understanding of the activity itself, and of what others described and asked during the activity. Examples of this theme were:

"Found myself somewhat limited by my own pre-conceptions of what I would and could not do." (B4.UMinho)

"Assumed things that weren't said (assumed sky was blue, grass was green…)" (C2.ISTTu2)

"Lack of understanding in the questions" [T] (B6.UMinho)

Observing+

Comments here referred to observing and analysing the image to capture the necessary information to be transmitted for the next group. Not surprising, this theme was only referred to by students in role A as it was their given function. Examples provided by students were:

"I was able to observe a lot of details." [T] (A5.UMinho)

"I think we did a good job at analysing the image." (A5.ISTMo1)

"We managed to capture more of the important aspects." (A6.ISTMo1)

Observing-

Only one student mentioned not observing the image effectively as follows: *"I did not observe attentively the smallest details of the images."* (6A.ISTMo1)

Participating+

Under this theme, students stated they participated actively in the activity. One student referred to their participation and the other two to the work in groups, as follows:

"Interventional, interested, commented." [T] (C5.ISTh2)

"Because we were all working for the same thing and there was a commitment from everyone to be able to draw." [T] (C3.ISTMo1)

Participating-

Only two students mentioned that they did not participate actively during the activity. Examples of these were:

"I didn't speak too much." (1B.ISTTu2)

"I felt I could've interacted more in answering the questions." (2B.ISTFr1)

Remembering+

In this theme, only two students in role B mentioned that they were able to keep the information described to them: *"I was basically able to retain the necessary information to help describe what the drawing would become."* [T] (B5.ISTMo4).

Remembering-

Many more students referred to this theme than *"Remembering+"*. They recognised that their memory was not good enough because they forgot something. Also, students specifically mentioned they forgot to describe the details of the image and to provide all the details received and ask certain questions. Students mentioned that time constraints and assumptions were the cause for forgetting to explain and ask. Examples provided by the students were:

"My memory could be better." (7B.ISTTu1)

"We forgot some details when answering C's questions." [T] (5B. ISTMo2)

"Time constraint makes you forget the simplest questions." (2C.TUDelft2019)

b. Points for improvement

The researchers were also interested in investigating whether students recognised points for improvement (Figure 11). Pay attention to details and describe information were points for improvement frequently indicated by students in the three roles (Figure 11). Other points for improvement indicated by students were describing information clearly, slower or faster, with more detail and from general to detail, asking for clarification and more questions, managing time, organising speech and planning a strategy to describe information, listening before rushing to draw and take notes and not assuming or ignoring information.

5.5.3. Importance of communication perceived by students

Students were also asked whether this activity helped them to understand the importance of communication and why. The results of the questionnaire showed that 38.7% and 52.5% of students *strongly agreed* and *agreed*, respectively, and that this activity helped them to understand the importance of communication

(Figure 12). Only 7.8%, 0.8% and 0.3% responded *neither agree nor disagree*, *disagree* and *strongly disagree*.

To further explore the quantitative data, the written explanations of the students were analysed. Three categories emerged from the qualitative data of OQ2: C1) Awareness, C2) Experience and C3) No gain. Themes arising from the analysis were grouped into one of these categories (Table 13) and were used to summarise the benefits of the activity perceived by students. The findings showed that this activity created awareness and experience of communication competencies for most students.

C1) Awareness: This category concerns the awareness students gained during the communication activity. Most students perceived they gained awareness of this activity.

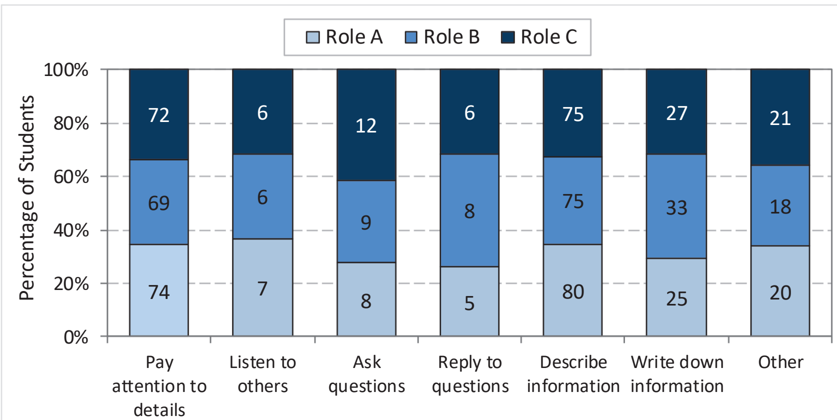

Figure 11 - Points of improvement indicated by students (n = 385) per role (A, B and C) More than one option was allowed.

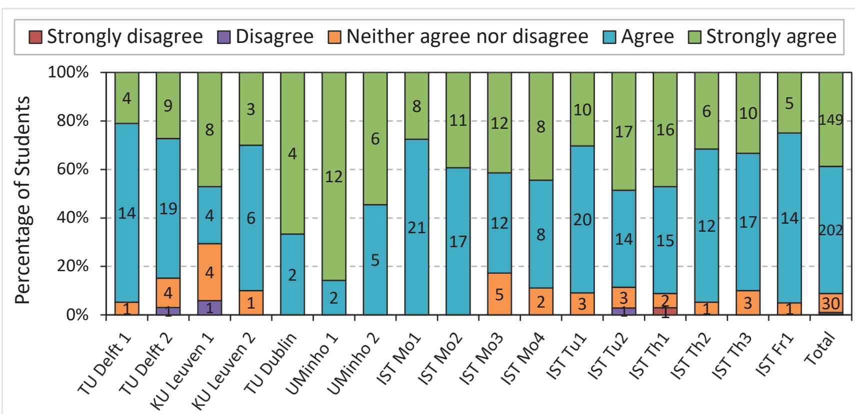

Figure 12 - Students' perceptions (n = 385) on whether this activity helped them to understand the importance of communication on a 5-point Likert scale (strongly agree, agree, neither agree nor disagree, disagree, strongly disagree).

Table 13 - Themes and categories that emerged from students' responses to OQ2 of the questionnaire (n = 385). # Students is the number of students who mentioned each theme.

Categories	Themes	# Students
C1) Awareness	Barriers in communication	67
	Details	49
	Conveying/explaining/answering	46
	Team/group communication	42
	Importance of communication	37
	Asking questions	26
	Managing/planning/organising	22
	Understanding	21
	Strengths and points for improvement	20
	Listening	19
	Assumptions	10
	Taking notes	8
	Communication styles	8
	Observing	1
C2) Experience	Communication process	15
	Team/group communication	7
	Engagement/fun	5
	Interaction between people	2
C3) No gain	Have awareness already	18
	Nothing new	6
	Have experience already	4

5

Barriers in communication

This theme was the most selected by students. General comments about the difficulties in the communication process were pointed out by students here. Students perceived that effective communication is hard because information can be easily misinterpreted or lost in the communication chain. These difficulties impacted communication outcomes according to students. For that reason, they recognised that communication should be as concise and clear as possible. Examples given by students were as follows:

> *"I had no idea how hard it could be to transmit information between sources*." (A2.ISTTh3)

> *"It was a good way to show how information can get lost, twisted and wrongly interpreted in a verbal description."* (A4.ISTFr1)

> *"Because we realize the impact that communication failures can have on a project's final result for example."* [T] (A6.ISTTh1)

Details

Under this theme, comments that referred to details were grouped. They go from paying attention to details, providing detailed explanations and responses and asking detailed questions. Students also mentioned how details can be easily lost and forgotten and how selecting and communicating the fundamental details can impact the communication outcome. Examples provided by students in this theme were:

> *"This activity helps us to understand how important it is to pay attention to details, ask the right questions and in detail."* [T] (A1.ISTMo4)

"Interesting to see the amount of detail that's lost when communicating, especially the thing that seem obvious like it's a silhouette." (C3.TUDelft2019)

"It's a good example of how missing one detail/getting something wrong can make a huge difference in the outcome." (C4.ISTMo3)

Conveying/explaining/answering

This theme encompassed comments in which students were specific about providing clear and concise information. Some students expressed how this activity helped them to gain awareness of this and others mentioned the consequences of not doing it effectively. Examples in this theme were:

"It's important to understand what to answer when you need to pass some information." (B7.ISTMo3)

"You should really try to explain something with a neutral base and think about possibilities how it may be understood wrong." (A5.ISTTu1)

"The hurried speech was responsible for communication failures."[T] (C5.ISTTh1)

Team/group communication

Under this theme were general comments in which students referred to gaining awareness of the difficulties of working in teams, the communication flow between team members, and the engineering role in the team. Students' responses in this theme were:

"The information required strongly depended on the efficiency of the communication between each group." (C2.TUDelft2019)

"Because it helped understand how communication can be lost between two groups." (C1.ISTMo4)

"*It's important for us to be aware of what happens in the "real" world, as we will play roles that may be included in any of these roles*." (A5.ISTTh3)

Importance of communication

It is not surprising that *the importance of communication* was mentioned by students, given that they were prompted (in the questionnaire) to explain how the activity helped them to understand the importance of communication. Comments in this theme were generic in which students stated that communication is key to achieving objectives, is essential for engineers and generates interaction with others and relationships. Also, in this theme, comments were given that referred to the positive impact of communicating effectively, especially in engineering professions. Students expressed the importance of communication as follows:

"Communication is the basis of all relationships. It is important to know how to communicate to get the best results, especially if there are intermediaries." (B4.ISTMo2)

"Because good communication is essential when trying to describe things to others, otherwise the information transmitted might be misunderstood." (A5.TUDelft2019)

"This activity is definitely associated with the computer software production cycle. This process is only possible if there is effective communication." (A1.ISTTh1)

Asking questions

Under this theme, students stated that this activity helped them to gain awareness of effectively asking questions. Students mentioned that making all the necessary questions (general and in-depth) help their understanding, acquisition of information and transmission of the message received. They expressed these as follows:

> *“It showed me the importance of details and questioning the aspects we usually take for granted.”* (A1.ISTMo1)

> *“The straightforward question of team C: "What did they describe you?" made me realize that there are sometimes "out of the box" ways to achieve goals through communication. It allowed me to give a much more comprehensive description than with more closed questions.”*[T] (B2.ISTFr1)

> *“Being able to express ideas well and try to ask the important questions help to pass information better between people.”*[T] (C5.ISTMo3)

Managing/planning/organising

Comments here referred to the importance of structuring and selecting information and having a strategy or plan to transmit the message. Students referred to this often due to the time constraints. Examples in this theme were:

> *“Explaining things more succinctly and organised leads to better results”* (C5.ISTMo1)

> *“Because it is through efficient (time) and effective (results) communication that you can communicate in the best way*.”[T] (A2.ISTTh1)

> “*Because not always we have all the information to give or the time to give it correctly and we must learn how to deal with that.”* (A3.ISTMo2)

Understanding

In this theme, students mentioned that this activity helped them to think about the perspective of others, to recognise that not everybody has the same information, and how one should be concise and clear when communicating to create understanding in others, otherwise, communication is affected. Students showed these with the following examples:

> *“If the communication is not done properly, then the other's understanding will be affected.”* (B1.ISTMo1)

> *“It was important to understand each phase of communication and remember that not all groups had access to all the information.”*[T] (C1.ISTTu1)

> *“It's very important to know to describe what we want to describe and to make sure the person on the receiving end is setting the idea we want to transmit*.” (B2.ISTMo2)

Strengths and points for improvement

This theme referred to comments of students showing that this activity helped them to recognise where students failed during the activity and to reflect on their strengths and points for improvement. Examples of students’ responses were:

> *“It forces each group to think where we failed and to rethink.”*[T] (C1.ISTTu2)

"It helped me to understand that I'm really bad at writing down the important information." (B4.ISTMo1)

"I already knew how to ask questions. In fact, I did it well."[T] (C4.ISTTh1)

Listening

Under this theme, students were specific about the importance of listening and paying attention to others. Students often mentioned that without this skill, one is not able to understand others nor effectively transmit the information received. That was why this theme often appeared with the theme *conveying/explaining/answering*. Examples of students were:

"It proved that listening to others is important in order to be able to later describe better." (B6.ISTTh3)

"It's important to listen to other people and to ask specific questions in order to get a better understanding of a particular situation." (A3.ISTMo3)

"It helps to realize the importance of paying attention and writing information in order to be able to convey it clearly." (B5.ISTMo4)

Assumptions

Responses in this theme were specific to assumptions that people make and the importance of not making them by paying attention to what is transmitted and to ask questions when there is not enough information to make conclusions. Students showed these with the following responses:

"We can conclude that we often start from assumptions (like the colour of the elements of the image) instead of really thinking. We are pre-formatted to communicate taking this information into account."[T] (B2.UMinho)

"Pay attention to details and, mainly, do not assume information that was not said."[T] (C2.UMinho)

"It made me realize that when lacking information, ask questions first, rather than assuming my point of view is correct." (C7.ISTTh3)

Taking notes

Under this theme, students mentioned how important taking notes is, along with listening, to be able to remember information and provide clear messages. Examples of how students showed these were:

"Helps to understand the importance of paying attention and writing information in order to be able to transmit it clearly."[T] (B5.ISTMo4)

"It is extremely important to listen carefully before writing any notes."[T] (B5.ISTMo4)

"It also showed that I need to write stuff down, memory is not enough." (B6.ISTTh3)

Communication styles

Students indicated that this activity helped them to gain awareness that people are different as they see, think and perceive differently. This theme is often linked with themes like *conveying/explaining/answering* and *understanding* because students realised the need to put themselves in the other person's shoes and adapt communication to them and be clear and concise to convey information. Examples considered in this theme were:

*“People interpret things the way they want to, not like it’s actually said.” (*A6.TUDelft2019)

*Because with this activity I realized that not everyone imagines the same things by just saying the word 'tree' for example. (*A2.UMinho)

“Often people have to realize that we are all different, which will imply that we all have different perspectives and that if we don't know how to explain it properly there will be misinterpretations.”[T] (A2.UMinho)

<u>Observing</u>

5

This theme was only mentioned once and the student stated they gained awareness of several ways of communicating through the activity and one of them was observing (*“Because the dynamics showed the complexity of communication in several ways, from observing, speaking, paying attention, listening, knowing how to ask the right question for a less distorted conclusion as possible.”*[T] A6.UMinho).

***C2) Experience*:** This category is characterised by the experiences students had during the communication activity.

<u>Communication process</u>

Responses under this theme were general comments in which students practised and improved their communication competencies and experienced the communication process existing in the engineering real world. Examples in this theme were:

“*I believe it was a good exercise to develop other ways of communication*.” (A4.UMinho)

“It's a good basic exercise to show how important small things can do with wrong information.” (B4.TUDelft2019)

“*It was important to showcase communication in a similar way to what might happen in a more hierarchic, professional setting*.” (A5.ISTMo3)

<u>Team/group communication</u>

Different from the previous theme, comments here were specific when students experienced teamwork within this activity and related to engineering work experiences. Examples in this theme were:

“As it evolved 3 teams and each one had their responsibilities, the only way to achieve the goals was to make sure everyone communicated well to one another.” (A3.ISTTu1)

“This is a brilliant example/exercise of what transmitting core information is, between working groups, which in engineering is essential.” (B1.ISTTu2)

“This activity showed us an example of what we are going to find after starting to work. Clients provide information on what they want to the project manager, which by their turn forward such information to the developers. It is not long for the three parties to explain/receive information.” (A7.ISTTh3)

Engagement/fun

Under this theme, comments were listed that showed that students enjoyed the activity. For example:

"I found the dynamics amazing!"[T] (B3.UMinho)

"It's a really simple activity which can be understood from everybody, that in a short time evolves from the very beginning to the finished product." (C4.UMinho)

"It was a fun experience."[T] (B6.ISTTu2)

Interaction between people

Only two students identified that this activity allowed them to work with people they did not know. An example of this was:

"*Good initiative to interact with strangers, one of the situations that do not occur often in our lives"* (A2.ISTTu2).

C3) No gain: This category is defined by themes in which students mentioned they did not gain any awareness, experience or anything else by taking part in the activity.

Have awareness already

Students in this theme stated they had awareness of the importance of communication already before the activity. However, most of them still mentioned that this activity improved their communication awareness or experience. Examples given by students were:

"I already knew how important communication is. This only makes it more clear." (B7.ISTTu1)

"I already knew the importance but more at the theoretical level, here I was able to practice the consequences of good and bad communication."[T] (A2.ISTFr1)

"I knew it. It did prove it." (A2.TUDelft2019)

Nothing new

Few students mentioned that they did not gain anything from this activity either because it was too short or too simple or because it was not useful for them. Examples of how students expressed this theme were:

"*One hour isn't enough to learn anything new about a topic that important as communication.*" (B7.ISTTu2)

"*In the meantime, I don't really feel that I gained or lost anything from this activity.*" (C2.ISTMo4)

"*I don't really see the point of the exercise; it is too artificial to be useful, plus, regularly we don't have such time constraints when we're doing important communication activities."* (B7.ISTTu2)

Have experience already

Comments in this theme were similar to the theme *Have awareness already* but, in this case, students mentioned they already had experience with communication. Examples provided by students were:

"I already knew how to ask questions." (C4.ISTTh1)

"*Before this activity, multiple life events had already shown me that communication is key, not just for work-related activities, but for general life purposes.*" (B1.ISTMo4)

5.6. Discussion

The main research question of this study was: *"What are the characteristics of a game based-learning practice that stimulates engineering students to practise and trigger reflect on their communication competencies?"* Having used a mixed-method approach and the *Chinese Whispers with a Twist* as a case study, it was found that the characteristics that make the activity effective are active participation, engagement, rules, reflection, risk taking and cooperation. This section will discuss the evidence provided by the data analyses for the identification of these characteristics.

As present in the literature (Garris, Ahlers et al. 2002, Bodnar, Anastasio et al. 2016), games engage students because they are interesting and enjoyable. This activity is effective as a game-based learning activity because students actively participate and engage in the activity as they reported in the qualitative data of both open questions under themes *"participation+"* and *"engagement/fun"*. Through engagement and active participation, students indicated that they gained awareness and experienced communication competencies.

Rules are an element of games, as they are set by rules (Garris, Ahlers et al. 2002). The rules in this activity were that students had limited time to describe the image, listen, ask and answer questions, and that they could not ask questions for clarification. Some students did not find the rules a constraint to their communication competencies as evidenced by the themes *"planning/strategy+"* and *"managing+"*. Because students had a strategy in place to observe the image, transmit information and ask questions, they were able to manage their time well during the activity. On the other hand, for some students, the rules imposed on students caused difficulties in communication to certain students. This was verified by the ineffective communication competencies perceived by students under themes *"planning/strategy-"* and *"managing-"*. Here, students had issues with planning and managing time during the activity and they perceived points for improvement including the organisation and time management of their speech, their listening skills and taking notes.

Another characteristic that makes this activity an effective game is the reflection. This finding can be seen from two perspectives. First, we found that students indicated *"effective and ineffective communication competencies"* when they reflected on their communication competencies asked in the questionnaire. The quantitative part of the questionnaire showed that most students perceived they were effective communicators, however, many identified points for improvement. The qualitative part of the questionnaire corroborated these findings as students perceived that their communication competencies were both effective and ineffective during the activity.

It is evident from the questionnaire that students reflected on issues with the details. In the quantitative part of the questionnaire, *"pay attention to details"* was the second most frequently indicated point for improvement by students. In the qualitative part, the theme *"details"* was frequently mentioned by students, either as effective but mostly as ineffective communication. Under this theme, students stated they did not pay attention to details, describe with detail, nor answer and ask in detail. This finding was also verified in the rubric as the category *"details"* obtained fewer scores compared to the other categories.

Reflection on another point for improvement often indicated by students was *"describing information"*. This outcome was also found in the qualitative data in which students perceived they did not convey, explain and answer effectively. Other themes that emerged from the qualitative analysis, which were also present in the quantitative data were *"listening"*, *"asking questions"* and *"taking notes"*.

Evidence was found in the qualitative analysis of additional findings which was not present in the quantitative data. Students reflected on the barriers in communication, the need to be clear and concise when communicating with other people, and think about the others' perspectives by putting themselves in the shoes of others to avoid misinterpretations when they communicate. These findings, under themes *"Noise-"* and *"Barriers in communication"*, showed that this active learning activity provided students with reflection on communication competencies such as *adaptive communication style*, which were present among the most important competencies desired by the industry in *Chapter 3*, and *pitching skills*, which were not yet mastered by engineering students as shown in *Chapter 4* nor practised much by lecturers as presented in *Chapter 3*.

The other perspective in which the occurrence of reflection was verified is in the feedback session at the end of the activity. This session was intended to link what happened in the game and the engineering real-world (Garris, Ahlers et al. 2002). In these feedback sessions, students were able to draw a parallel between the activity and engineering work as present in the theme *"team/group communication"*. This is an interesting finding as this activity was designed to plug-and-play in a free context, although created to mimic an engineering environment of communication in teams. According to the contextual learning approach, activities should be contextualised to help students to connect academic content to the context of real-life (Johnson 2002). In this activity, the connection between the activity and the real engineering environment was possible because the reflection was guided by lecturers to the context of each engineering field. We believe that the outcomes of the qualitative analyses can guide educators in this feedback session at the end of the activity which was intentionally positioned to allow students to learn from their mistakes and reflect on what they have done and learned.

As in previous game-based studies (Garris, Ahlers et al. 2002), this activity gave students a training environment in which they could take risks and make mistakes without consequences. This is evident by the drawing scores measured with the rubric that showed that many students failed to communicate in this activity, as many groups did not obtain even half of the total number of points for their drawing outcome, and the qualitative analysis that demonstrated that students identified ineffective communication competencies, however, students still produced an outcome without consequences.

Finally, another characteristic of the activity that makes it effective is its cooperative nature. Students perceived that this cooperative activity allowed them to interact with other people, experience teamwork and become aware of team communication as evidenced in the second open question of the questionnaire under themes *"interaction between people"*, experience and awareness: *"team/group communication"*, respectively. Similar results were found in previous research where students' interpersonal interaction increased within teams compared to individual work (Johnson and Johnson 1998) and communication and teamwork were developed in cooperative learning environments compared to lectures (Terenzini, Cabrera et al. 2001).

5.7. Conclusion, limitations and future work

The research presented in this chapter investigated the outcomes of the implementation of a communication activity called *Chinese Whispers with a Twist* as a case study of a game-based learning practice over five engineering institutions. The activity was designed to practice and reflect on students' communication competencies such as describing information in a short time, listening skills, and ask and respond to questions. This research provides support for the effectiveness of this activity as a game-based learning practice in engineering education because students actively participated and engaged in the activity, had to follow rules, reflected on their communication competencies and the existing communication barriers and styles, gained awareness and experienced communication in teams and cooperated with different people. The author encourages educators to use activities, such as the one presented in this chapter, to put students in active learning activities where they work in teams and practise and reflect on their communication competencies.

This research also contributes to engineering education with the robust methodology used. A mixed-method approach was applied to analyse the learning outcomes. Also, a scoring rubric, using a ratio scale on which the elements displayed in the image can be quantified, was used to measure students' communication performance. Students' perceptions were analysed using both quantitative and qualitative approaches. The quantitative analysis allowed for defining a precondition that the activity is effective to practice and stimulate reflection on communication competencies. The qualitative analysis was used to complement and enrich the data of the quantitative approach and extensive and continuous iterations were applied by the researchers during this qualitative phase to provide truthfulness to the results. Also, the material necessary to replicate the research study and re-implement the activity in other universities was made freely available. Finally, a large sample size of students of different engineering universities was used. The authors wholeheartedly recommend researchers and educators to work in multidisciplinary teams and provide transparency during the research process as conducted in this chapter.

The main limitation of the research in this chapter is that it is a case study and the results are contextual to participating engineering students and may be different for other cases (Cohen, Manion et al. 2013). However, the findings over the five different engineering universities indicate that they can be transferred to other engineering contexts.

A further limitation is that the last question of the questionnaire *("Do you feel that this activity helped you to understand the importance of communication?"*) may have biased the students to presume that communication is important. The authors recommend rephrasing this question in future uses of the questionnaire to a more neutral question, for instance: *"what did you learn from this activity?"*.

As future work, there is value in conducting interviews with past participants to investigate the benefits students perceived with the activity in the long term, i.e., whether students remember the activity and how it shaped their communication competencies in the period after they took part in the activity. This will be explored in the next chapter.

"It's never crowded along the extra mile."

Wayne Dyer

CHAPTER 6

Exploring the effectiveness and the transversal competency retention of the *Chinese Whispers with a Twist* activity one year later

This chapter is based on the published article:

Leandro Cruz, M. and Saunders-Smits, G. N. Exploring the effectiveness and the transversal competency retention of a game-based learning activity one year after student participation. Submitted for publication to the *Journal on Teaching Engineering*. 1(1): 94-112.

6.1. Introduction

In *Chapter 5*, it is reported a game-based learning activity, the *Chinese Whispers with a Twist*, created to help students to practice and trigger reflect on their communication competencies. The research presented in *Chapter 5* investigated the effectiveness of this teaching activity immediately after the intervention. The findings showed that the characteristics that make the game-based activity effective were active participation, engagement, rules, reflection, risk-taking and cooperation.

While the previous chapter is a full research study, the current chapter is only an exploratory study. This type of study is conducted to understand a phenomenon, especially when there is a lack of sufficient information about a topic or to show whether it is worthwhile or feasible to conduct the research (Creswell 2003, Sarantakos 2005). This study aims to develop an initial understanding of what students retain of the game-based learning activity or, in other words, how much effect this intervention had on students' communication competencies after a certain period to provide a platform for further investigation. It is expected that these findings will show what characteristics make the game-based learning activity effective to stimulate students to practice and trigger reflect on their communication competencies one year after student participation. In this exploratory study, semi-structured interviews were conducted with one cohort of students to investigate whether engineering students remember the game-based learning activity and what they recall from their performance and experience in the activity, and what benefits they feel they have gained from the activity one year after their participation.

6.2. Methods

The research in the current chapter is an extension of *Chapter 5* to explore the characteristics that make the *Chinese Whispers with a Twist* activity effective to retain the transversal competencies of the participating students.

The sampling strategy used in this chapter is convenience sampling (Cohen, Manion et al. 2007). The researcher has purposely selected the cohort of engineering students who attended the *Chinese Whispers with a Twist* activity at TU Delft in March 2018. There were two reasons for this choice: first, these students belonged to the same university as the researcher, which facilitated the interviewing process and second, the interviewing period fitted into the time frame of the researcher's doctoral thesis. As this study is only exploratory and no generalizations will be done, this choice does not hinder the outcomes (Cohen, Manion et al. 2007). This cohort of students will be named cohort TU Delft 2018 from here on.

All twenty-one students of the cohort TU Delft 2018 were contacted by email to take part in a semi-structured interview. The use of interviews was selected to explore the characteristics previous identified in *Chapter 5* and to gather a deep understanding of what students retain of the game-based learning activity (Creswell 2003, Cohen, Manion et al. 2007). Students were offered a chocolate bar of *Tony's Chocolonely* for their participation. Without selecting the students, out of the twenty-one students, nine accepted to be interviewed. This sample consisted of five males and four females, of which five were Dutch students and four were international students coming from the United Kingdom, Greece, Spain and India.

The interviews were conducted in English and took place between 25 March and 21 April 2019, one year after students participated in the *Chinese Whispers with a Twist* activity. The period of one year between students' participation and the interviews was chosen for this exploratory study to investigate the validity of this activity to stimulate students' practise and reflection of their communication competencies, although other periods would be interesting to investigate. The interviews lasted approximately one hour. The following questions were asked to students:

1. Do you remember this activity? (The author showed the image students had to draw, present in *Chapter* 5, Figure 7 to refer to the activity.)
2. What was your role/function in this activity?
3. What do you remember from this activity?
4. How did you perform in this activity?
5. How did you experience this activity?
6. What were the main key takeaways of this activity? What are the most important aspects you learned from this activity?
7. In what ways do you think your participation in this activity has affected your communication competencies?
8. In your opinion, what is the best way to learn communication competencies?

The outcomes of questions 1 and 2 will be presented in section 6.3.1, questions 3 and 4 in section 6.3.2, questions 5 and 6 in section 6.3.3 and finally, questions 7 and 8 will be reported in section 6.3.4.

The interviews were recorded and transcribed using *HappyScribe* by the researcher, as described in *Chapter 3*. They were analysed with a General Inductive Analysis to acquire students' experiences during the activity (Thomas 2006), as motivated in *Chapter 5*. The coding phase was carried out in *Microsoft Word*. The author coded each transcript assigning a combination of coding methods: previous codes used in the analysis of the open responses in *Chapter* 5, section *5.6. Results* (Table 12 and 13) and descriptive codes that emerged from the data (Saldaña 2016) to parts of the text which the author felt that students experienced communication competencies with the activity. This coding approach is intended to corroborate and possibly complement the findings of *Chapter 5* (Saldaña 2016). Having codes from the previous chapter helped to relate to what students mentioned they experienced with the activity in the previous study and to identify similar experiences. The author went back and forth to chunks of text and the codes attributed to them and scanned the transcripts to check whether there were missing experiences. Next, the author extracted the chunks of text and grouped them based on similar codes and attributed the categories based on the codes, which turned out to be the same as in *Chapter 5*. Since the categories are the same, their definitions will not be repeated in this chapter as they can be found in *Chapter 5* sections *5.6.2. Students' perceived performance* and *5.6.3. Importance of communication perceived by students*. The previous and new themes are explained with students' quotes. They are between quotation marks and are associated with each interviewee. All data were analysed anonymously and students were given a random identification code from S1 to S9.

6.3. Results

In this section, the findings that emerged from the interviews conducted one year after students participated in the *Chinese Whispers with a Twist* activity are presented. This section starts by showing that all students remembered the activity. This is followed by an analysis of students' communication performance perceived by the students. Finally, the benefits that students reported they gained from the activity are described as well as how students think they best learn communication competencies.

6.3.1. Students' memory about the activity

The first goal of the interviews was to understand whether students remembered the activity and what they remembered. The author showed the image that students were asked to communicate and draw during the *Chinese Whispers with a Twist* activity to the students and all of them immediately remembered the activity and the role they played in it. Students showed some of their memories as follows:

> *"I remember that someone had to look at this thing and the rest of us didn't know and then we had to draw what someone else's told us to draw and then it had to look like this."* (S2)

> *"I think, I had to pass on the information. Yes, like between the first one and then the third person."* (S5)

> *"We were a team of four people, four or five people and, I think, it was mostly about transfer of information, of how information is transmitted."* (S9)

6.3.2. Students' perceived performance one year after the activity

Students were also asked about how they performed during the activity. Two categories emerged from the interviews: C1) effective communication competencies and C2) ineffective communication competencies (defined in *Chapter 5*, section *5.6.2. Students' perceived performance*). The themes and the students who mentioned them are shown in Table 14. These categories and themes are used to summarise students' perceptions of their communication competencies. The themes of effective and ineffective communication competencies will be presented together because they were reported by students for the same themes.

<u>*Conveying/explaining/answering+*</u>

In this theme, students referred they described well and used the information they observed or heard to convey the message. However, for S1 effective transmission was not possible right from the start. S1 mentioned that the message was conveyed after some refinements. Students' expressions were:

> *"But the guy was very good in explaining, the guy who explained to us."* (S2)

> *"In how far I could bring the message across, it was OK."* (S5)

> *"But eventually they refined the way they were communicating so that I could understand what they meant and put it in context and tried to make a figure out of it."* (S1)

Table 14 - Themes and categories attributed in the previous chapter to the students' open-response 1 that emerged in the interviews with the nine students of cohort TU delft 2018.

Themes	Categories	Student codes								
		S1	S2	S3	S4	S5	S6	S7	S8	S9
Conveying/explaining/answering	Effective (+)	✓	✓			✓			✓	
	Ineffective (-)	✓	✓	✓	✓	✓		✓	✓	
Asking questions	Effective (+)	✓	✓	✓						
	Ineffective (-)	✓		✓		✓		✓		✓
Details	Effective (+)		✓		✓				✓	✓
	Ineffective (-)			✓	✓				✓	✓
Planning/strategy	Effective (+)		✓						✓	
	Ineffective (-)		✓							
Listening	Effective (+)	✓						✓		
	Ineffective (-)					✓				
Managing	Effective (+)		✓							
	Ineffective (-)									✓
Taking notes	Effective (+)						✓			
	Ineffective (-)									
Noise	Effective (+)									
	Ineffective (-)	✓	✓	✓	✓	✓		✓	✓	
Observing	Effective (+)									
	Ineffective (-)								✓	
Participating	Effective (+)									
	Ineffective (-)									
Remembering	Effective (+)									
	Ineffective (-)					✓				

Conveying/explaining/answering-

Almost all the students mentioned this theme. Students realised they could have described the image differently. Some students mentioned they should have given fewer details and more critical information, others said they could have described more accurately. They also realised that describing the image was not an easy task and that they omitted certain aspects that they assumed the receiving party would know implicitly. Students also referred to the difficulties they experienced when answering the questions because either they did not have enough information to respond or they did not understand the information transmitted. Examples under this theme were:

“The implicit details that I assumed I didn't get across.” (S8)

"There were some answers they couldn't give us." (S3)

“Because when you're actually describing it you realise it's not as easy.” (S7)

Asking questions+

Students in this theme mentioned what questions they asked (including detailed and clarifying questions) and how they asked questions (for instance creatively) to communicate effectively. Examples provided by students were:

“We did ask questions. I did ask. They were like clarifying questions rather than more general kind of questions.” (S4)

“Then we had to kind of creatively ask around to still find an answer.” (S3)

Asking questions-

Under this theme, students mentioned they were not able to ask the right questions or asked insufficient questions. Other students remember they were too impatient to wait for the answers. Examples of these were:

“I wanted to say things like they were not asking.” (S9)

"I and the other person in the last role were both a little impatient waiting for the whole answer." (S3)

Details+

Students in this theme referred specifically to the details they described, asked and draw. Examples of these were:

“I think we had most of the things.” (S2)

“So I was really looking for specific information.” (S4)

“We distributed the work between basically the large overall part and the details.” (S8)

Details-

Students indicated that they did not describe certain aspects of the image because they assumed they were implicit in the description or they forgot details that were told. Also, S4 expressed the need to describe not all the details but the essential details to convey the overall picture. Examples provided by students were:

“Because when you have the picture in your head and you just describe the things that you see. You're not necessarily describing all the details but implicitly in your head they are included in what you say.” (S8)

“We said three trees. But we didn't get the height right.” (S9)

“Going back, they probably could have done differently such that in maybe explaining less they would have conveyed the idea a bit better and would have given like the essential details or the essential points of the picture.” (S4)

Planning/strategy+

Students revealed two strategies they adopted during the activity: the distribution of the work between the team members and the planning in advance of what to ask. Students expressed these as follows:

“Then we come up with already some questions that we had and we could ask.” (S2)

“We were two people describing the thing and, I think, we distributed the work.” (S8)

Planning/strategy-

However, the strategy of planning in advance of what to ask did not work well as stated by S2:

"So, we didn't really anticipate something like this. So, all the questions were out of the window."

Listening+

Students in the code “*listening+*” mentioned that they listen attentively and carefully. Examples in this theme were:

"And then, of course, you have to carefully listen to what they say, filter the information and see: Is this what I need or is this what I want to know?" (S1)

"I listen a lot." (S7)

Listening-

However, students also found difficulties when listening to each other. They express these as follows:

"And there you were trying to say something but they were listening but it was not entering in their minds what you were saying." (S5)

Managing+

Only S2 expressed this theme. She mentioned her group had shown efficient management skills because they were fast and efficient by asking lots of questions, as follows:

"Quite efficient. Just because we asked a lot of questions, I guess, about what to do."

Managing-

Also, only one student referred to this theme. S9 mentioned inefficient management skills in his group including difficulties to stick to the time given and with the amount of information, as follows:

"The information was just too much for the person to handle (…) Issues with the time frame."

Taking notes+

In this theme, S6 referred that they were efficient to write down the information they observed from the image. She expresses this as the following:

"We wrote what we saw."

Noise-

This theme was expressed by all students, except S6. Comments in this theme referred to barriers in student's communication such as the difficulties to understand the descriptions and the big picture, the losses of information along the communication chain and the assumptions made. Most of these issues happened because students thought it was easy to convey information and that information was not clearly transmitted. Students realised it was harder than it seemed. Also, in this theme, another communication issue was pointed out by S3. She mentioned that her group experienced language issues due to the different backgrounds of the team members who have English as a second language. Examples in this theme were:

"We didn't have an accurate representation at the end because I didn't really have any idea what it was that we were supposed to do. I mean, I didn't actually have the big picture." (S4)

"The implicit details that I assumed I didn't get across." (S8)

"We also had some language difficulties because we had a Spanish girl and then the others were Dutch but not all of them as fluent in English." (S3)

Remembering+

This theme was only referred to by S5. This student was in role B and showed frustration because she could not tell everything she memorised from the information given by role A.

"But it was frustrating. Because the first person told me a lot of things. So yes, all the 10 things in your mind and you want to tell them all 10 and then the next person is only asking about two so you want to bring the others also."

6.3.3. Benefits of the activity by students

Students were asked in the interviews about their experiences during the activity and the takeaways and important aspects they perceived they gained from it. This was inquired to investigate the benefits of the activity according to students. Three categories emerged from the interviews: C1) Awareness, C2) Experience and C3) No gain (defined in *Chapter 5*, section *5.6.3. Importance of communication perceived by students*). The themes that arose from the analysis were grouped into one of these categories (Table 15) and were used to summarise the benefits of the activity perceived by the students. The findings showed that all students stated that this activity created awareness and experience of communication competencies.

C1) Awareness

Barriers in communication

In this theme, students mentioned the awareness they gained of the difficulties to change people's minds and to get the idea across when not everyone has access to the same information and the right questions are not asked. Also, students gained awareness of the need to be precise and clear and not rush when describing, asking and responding to questions, otherwise, the flow of information is disrupted or information gets lost. Students showed this awareness as follows:

"It's actually quite hard to tell someone how to do something when someone doesn't have in his mind like what to do." (S1)

"We need to be very precise about information and that it will get distorted as it goes down the chain." (S9)

"The other person was thinking on a different level. So maybe he was thinking about a cat and I was thinking about a tree and then the questions were all about the cat. But to change the person's mind from cat to tree it's difficult." (S5)

Details

All the comments that refer to awareness for details were considered in this theme. Students mentioned the details they missed, took for granted, did not ask about and assumed they had said or that the other would think the same way as they did. Another student mentioned that only after participating in the activity students realised the details they needed to convey the message. Examples of these were:

"The implicit details in your head." (S8)

"We rush and miss details because they were not told yet." (S3)

Table 15 - Themes and categories attributed in the previous chapter to the students' open-response 2 that emerged in the interviews with the nine students of cohort TU delft 2018.

Categories	**Themes**	**Student codes**								
		S1	S2	S3	S4	S5	S6	S7	S8	S9
C1) Awareness	Barriers in communication	✓	✓	✓		✓		✓	✓	✓
	Details			✓	✓		✓		✓	✓
	Conveying/explaining/answering	✓	✓	✓			✓			✓
	Team/group communication	✓					✓	✓		
	Importance of communication		✓							
	Asking questions		✓		✓	✓		✓		✓
	Managing/planning/organizing			✓	✓					✓
	Understanding	✓					✓			
	Strengths and points for improvement			✓						
	Listening			✓						
	Assumptions					✓	✓	✓	✓	
	Taking notes									
	Communication styles		✓	✓			✓	✓		✓
	Observing									
C2) Experience	Barriers in communication (N)					✓			✓	
	Conveying/explaining/answering (N)	✓		✓				✓		
	Asking questions (N)	✓		✓						
	Managing/planning/organizing (N)			✓						
	Listening (N)	✓		✓						
	Communication process			✓				✓		✓
	Team/group communication		✓	✓	✓		✓			
	Engagement/fun		✓	✓	✓	✓	✓	✓	✓	✓
	Interaction between people		✓	✓	✓		✓			
	Competition		✓				✓			
C3) No gain	Have awareness already									✓
	Nothing new									
	Have experience already									

(N): new themes that emerged from the analysis of the interviews.

"I think we would get better results because now we'd at least know how precise you have to be and how much details you have to give." (S9)

<u>*Conveying/explaining/answering*</u>

Students mentioned that this activity helped them to realise the importance of transmitting information clearly and concisely in a short time to get the message across, avoid misinterpretations and information loss. Students expressed the following:

"You realize the importance of transmitting information and things like that." (S1)

"You have to be precise when giving information because then it can turn out to be like a completely different thing." (S6)

Team/group communication

In this theme, students referred to the difficulties of understanding the team members and to working in teams.

> *"There were some similarities in the sense that, you know, sometimes you talked with another person in your group and you'll see eventually you'll see that they didn't understand what you meant."* (S1)

> *"You see that if you do a group work that everyone works on something and everyone has a certain expectation of what's going to come out. And sometimes you noticed that something came out that you didn't expect while you were still talking to a certain person about it."* (S7)

Importance of communication

Students were not generic in their comments and this code was only mentioned by S2, who expresses that communication is important to obtain good results, as follows:

> *"Communication is key for us."* (S2)

Asking questions

In this theme, students referred to the need to ask clear and concise questions to be understood and the right questions to get the necessary information to complete successfully the tasks. Students also mentioned they gained awareness of the difficulties to pass information when the questions were not asked. Students showed these as follows:

> *"You have to ask questions so that you can get it."* (S2)

> *"It was also difficult. You want to say there was a tree and someone is asking the wrong questions and then you have to sort of hint that there was a tree without really saying it."* (S5)

Managing/planning/organising

Most comments in this theme referred to the limited time students had during the activity. A student raised the need for planning the transmission of the information and not rushing with the time pressure. Examples of these were:

> *"The main point about this activity was we had a lot of time pressure like a defined, you know, you only have two minutes to do this."* (S4)

> *"So there are many things which you could talk about. But first you would say that there were three trees and the shortest is in the middle or something like that."* (S9)

> *"Take time to explain. Don't panic a lot."* (S9)

Understanding

Students mentioned that this activity helped them to understand that information should be carefully passed and make sure the person on the receiving end understands the message.

> *"You really have to be careful about how you formulate it and make sure that the way you formulate it helps them understand exactly what you mean. Which is as this exercise showed, revealed even for simple things."* (S1)

> *"You actually have to be really precise when you describe something and ask and make sure they understood the same as you understood."* (S6)

<u>*Strengths and points for improvement*</u>

This theme was only mentioned once by S3. She referred that she is an extrovert and realised that she needs to improve her listening skills because during the activity she asked questions but did not listen attentively. She expressed this as follows:

> *"I have the tendency then to already go ahead and continue on the next question while sometimes it's better to wait for the whole answer and then ask that question."* (S3)

<u>*Assumptions*</u>

Under this theme, students mentioned they assumed certain aspects that were not told and realised the importance of being clear and make sure all the information is conveyed. Examples in this theme were:

> *"You're making your own ideas about it and maybe it's very different from what he tries to explain to you."* (S5)
>
> *"We made it like pointy mountains. But of course, they weren't pointy."* (S7)
>
> *"I can see a lot more that indeed you have to be aware of the implicit things you keep in your mind."* (S8)

<u>*Communication styles*</u>

In this theme, students expressed they realised that people are different and think and interpret differently according to their backgrounds and experiences. Because of people's differences, one student mentioned she realised that she needed to adapt their behaviour to others. They gave the following examples:

> *"People have different backgrounds and for them, one concept can be totally different to your concept in something as simple as a tree."* (S6)
>
> *"Even though you say something to someone they might not interpret it the same way that you interpret it."* (S7)
>
> *"I had to think about introverts. If you're the extrovert that was a realization in this aspect. I had that realization and I think I took that away from it in general. Like not everybody's extrovert. Maybe calm me down sometimes."* (S3)

C2) Experience

<u>*Barriers in communication*</u>

Students in this theme referred to the difficulties they experienced during the activity in terms of changing people's ideas and putting visual information into words. Examples given by the students were:

> *"It did make me see that if someone has like a fixed idea or something then it's hard to change it."* (S5)
>
> *"It shows that you have a certain mental picture in your head about the image in this case and that communicating that exact image is very difficult."* (S8)

<u>*Conveying/explaining/answering*</u>

In this theme, students mentioned they experienced pitching skills, i.e., they practised how to convey a message in a short time and what happens when the information is not clearly transmitted. S3 also experienced that this activity allowed introverted students to practice:

> *"Communicating in a shorter way or concise and then still be clear enough that a person can draw the drawing basically that's, I think, something that when looking back I practised here."* (S3)

> *“It's interesting to see that you try to explain something and people interpret what you are saying.”* (S7)

> *“They were in the beginning kind of uncomfortable having to ask questions or describe something. (…) For introverts is hard to describe something and ask the questions. That’ a good practice.”* (S3)

<u>*Listening*</u>

Students expressed that this activity was a good practice of listening skills. S3 mentioned that especially for extroverts, this activity is a great exercise to learn to attentively listen to others, take on the information and convey the message.

> *“It was a good exercise in realizing the importance of asking questions and listening attentively.”* (S1)

> *"For an extrovert, it's the listening that's a good practice."* (S3)

<u>*Managing/planning/organising*</u>

In this theme, S3 mentioned students experienced pitching information in a short time with this activity and the need to prioritise the information, i.e., go from the general to the particular. She expressed these as follows:

> *“I think that's something I re-experienced here. Sometimes a long story with telling it front and back and up and down works. Sometimes to the point is also nice.”* (S3)

<u>*Team/group communication*</u>

The comments in this theme referred to the communication and behaviour within the team. The following examples showed how students perceived this activity improved their team communication and helped them to learn how to behave towards others and respect the team members:

> *“This activity helped me with the other course because it helps you a lot to work in a team and respect.”* (S6)

> *"I think it made us all feel more comfortable together. And in that respect, it improved communication because people felt they could speak more freely. For instance, make you feel more comfortable with people than you can share your ideas freely."* (S4)

> *“I had to watch out my behaviour towards them sometimes.”* (S3)

<u>*Engagement/fun*</u>

The comments of the students in this theme showed they enjoyed the activity a lot. One student was more specific and mentioned that simple tasks as asking questions can be a fun exercise. Also, in this theme, students mentioned they liked the activity because it was a hands-on activity. Examples of these were:

> *"Pretty. All of that was just interesting. So no matter if I was good or bad but for me, it was just a learning exercise. So, I enjoyed it."* (S9)
>
> *"So that showed them that having to ask questions or describe something that it's also fun I think that was the good part of the process."* (S3)
>
> *"This one was more dynamic."* (S6)

<u>*Interaction between people*</u>

In this theme, students mentioned that this activity allowed them to get to know their peers better and engage with the team members, as in a team-building exercise. Students showed evidence of this as follows:

> *"It helped to just have also a little bit of team building."* (S2)
>
> *"For us as a group, it was a good way to familiarize with each other. The others were all from the same master track, I was the odd one out so I didn't really know them."* (S3)
>
> *"I get to know more about the person with whom I was giving information. It affected more my relationship with that person."* (S6)

<u>*Competition*</u>

Students in this theme referred that they experienced competition between groups and that the spirit of competition encouraged them to work together to perform better and develop their communication competencies to defeat the other groups. Examples of this were:

> *"So, it felt like a competition. It was very nice. (…) I wanted to do better than the other groups. So that brings your own group a little bit closer and you're going to work better and more efficient because you want to do better whatever it is."* (S2)
>
> *"So, like being in a competition. It's like a game let's say that really involves communicating skills."* (S6)

C3) No gain

<u>*Have awareness already*</u>

Only one student mentioned this theme. Although S9 expressed that he had awareness of the barriers in the flow of information and the need to be clear, he also mentioned that this was a takeaway from the activity, as follows:

> *"I've always been aware that information has to be very precise or there's always distortion. (…) "This is something which I've seen online as well. Where they show how information is gonna break from one person. So, I think that was the biggest takeaway here."* (S9)

6.3.4. *Learning communication competencies according to students*

The last question of the interviews intended to investigate what the best way to learn communication competencies is according to students. The themes that arose from the analysis of the interviews (Table 16) were used to complement the previous qualitative data in the search for the characteristics of the effective game-based learning activity.

Table 16 - Themes that emerged from the interviews with the nine students of cohort TU delft 2018 when students were asked: *"What is the best way to learn communication competencies?"*

Themes	**Student codes**								
	S1	S2	S3	S4	S5	S6	S7	S8	S9
Hands-on	✓	✓		✓			✓	✓	
Reflection			✓	✓				✓	✓
Teamwork						✓	✓	✓	
Embedding			✓					✓	
Comfort environment				✓					

<u>*Hands-on*</u>

This theme showed comments of students about the need to practice communication competencies during their studies. Students mentioned that learning of communication competencies happens when they are exposed to situations in which they have to actively communicate and be confronted with their effective and ineffective communication competencies and where they can improve. They referred that this activity is one of those situations. Examples under this theme were:

> *"But it's more you learn by doing so just by doing this you change your way of thinking and that doesn't have to happen actively but the thing is it happens passively, like without you noticing it and you change your behaviour."* (S7)
>
> *"I think at least what I have found is that it's always by exercising. So, this kind of hands-on exercises… because if you have a professor in front of you that tells you off communication is important and you need to do this and this. You understand the importance, I guess, but you will have never actually experienced it. So, it kind of goes to one ear and exits through the other. Whereas if you do an activity and you really realize yourself. Okay, this is really a problem then, I think, it stays in the back of your mind as an experience that really made an impact on you."* (S1)
>
> *"I think actually exercises like this really help. Because my experience is that most of the people when you ask them whether they're a good communicator or not. Usually, they say yes, I'm the best and everyone else is very bad at communicating. But I think it's good to actually maybe use a test or something to see whether you're actually good at or what you are bad at, what communication you're really bad at listening or something like that. That can really help you to improve those things, to be really conscious of them."* (S2)

<u>*Reflection*</u>

In this theme, students showed the importance of reflecting on the activity and on what students did and should have done as individuals and team. They mentioned that they gain from practising when they reflect on the experience. Examples of these were:

“We could do these communication activities. And we'd done the activity. But if you don't think about it and consider and understand how we can improve and what the problems were then you haven't really gained anything. So, I think the value of doing something like this would be to force you to go through this process of critically analysing and understanding and really appreciating the value of what we did.” (S4)

“I recognize that sometimes it [self-reflecting] can be confrontational if you discover that you lack a certain skill that you thought you had or you sometimes have to think about your own shortcomings. But I know it's a valuable skill to have.” (S8)

"But to do it and actually address it as a topic for the whole lecture as a team and discuss it, it's a good thing." (S9)

Teamwork

Students referred that activities that involve interaction between team members are a great way to practice communication competencies because students are encouraged to communicate with the team members and solve problems together. Students mentioned that teamwork in which students can perform the work individually are not effective to stimulate communication competencies because the interaction is not required. Also, they stated that it is important to reflect on the work and communication of each individual and the team.

"We have a lot of group work here and you definitely communicate a lot. And that's very useful, I think." (S7)

"Let's say a lot of teamwork. But teamwork in a serious way. For me it was really nice to have to work with my team but be forced to be constantly communicating with each other all the time." (S6)

“I think in the courses in which you work together, of course, you practice communication by doing it but it would help, I think, that you are forced to stop for a moment and think about OK. How's it going? How should it be going? What's going wrong and what's going well? Things like that.” (S8)

Embedding

Under this theme, students highlighted the need to emphasise communication competencies in the curriculum. They proposed that these competencies should be embedded in the existing courses, as the *Chinese Whisper with a Twist* and not as a separated course in the curriculum. Examples of these were:

"Don't dedicate a course to it. That was horrible. Nobody actually learned anything from it, I think. I think the way it was done with this course is good. That was hooked to a general subject which was the subject of the course but kind of inside line hooked out a couple of tactical moments brought it like OK you know you had to go and do group work and there are roles and there are introverts and extroverts and that you kind of inside line now we're going to do this exercise where it's made clear. I think that's a better way than just dedicating a course to it." (S3)

“Maybe not more emphasis in the sense that you teach a course about it but, for instance, make it part of every course that you would think about okay - what did you learn?” (S8)

<u>*Comfort environment*</u>

Only one student mentioned this theme. S4 referred that students need to gain awareness or practice transversal competencies including communication competencies at the university so that they can take risks and learn from the failures. He expressed this as follows:

> *"So, I think, it's nice to learn them at university or in this environment because it's kind of safe and the consequences are low."* (S4)

6.4. Discussion

The current chapter is an extension of *Chapter 5* to explore the effectiveness of the game-based learning activity to retain the transversal competencies students practised and reflect on one year after they participated in the *Chinese Whispers with a Twist* activity. To do so, the characteristics that make this activity valid were explored with semi-structured interviews carried out with a cohort of engineering students. In this section, these characteristics will be compared to those found in *Chapter 5*.

In *Chapter* 5, the game-based learning activity was proven valid because of six characteristics: active participation, engagement, rules, reflection, risk-taking and cooperation. The research in the current chapter not only corroborates the characteristics found in *Chapter 5* but also complements the findings, highlighting two other characteristics that are competition and plug-and-play.

The first two characteristics, active participation and engagement, were identified by the participating students under the existing theme *"engagement/fun"* and the new theme "*hands-on"*. One year after students took part in the activity, they remembered the activity because it was fun and engaging. Different from the previous chapter is the new theme *hands-on*, in which students mentioned that this game-based learning activity is a great exercise to practise and think about their communication competencies.

The third characteristic was the rules. One year after students participated in the activity, they still remembered the roles they had and the constraints of the activity, including the limited time to describe the image, listen, ask and answer to questions, and the fact that they could not ask questions for clarification nor give information that was not asked. This was expressed in both chapters under the themes *"planning/strategy+/-"* and *"managing+/-"*, in which some students mentioned they dealt and adapted well to the rules, they planned and managed the time but others students experienced difficulties, they failed to plan or did not manage the limited time. An additional finding from the interviews which was not present in *Chapter 5* was concerning the two last rules in which students in role B could not ask questions and could only respond to the questions posed to them. These rules triggered some frustration in one student (S5) from the fact that she could not tell all the information she had received because her peers were asking the wrong questions. In summary, rules are a characteristic of the game-based activity that allow students to deal with uncertain events that would not normally happen in the real world but that prepare students to be ready to react promptly.

The fourth characteristic, reflection, was shown by students in the interviews under the theme *"reflection"*. Students highlighted the usefulness of having to reflect on their individual and team performance after the activity because they stated that the learning happens not only when they experience something but after reflecting on it. This is supported by Kolb's theory (Kolb 1984) which "*learners need to reflect on what they experienced, conceptualise and draw conclusions from their experiences and critically use the knowledge gained from the experiences in future scenarios"*.

The next characteristic was risk-taking. The research of the current chapter showed this with the themes *"comfort environment"* and *"embedding"*. Students perceived that activities like the *Chinese Whispers with a Twist* should be embedded in existing courses and connected to the engineering context to become a safe environment. This way students can make links to the engineering world without being afraid to make mistakes and fail. This finding shows an extra characteristic found in this exploratory study that demonstrates the effectiveness of this activity. This characteristic is plug-and-play. As mentioned in *Chapter 5* and proven in the current chapter by the theme *"embedded"*, this activity was effective because it was designed to be implemented in existing engineering courses where students have a reflection moment at the end of the activity to contextualise the content of communication in teams to the engineering environment of the course.

The last characteristic found in *Chapter 5* was cooperation. In both chapters, this characteristic is shown by the themes: *"interaction between people"* and *"team/group communication"*. The research of the current chapter also evidenced the cooperative nature of this activity with the theme *"teamwork"*. In these three themes, students felt that this activity was effective to practice and reflect on communication competencies because of the interaction between the team members, the team building created, and the behavioural changes that occurred towards the team members.

An extra characteristic of the game-based learning activity that was identified in this chapter under the theme *"competition"* was competition. Although research has shown that cooperation improves interpersonal interaction, social support and self-esteem compared to competition (Johnson, Johnson et al. 1998, Johnson and Johnson 1998), in this chapter competition encouraged students to work together and perform better as a team in terms of communication to compete against the other teams.

The characteristics of the game-based learning activity found in this chapter proved that this activity is effective to retain the transversal competencies students practised and reflected on in the activity. This is evident by the fact that students remembered it one year later. They also spoke about the competencies they gained awareness of and experienced in the activity. Interesting findings were found in the data of the interviews that were not present in the data of the previous chapter. Students perceived they practised the following communication competencies: *"Conveying/explaining/answering"*, *"Managing/planning/organising", "Asking questions"* and *"Listening"*, which in the previous chapter they only stated they gained awareness. Also, students experienced barriers in communication that involved language and cultural background issues. This finding was found in the previous chapter through the lower rubric scores obtained from a few groups that belonged to different nationalities compared to single nationality groups. It is recommended that the intercultural aspects should be taken into account by the lecturers and discussed with the students to avoid integration and discrimination problems among the students.

6.5. Conclusion, limitations and future work

Unlike most studies in engineering education, the research in the current chapter explores the retention of transversal competencies over a long time rather than focusing only on evaluating the acquisition of transversal competencies immediately after the interventions, as done in *Chapter 5*. This research complements the results presented in the previous chapter and indicates that students retained the communication competencies gained during the game-based learning activity after one year. This seems to be due to the following characteristics of the activity: active participation, engagement, rules, risk-taking, reflection, cooperation with team members, competition between teams and plug-and-play.

This exploratory research provides a platform for further investigation in the field of transversal competency retention in engineering education by showing that it is worthwhile and feasible to investigate the retention of transversal competencies of participating students one year after the intervention conducting interviews. The evaluation of the transversal competencies after some time is considered a fundamental requirement to understand how the teaching practices shape students' competencies in the period after their participation and whether students retain the necessary competencies for employment. Thus, although time and resource consuming, it is recommended that researchers and educators in the field of engineering education do not only focus on course evaluations but go beyond that, and follow students in the years after they took part in these courses.

The limitations of this chapter are the limitations of most exploratory studies. The interviewed participants consisted of a limited number of students who participated in the activity in only one university. These students were not randomly selected and it is not possible to exclude that the students who participated in the study were those who had a better recollection of the teaching activity. However, this sample is considered a representative group of the entire original sample joining in the activity (n = 393) because it is a heterogenic population in terms of gender and nationality. The other limitation of this research is related to the interaction of the participants with biological, environmental and interventions that were not investigated and may have influenced the memories of participants' experiences in the activity.

As future work, a phase of quantitative data collection may be carried out to build on the results of the qualitative phase with the cohort of TU Delft 2018 (Creswell 2003). This way, the quantitative data may assist in the interpretation of the qualitative results and the qualitative findings can be generalised to different samples (Creswell 2003). This is called sequential exploratory research and its advantages are that it is easy to implement and straightforward to analyse and report, and expands on the qualitative outcomes.

*“If people are doubting how far you can go,
go so far that you can’t hear them anymore.”*

Michele Ruiz

CHAPTER 7

Conclusions, reflections and recommendations

This chapter concludes this doctoral thesis, examines whether the aims have been met and answers the main research question. Together with the conclusions of this research, the contribution of the research to the field of engineering education will be discussed. Following this discussion, recommendations are offered for researchers and educators in the field of engineering education.

The research in this thesis has started with the premise that measurement and development of transversal competencies are topics of great emphasis in engineering education. On the one hand, there was lacking an instrument that could be used to measure transversal competencies perceptions in different contexts. On the other hand, there were still concerns about the employability of engineering graduates due to the lack of graduates' transversal competencies. These deficiencies in the practice and instruction of transversal competencies were also experienced by the researcher during her previous engineering studies and motivated her to pursue research on the topic. The research in this thesis works towards the creation of an instrument that addresses the limitations found in the literature and can be used to measure perceptions of transversal competencies in engineering education, and the development of a new game-based activity that stimulates engineering students to practice and reflect on their communication competencies, necessary for employment. The main research question of this thesis was:

What are the characteristics to measure perceptions of transversal competencies and stimulate the practice and reflection on transversal competencies in engineering education?

To answer this research question, three sub-questions were developed:

(1) *What are the methods used over the past 20 years that measure the following transversal competencies: communication, innovation/ creativity, lifelong learning and teamwork, or their perceptions?*
(2) *What are the characteristics of a valid instrument that measures perceptions of transversal competencies in engineering education?*
(3) *What are the characteristics of a game based-learning practice that stimulates engineering students to practise and trigger reflect on their communication competencies?*

In the following section, a reflection on the research done in this thesis will be made in the light of answering the three sub-questions, and the main conclusions per chapter will be presented.

7.1. Summary of the main findings and conclusions

The first sub-question posed in this thesis was addressed in *Chapter 2*. The research in this chapter described a systematic literature review on the methods used in engineering education between 2000 and 2017 to measure communication, innovation/creativity, teamwork and lifelong learning or their perceptions. This was conducted to identify the current instruments in the engineering education literature and how the instrument present in this thesis can contribute to this field.

In this systematic literature review, the methods used to measure the transversal competencies above mentioned or their perceptions were identified and analysed, validity and reliability properties were investigated and the criteria used to measure the transversal competencies as well as three types of the purpose of the measurements were identified (evaluation of the course and programme effectiveness to enhance the quality of teaching and student learning, assessment of student's performance to give summative grading and/or formative feedback, and measurement of students' abilities to characterise student populations).

The findings showed that 99 studies published in three databases (ERIC, Scopus and Web of Science) measured at least one of the above transversal competencies or their perceptions. In these studies, the following seven different measurement methods were found: questionnaires, rubrics, tests, observations, interviews, portfolios, and reflections. Of these, questionnaires and rubrics were the most common assessment methods reported and the qualitative methods, such as observations, interviews, portfolios and reflections, were used in a limited number of studies. Also, a growing number of papers reporting on methods measuring transversal competencies or their perceptions was found. However, many of these methods lack competency definitions and criteria, and evidence of validity and reliability properties, or in other words they were not rigorously designed and implemented to measure transversal competencies or their perceptions, and the research data did not indicate that the methods were able to be used or successful to measure the transversal competencies or their perceptions. In this chapter, practical guidelines for educators and researchers to measure transversal competencies or their perceptions are listed.

Conclusion 1: The methods used over the past 20 years to measure the following transversal competencies: communication, innovation/ creativity, lifelong learning and teamwork and their perceptions were questionnaires, rubrics, tests, observations, interviews, portfolios, and reflections.

The second sub-research question of this thesis was the subject of the research presented in *Chapters 3 and 4*. The research in these chapters aimed to address the limitations found in *Chapter 2* regarding the lack of competency definitions, descriptive criteria and validation and reliability properties by provided an instrument that measures perceptions of transversal competencies and can be used in engineering education.

In *Chapter 3*, this instrument is presented. It is called COMπ (COMPetency Instrument), is based on the industry competency framework of Siemens, the Netherlands and consists of 36 transversal competencies with four descriptive mastery levels that are divided into five domains: communication, teamwork, lifelong learning, innovation and entrepreneurial competencies. COMπ was used to investigate the transversal competency levels that BSc and MSc engineering students should possess at graduation according to European industry and to study the extent to which the transversal competency levels indicated by the industry were covered in the BSc and MSc programmes of a representative engineering department of Delft University of Technology, both formally reported in the learning outcomes and according to the perception of lecturers. Finally, a part of COMπ was used to identify what educational practises and methods were used by the lecturers to address the transversal competency levels.

The results showed that the transversal competencies that required the highest mastery levels for BSc and MSc graduates according to industry were: *strengths and weaknesses awareness*, *interdisciplinary thinking*, *actively seeking learning*, *problem solving*, *writing skills*, *listening skills*, *risk tolerance*, *critical thinking*, *presentation skills* and time *management*, and the most important transversal competencies for engineering graduates according to industry were: *actively seeking learning*, *strengths and weaknesses awareness*, *problem solving*, *autonomous work*, *project management*, *curious for innovation*, *engagement in teamwork*, *technology benchmarking*, *collaborative goal-oriented* and *adaptive communication style*. It was also found that COMπ triggered lecturers to reflect on the transversal competency levels they think their students acquire in their courses as well as the practices and methods they use to reach these levels. What was also highlighted in this chapter was a gap between the formal and perceived curriculum that was shown by the discrepancies in the transversal competency reported in the course learning outcomes compared to the transversal competencies mentioned by the lecturers.

In *Chapter 4*, COMπ is further explored. The validity and reliability of COMπ were tested through exploratory and confirmatory factor analyses and Cronbach's alpha, respectively. Also, COMπ was used to investigate the transversal competency level perceptions of BSc and MSc engineering students using a sample of 1087 engineering BSc and MSc students from Delft University of Technology.

The results showed that COMπ described in *Chapter 3* with 36 transversal competencies was reduced to 25 competencies within the same five domains after the exploratory factor analysis. COMπ demonstrated a good model fit for the five-factor model with the 25 items in the confirmatory factor analysis and all five scales were reliable according to the Cronbach alpha calculation. It was also found that COMπ triggered students to reflect on their transversal competency levels. The five highest transversal competency engineering students perceived they were most competent in were: *listening skills*, *strengths and weaknesses awareness*, *cross-cultural understanding*, *actively seeking learning* and *problem solving*, while the five lowest transversal competency levels were: *stakeholder management*, *business acumen*, *financial awareness*, *idea implementation* and *technology benchmarking*.

The findings in chapters 3 and 4 showed that COMπ is innovative because it brings individual elements (nuanced competencies with definitions and descriptive levels) together into one coherent instrument that can be used as a measurement of the transversal competencies required for engineering graduates according to industry, an assessment by lecturers of students' levels of transversal competency and by students themselves to trigger reflection of their transversal competencies.

Conclusion 2: The characteristics of a valid instrument that measures perceptions of transversal competencies in engineering education include the nuanced competencies with definitions and descriptive levels.

The third sub-question of this thesis was the subject of chapters 5 and 6. The research in these chapters aimed to provide a game-based learning activity to help students to practice and reflect on their communication competencies. This game was created as a deliverable of the PREFER project that aimed to develop new curriculum elements that stimulate engineering students' transversal competencies.

In *Chapter 5*, an innovative game-based activity, called *Chinese Whispers with a Twist*, was developed to stimulate students practice and reflection on their communication competencies such as describing information in a short time, listening skills, and ask and respond to questions. This activity was implemented for 393 engineering students at five European engineering universities. The characteristics that make this activity effective to practice and trigger reflection on their communication competencies were investigated in a case study using a mixed-method approach that investigated how students evaluate their communication competencies and points for improvement, how their perceived communication competencies and areas for improvement correlate with their performance in the activity and finally what the aspects of the importance of communication competencies are that engineering students become aware of or experience in the activity.

The data from the mixed-method approach and the mixed sample showed that the *Chinese Whispers with a Twist* activity is effective to stimulate engineering students to practice and reflect on their communication competencies due to the following characteristics of the activity: active participation, engagement, rules, reflection, risk-taking and cooperation.

In *Chapter 6*, a small exploratory study was carried out to investigate the retention of the effects of the game-based learning activity presented in *Chapter 5*. Semi-structured interviews were carried out with nine students one year after they participated in the activity at Delft University of Technology. The interviews aimed to investigate what engineering students remember about the activity, their performance and experience in the game-based learning activity and what benefits they feel they have gained from the activity one year after their participation.

The results showed that students remembered the activity one year after its implementation and the effective and ineffective communication competencies that they experienced during the activity. Students were also able to highlight the benefits gained from the activity. This exploratory study appears to indicate that this type of game-based learning activity has longer-lasting effects and the results of the interviews seem to not only corroborate the findings in *Chapter 5* that show the characteristics that make the game-based learning activity effective to help engineering students practice and reflect on their communication competencies but also to complement them by evidencing two extra characteristics: competition among team members and plug-and-play, i.e., an activity that can be embedded in and contextualised to any engineering course rather than given as a separate course.

Conclusion 3: The characteristics of a game based-learning practice that stimulates engineering students to practise and reflect on their communication competencies include active participation, engagement, rules, reflection, risk-taking, cooperation among team members, competition among teams and plug-and-play.

With the summary of the findings of the research conducted in this thesis, the main research question can be answered. To do so, the characteristics to measure perceptions of transversal competencies and stimulate practice and reflection on transversal competencies in engineering education are presented in Table 17.

7.2. Discussion of the findings and conclusions

In this section, a discussion on the findings and conclusions presented above will be made to shed a light on the contribution of this thesis to measuring perceptions of transversal competencies and practising and triggering reflection on transversal competencies in engineering education.

Table 17 – Characteristics to measure perceptions of transversal competencies, and practice and trigger reflection on these competencies in engineering education.

Measurement of perceptions of transversal competencies	Practice and trigger reflection of transversal competencies
- Provide transversal competency definitions and descriptive levels - Analyse the validity of the measurement to evaluate whether it can be used and is successful to measure perceptions of transversal competencies - Test instruments with different samples - Use mixed research methods - Evaluate retention of transversal competencies	- Include characteristics such as active participation, engagement, rules, reflection, risk-taking, cooperation among team members and competition among teams in competency development activities - Design these activities plug-and-play so that they can be integrated into existing courses and in any engineering context

7.2.1. Reflection on contribution to measuring perceptions of transversal competencies

The inclusion of transversal competencies in engineering curricula has been emphasised over the last decades by the world's accreditation bodies (Engineering Accreditation Commission 2000, EHEA 2015) and many other studies (McMasters and Matsch 1996, Shuman, Besterfield-Sacre et al. 2005, Spinks, Silburn et al. 2006, Passow and Passow 2017). One of the reasons to include transversal competencies in the engineering curriculum was to ensure that engineering graduates have the right competencies for employment (Scott and Yates 2002, Male, Bush et al. 2011, Passow and Passow 2012). The emphasis on the inclusion of transversal competencies has triggered the need for instruments that could measure and assess these competencies, or even reflect on these transversal competencies.

The outcomes of the systematic literature review presented in *Chapter 2* of the methods that measure transversal competencies and their perceptions highlighted that most of the instruments lack competency definitions and criteria, and validity and reliability analyses that evaluate whether they can be used to measure transversal competencies or their perceptions. These issues were also highlighted in literature published after this systematic literature review in Chan (2017) and Carthy, Gaughan et al. (2019).

Based on the findings, a holistic instrument, COMπ consisting of clearly defined more nuanced competencies with four descriptive levels is presented to measure perceptions of transversal competencies and is used in different contexts in engineering education (*Chapter 3 and 4*). First, COMπ is used by the industry as a measurement of the transversal competency levels that BSc and MSc graduates should master for each competency before entering the labour market and the most important competencies required of graduates. This is a new approach compared to what has been done in literature until now, which focused only on the transversal competencies that are deemed important for engineering graduates (Spinks, Silburn et al. 2006, Saunders-Smits and de Graaff 2012, Meier, Williams et al. 2000, Brumm, Hanneman et al. 2006, Passow and Passow 2012, Passow and Passow 2017, Scott and Yates 2002, Nair, Patil et al. 2009, Male, Bush et al. 2011). Despite the research differences between these literature studies and *Chapter 3*, it was found that the following transversal competencies: *problem solving, actively seeking learning, strengths and weaknesses awareness, curious for innovation*, *technology benchmarking, listening skills*, *writing skills*, *presentation skills, adaptive communication style, interdisciplinary thinking* and *collaborative goal-oriented*, should continue to be the focus of engineering curriculum because they were found to be of importance to graduates by the industry in previous literature as well as in *Chapter 3* and/or requiring the highest levels by the industry in *Chapter 3*.

Second, COMπ is used by lecturers as a (self-)assessment tool to identify the transversal competencies present in the learning outcomes of the courses of a BSc and MSc engineering programme, as well as the teaching practices or methods they use to reach the transversal competency levels. This approach of mapping the stated learning outcomes of the engineering programme courses against the transversal competencies present in COMπ and triggering lecturers to reflect on their practices to develop the transversal competencies was new compared with the usual studies that reported on the development of transversal competencies in the engineering curriculum, e.g. according to students' perspectives (Beagon, Niall et al. 2019, Chassidim et al. 2018). From the comparison between the transversal competencies reported in the course learning outcomes and perceived by the lecturers, a gap was found between the formal curriculum and the perceived curriculum (van den Akker, Kuiper et al. 2003). This seemed to indicate that aerospace engineering students were practising transversal competencies in courses that were not specified in the course learning outcomes by the lecturers. This means that significant investment from educators at the faculty of aerospace engineering of TU Delft is needed to improve the description of the course learning outcomes to include the transversal competencies. Explicitly formulated transversal competencies in the learning outcomes will provide awareness to the aerospace students of what transversal competencies they can learn in each course so that they can make informed decisions when selecting their courses and can develop a better lexicon for the transversal competencies necessary for the labour market. Also, it will ease the assessment by accreditation boards and it will be possible to prove that the transversal competencies in question are taught to the level specified in these engineering programmes. Finally, uncovering the implicit transversal competencies hidden in the learning outcomes will avoid that the transversal competency learning outcomes are dependent on individual lecturers which can bring incoherency in terms of the range and levels achieved by students during their degree, and vulnerability on the teaching and assessing of the transversal competencies when the courses' lecturers change. For these reasons, extreme efforts need to be made on the improvements in the description of course learning outcomes of the BSc and MSc programmes of the aerospace engineering faculty with regards to the inclusion of transversal competencies.

Finally, COMπ is used by students as a (self-)assessment tool that triggers BSc and MSc engineering students to reflect on their transversal competency levels. The findings of this evaluation indicate that a large sample of aerospace engineering students perceived they were highly competent in *listening skills*, *problem solving*, *actively seeking learning*, *strengths and weaknesses awareness*, and *cross-cultural understanding*. Similar results were found in Direito, Pereira et al. (2012) and Chan, Zhao et al. (2017). These two studies as well as Lizzio and Wilson (2004) measure students' perceptions of their transversal competency levels. Compared to these studies, the research in this thesis stands out for the following reasons: COMπ provides a list of nuanced transversal competencies with their definitions and descriptive levels, the validity and reliability properties are evaluated in the sense that COMπ is successful to measure perceptions of transversal competencies, and the sample used is large and with students from different years of study. This is not the case in the studies of Lizzio and Wilson (2004), which used a low sample size and only first-year students, Direito, Pereira et al. (2012), which did not evaluate the validity and reliability of the instrument and Chan, Zhao et al. (2017), which used a sample of first-year students only. Next, COMπ was based on an industry competency framework used to assess employees' skills and personal development. This has reduced the limiting factor to the assessment of transversal competencies highlighted by Markes (2006), i.e., universities and non-academic establishments create overwhelming lists of transversal competencies without collaborations between each other.

There is, however, a more recent valid instrument to measure students' perceptions (Chan and Luk 2020), which emerged while the researcher was conducting her thesis, that showed the validity and reliability measurements. The advantage of COMπ presented in this thesis compared to the instrument in Chan and Luk (2020) is that COMπ can be used not only to measure students' perceptions of their transversal competencies or trigger their reflection but also to measure the desired transversal competency levels for engineering graduates according to industry and to (self-)assess the transversal competencies present in engineering courses according to lecturers.

7.2.2. Reflection on contribution to practising and triggering reflection on transversal competencies

As shown throughout this thesis, there is a consensus in engineering education that highlights the urgency to develop the transversal competencies of future engineers to better prepare them for employment (Scott and Yates 2002, Male, Bush et al. 2011, Passow and Passow 2012). Besides emphasis on the transversal competencies given by the accreditation bodies (Engineering Accreditation Commission 2000, EHEA 2015), focus on new teaching practices (Prince and Felder 2006, Edström and Kolmos 2014, Hadgraft and Kolmos 2020) have been made to develop transversal competencies in engineering education. However, a gap between what engineering education provides and industry perceives graduates should be competent still exist (Meier, Williams et al. 2000, Mills and Treagust 2003, Nair, Patil et al. 2009, Trevelyan 2010). According to these studies, the industry feels that engineering graduates lack transversal competencies such as communication, interpersonal skills, management skills and team working.

A reason for this gap highlighted by Mills and Treagust (2003), Trevelyan (2010) and Trevelyan (2019) is that engineering curricula are still content-driven as they heavily emphasise technical courses without relating them to engineering practice (Mills and Treagust 2003, Trevelyan 2010, Trevelyan 2019). They also mentioned that students are not provided with enough design experiences and lack awareness of the social, environmental and economic issues present in the real-life engineering professions. The transversal competency deficiencies in engineering education are also attributed "to what instructors are doing or failing to do" (Felder and Brent 2005). This is highlighted in Mills and Treagust (2003) and Barrie (2007) as well. In the former, they mentioned that some teaching and learning strategies are outdated and need new approaches to learning (Mills and Treagust 2003). In the latter, academics perceived either that the teaching of transversal competencies is irrelevant and unrelated to the technical content or relevant but less important than the disciplinary content (Barrie 2007). Another limiting issue to reduce the competency gap is that engineering educators do not understand the nature of the transversal competencies, lack experience and confidence in teaching them (Jones 2009).

The PREFER project is a more recent effort to reduce the transversal competency gap in the field of engineering education and to increase the employability of future engineers. To achieve that, one of the goals of the project was to create innovative curriculum elements that stimulate the development of transversal competencies necessary for engineering professional roles. One of these elements is the *Chinese Whispers with a Twist* activity presented in *Chapter 5*. It is proven that this game-based learning approach helped engineering students to practice and trigger reflect on their communication competencies and students perceived they could relate the content of the activity to the engineering discipline and practice. Therefore, this activity seems to be effective to bridge the issues that lead to the competency gap pointed out by Mills and Treagust (2003), Trevelyan (2010) and Trevelyan (2019): the extreme focus on engineering science and technical competencies, the lack of relation between the knowledge learned and engineering professional life, and the use of outdated teaching and learning strategies.

One can argue that previous successful interventions have been created to achieve the same purposes (Beagon, Niall et al. 2019, de Graaff and Kolmos 2007, Hosseini, Hartt et al. 2019, Karunaratne and Perera 2019, Johnson, Johnson et al. 1998, Johnson and Johnson 1998, Maelah 2012, Prince 2004, Qian and Clark 2016, Strobel and Van Barneveld 2009, Terenzini, Cabrera et al. 2001, Woods, Hrymak et al. 1997, and Zhou, Kolmos et al. 2012). To enumerate a few, the literature review of Prince (2004) showed the positive outcomes of using active learning approaches such as collaborative/cooperative-based learning and problem/project-based learning (PBL) in engineering education. Among these outcomes was the increase in students' learning, achievements, attitudes, retentions and engagement. The use of cooperative learning when compared to individual work also improved academic achievement, interpersonal interaction and student attitude (Johnson, Johnson et al. 1998, Johnson and Johnson 1998) and enhanced engineering students' design, communication and group skills (Terenzini, Cabrera et al. 2001). Positive effects of PBL were also found in the literature (Woods, Hrymak et al. 1997, Strobel and Van Barneveld 2009). The performance of engineering students, who attended a PBL course, improved problem-solving, interpersonal and lifelong learning skills compared to conventional lectures (Woods, Hrymak et al. 1997). PBL promoted long-term retention of knowledge and skills and student satisfaction (Strobel and Van Barneveld 2009). Finally, students perceived they improved their teamwork and communication skills, confidence, understanding of the design process and self-directed learning in a PBL design project (Beagon, Niall et al. 2019). Game-based learning has also stimulated the development of students' transversal competencies such as critical thinking, creativity, collaboration and communication (Qian and Clark 2016) and their engagement and motivation (Hosseini, Hartt et al. 2019). Another teaching and learning strategy that showed a positive impact on student learning was company projects or industry internships (Karunaratne and Perera 2019, Maelah 2012, Zhou, Kolmos et al. 2012). They stimulated student self-confidence, problem solving skills, social interaction skills (Karunaratne and Perera 2019), motivation (Zhou, Kolmos et al. 2012), time management, oral communication and working in groups (Maelah 2012), and provide a real job experience where students build up their relationship with the industry and acquire industry work culture (Karunaratne and Perera 2019).

The above-mentioned studies showed the implementation of teaching and learning strategies at the course level. The difference between the approach undertaken in this thesis and these studies is that in the former a one-hour game-based learning activity was created to be “plugged and played” in existing courses and any engineering context, while the latter were developed specifically as full courses or to be implemented in a specific course. This characteristic of plug-and-play is a great advantage because it is not necessary to find space within the overcrowded curricula and willingness to create new activities by educators (Jennings and Ferguson 1995) nor disrupt the teaching content of regular courses and institutionalised academic traditions, common in high prestige universities (Hadgraft and Kolmos 2020). Another advantage of this activity is the fact that educators only need to follow the available instruction manual, created specifically to guide educators through the implementation of the activity. Thus, this last advantage helps educators with a lack of experience and confidence in teaching transversal competencies, an issue that hindered the teaching of transversal competencies pointed out by Jones (2009).

Besides the plug-and-play characteristic, the findings of this thesis indicated that the following characteristics are essential for the effectiveness of a game-based learning activity to practice and trigger reflection on communication competencies: active participation, engagement, rules, reflection, risk-taking, cooperation among team members and competition among teams. These criteria were similar for other student-centred approaches, above mentioned in the studies of Beagon, Niall et al. (2019), Hadgraft and Kolmos (2020), Hosseini, Hartt et al. (2019), Johnson, Johnson et al. (1998), Johnson and Johnson (1998), Prince (2004), Qian and Clark (2016), Strobel and Van Barneveld (2009) and Terenzini, Cabrera et al. (2001).

This thesis does not contribute only with the game-based learning activity but also with an exploratory knowledge retention study. Unlike most studies in engineering education, the research in this thesis did not focus only on evaluating the acquisition of transversal competencies immediately after the intervention but extended its attention to knowledge retention over a longer period. This was considered a fundamental requirement to assess the effectiveness of teaching interventions because engineering students need to retain the transversal competencies acquired during their studies, which are necessary for employment. The outcomes of this study indicated that it is worthwhile to conduct this type of study to demonstrate the effectiveness of interventions and understand the benefits to the student community after some time.

7.3. Recommendations for researchers

The methods and approaches used throughout the whole work in this thesis contribute to engineering education research and serve as resources and opportunities for future research. First, the research in this thesis has started with a literature review, which is essential to gather information and pave the way to understand the field of study, in case no literature review exists. In this thesis, a systematic literature review was used to systematically search for and synthesise research evidence (Saunders-Smits and Leandro Cruz 2020). It is recommended that researchers, especially young researchers, get informed about the typologies of literature studies of Saunders-Smits and Leandro Cruz (2020) to decide which one best applies to their field of investigation. In the case of conducting systematic reviews and meta-analyses, the PRISMA method provides a checklist to conduct transparent reporting of reviews (Liberati et al. 2009). Other practical guidelines for systematic literature reviews can be found at Borrego and Bernhard (2011) and Petticrew and Robert (2006).

Recommendation 1: To provide a robust and transparent reporting of the review studies, researchers need to be informed about the typologies of the literature studies and the existing alternative approaches, and use these guidelines to make explicit their decisions during the review process.

COMπ present in this thesis has the following characteristics: nuanced competencies with definitions and descriptive levels. Providing both transversal competency definitions and nuanced competencies, and define and describe each dimension or level of mastery should avoid conflicting measuring elements and reduce the subjectivity of the measurement. In this thesis, COMπ is evaluated in different contexts and the findings indicated that COMπ as a whole or in parts can be a research instrument that identifies the desired transversal competency levels and the most important transversal competencies of graduates according to industry, maps the transversal competencies in the course learning outcomes, assesses the transversal competency levels lecturers perceive their students acquire in their courses and what educational practises and methods they use to address the transversal competency levels, and finally measures students' perceptions on their transversal competency levels.

Recommendation 2: Researchers need to provide competency definitions and criteria with descriptive levels, and analyse the reliability and validity properties of the measurement to evaluate whether it can be used to measure transversal competency perceptions.

Recommendation 3: Researchers are encouraged to use COMπ as a full instrument or in shorter versions with fewer competencies to measure the perceptions of transversal competencies by different stakeholders in engineering education.

This research also contributes with the evaluation of the effectiveness of the *Chinese Whispers with a Twist* activity and what transversal competencies engineering students gain from the activity not only immediately after the activity took place but also one year after its implementation. The evaluation of the teaching intervention immediately after students participation was not based only on the common student self-assessment on whether they feel they improved a set of transversal competencies based on a numbered Likert-scale but, in this research, the perceptions of students' competencies were analysed using a mixed-method approach that allowed for a breadth and depth exploration of the findings.

Recommendation 4: Evaluation of teaching interventions should go beyond students' self-assessment of whether they feel they improved a set of transversal competencies on a numbered Likert scale. The use of mixed-methods research to evaluate performance and perceived performance of transversal competencies may be an option in engineering education research.

The evaluation of the activity one year after the intervention was analysed with an exploratory study. Its outcomes seem to complement the findings of the mixed-method approach used to evaluate the effectiveness of the game-based learning activity immediately after the intervention. Also, this exploratory study is an indication that it is worthwhile to conduct retention studies to see what students retain and how the teaching interventions shape students' competencies in the period after their participation. The outcomes of such a study can help educators to understand what teaching strategies work and what changes need to be done to improve students' learning. For this reason, the field of engineering education would benefit from evaluating the interventions in the long term and study the retention of transversal competencies, rather than relying on short-term evaluations only. For that to be possible, funds available for long-term research are needed as well as permission from ethical boards and the willingness of the participants for long-term studies and several data collections.

Recommendation 5: Researchers should follow up interventions to evaluate their benefits and the retention of students' transversal competencies in the longer term.

It is important to highlight that the interaction of students with the environment, more specifically their gains in transversal competencies in other courses, were not investigated in the retention study. This links to the research done in *Chapter 3*, in which the analysis of the transversal competencies perceived by the lecturers was only carried out at the course level. Because the analysis at the curriculum level was not made, it was not possible to prove whether all the transversal competencies were sufficiently taught over the whole engineering curriculum nor when students reach the transversal competency levels. For a whole evaluation of the transversal competency levels acquired by the students and whether they reach the levels required by the industry, an evaluation of the constructive alignment in the engineering curriculum is needed.

Recommendation 6: Researchers should collect data at the activity level but also course and curriculum levels, from the perspective of both lecturers and students, so that the development of students' transversal competencies can be monitored and adjustments can be made in the engineering curriculum to comply with the transversal competency levels in graduates desired by the industry.

7.4. Recommendations for educators

In this thesis, an innovative game-based learning activity is provided. It can either be used by educators as a plug-and-play activity in any existing course or serve as an example for how to design effective interventions to stimulate the practice and reflection on transversal competencies. The first recommendation for educators is to create engaging and fun activities where students can actively participate, experience and reflect on the transversal competencies. This is best done in teams in which students can collaborate with their team members and make mistakes without consequences as well as have healthy competition against other teams. In this research, it is found that embedding the transversal competencies in existing courses of the engineering curriculum, rather than treat transversal competencies as separate from the technical competencies, was best practice.

Recommendation 7: Educators should design engaging interventions and allow students to actively participate and trigger reflection on their transversal competencies, collaborate with team members, follow rules but give space for taking risks and competing with other teams. Preferably, these interventions should be developed as plug-and-play in any course and engineering curriculum context.

The findings of this thesis indicated that COMπ stimulated educators to reflect on the transversal competencies present in their course learning outcomes and the practices and methods they use so that their students reach the transversal competency levels. The use of COMπ by educators can facilitate them to keep track of what transversal competencies their students are learning in their courses. This way, educators can (self-)assess their courses and if the objectives are not met, they can rethink their teaching strategies and practices to develop those transversal competencies.

Recommendation 8: COMπ can be used by educators as a (self-)assessment instrument to assess the transversal competencies acquired by students in their courses, and the practices to achieve that.

COMπ can also be used to check the transversal competencies present in the stated learning outcomes by lecturers themselves or others. This helps to identify whether the learning outcomes are sufficiently reported. It is recommended that a comprehensive description of the transversal competencies in the learning outcomes of the courses should be given. This should help also students in developing an awareness of the importance of transversal competencies for their future careers, on deciding what courses are more appropriate to develop their desired competencies and create visibility and controllability of which transversal competencies are acquired during these courses and to what level.

Recommendation 9: Educators should develop coherent and consistent learning outcomes which adequately report the transversal competencies that students are expected to be taught.

Finally, as mentioned above, educators will also benefit from exploring the acquisition of students' transversal competencies not only after the course but also the retention of the transversal competencies over a long time. This should provide information on what teaching strategies work and what changes need to be done to improve students' learning.

Recommendation 10: Evaluating the retention of students' transversal competencies over long periods aid educators in improving their teaching practices and benefit the learning of the students.

7.5. Limitations

As all research studies, this thesis has two main limitations. The first limitation is that COMπ measures perceptions of transversal competencies, thus the outcomes are contextual to the perceptions of European industry, and lecturers and students of the Aerospace faculty at Delft University of Technology. This means that the outcomes can be transferred to other engineering contexts but are not representative of all industry representatives, lecturers and engineering students. A similar limitation is present in *Chapter 6* in which the exploratory study is conducted on a small sample with qualitative data which gives only indications about the experiences of the aerospace students who participated in the activity, and not the possibility to generalise the results. The other limitation of this thesis is that the research studies of COMπ and the Chinese Whispers with the Twist activity were conducted in parallel, and thus COMπ was not used by the participating students of the Chinese Whispers with the Twist activity as the self-assessment measure on whether they perceive that the activity helped them to practice their communication competencies. An interesting future work would be to use COMπ for this purpose, i.e., to use a shorter version of COMπ with the domains of communication and teamwork competencies to trigger the participating students of the Chinese Whispers with the Twist activity to reflect or self-assess their competencies.

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APPENDICES

Appendix A: Description of communication criteria used in literature and the corresponding studies.

Category	Criteria	Description	References
Oral Communication (n=31)	Organization (n=15)	Give a clear, logic, structured and organized oral presentation.	(Saunders, Glatz et al. 2003, Wasserman, Schmidt et al. 2003, Huyck, Ferguson et al. 2007, Amante, Lacayo et al. 2010, Keshavarz and Vaziri 2012, Ryan 2012, Jones and Abdallah 2013, Bousaba, Conrad et al. 2014, Mourtos 2014, Eichelman, Clark et al. 2015, García, Fuentes et al. 2015, Ortiz M., Ballesteros Sánchez et al. 2015, Uruburu Colsa, Ortiz Marcos et al. 2015, de-Juan, Fernandez del Rincon et al. 2016, Galván-Sánchez, Verano-Tacoronte et al. 2017)
	Visual/written aids (n=11)	Use media, graphics, writing texts that support the oral exposition	(Saunders, Glatz et al. 2003, Huyck, Ferguson et al. 2007, Keshavarz and Vaziri 2012, Ryan 2012, Jones and Abdallah 2013, Bousaba, Conrad et al. 2014, Mourtos 2014, García, Fuentes et al. 2015, Ortiz M., Ballesteros Sánchez et al. 2015, Uruburu Colsa, Ortiz Marcos et al. 2015, Galván-Sánchez, Verano-Tacoronte et al. 2017)
	Speech delivery (n=9)	Modulate the voice, maintain eye contact and use body language	(Saunders, Glatz et al. 2003, Wasserman, Schmidt et al. 2003, Amante, Lacayo et al. 2010, Keshavarz and Vaziri 2012, Ryan 2012, Bousaba, Conrad et al. 2014, Eichelman, Clark et al. 2015, Uruburu Colsa, Ortiz Marcos et al. 2015, Galván-Sánchez, Verano-Tacoronte et al. 2017)
	Content development (n=7)	Use orally appropriate, relevant and compelling content that shows mastery of the subject	(Saunders, Glatz et al. 2003, Wasserman, Schmidt et al. 2003, Ryan 2012, Jones and Abdallah 2013, Bousaba, Conrad et al. 2014, Eichelman, Clark et al. 2015, García, Fuentes et al. 2015)
	Time management (n=7)	Adhere to the presentation time limit	(Huyck, Ferguson et al. 2007, Amante, Lacayo et al. 2010, Keshavarz and Vaziri 2012, Ryan 2012, Bousaba, Conrad et al. 2014, Mourtos 2014, Galván-Sánchez, Verano-Tacoronte et al. 2017)
	Audience (n=4)	Interact with and adapt the oral communication to different audiences	(Wasserman, Schmidt et al. 2003, Bousaba, Conrad et al. 2014, Dohaney, Brogt et al. 2015, Ortiz M., Ballesteros Sánchez et al. 2015)
	Questions and answers (n=4)	Understand and answer questions	(Saunders, Glatz et al. 2003, Amante, Lacayo et al. 2010, Keshavarz and Vaziri 2012, Ryan 2012)

	Team uniformity (n=2)	Show homogeneous transition between the presenters (visual and oral presentation)	(Ryan 2012, Galván-Sánchez, Verano-Tacoronte et al. 2017)
Written communication (n=24)	Language (n=13)	Use the appropriate vocabulary, syntax and grammar	(Saunders, Glatz et al. 2003, Wasserman, Schmidt et al. 2003, Flateby and Fehr 2008, Keshavarz and Vaziri 2012, Jones and Abdallah 2013, Mourtos 2014, Eichelman, Clark et al. 2015, Frank, Kaupp et al. 2015, García, Fuentes et al. 2015, Backer 2016, Barr 2016, de-Juan, Fernandez del Rincon et al. 2016, Fries, Cross et al. 2017)
	Report organization (n=12)	Develop a clear, logic, structured and organized report	(Saunders, Glatz et al. 2003, Wasserman, Schmidt et al. 2003, Flateby and Fehr 2008, Keshavarz and Vaziri 2012, Jones and Abdallah 2013, Mourtos 2014, Eichelman, Clark et al. 2015, Frank, Kaupp et al. 2015, Barr 2016, de-Juan, Fernandez del Rincon et al. 2016, Ramírez-Echeverry, Olarte Dussán et al. 2016, Fries, Cross et al. 2017)
	Content development (n=10)	Write appropriate, relevant and compelling content that shows mastery of the subject	(Saunders, Glatz et al. 2003, Wasserman, Schmidt et al. 2003, Flateby and Fehr 2008, Keshavarz and Vaziri 2012, Jones and Abdallah 2013, Mourtos 2014, Eichelman, Clark et al. 2015, Frank, Kaupp et al. 2015, Barr 2016, Fries, Cross et al. 2017)
	Source citation (n=8)	Cite sources accurately	(Saunders, Glatz et al. 2003, Barnes, Dyrenfurth et al. 2012, Jones and Abdallah 2013, Eichelman, Clark et al. 2015, Frank, Kaupp et al. 2015, García, Fuentes et al. 2015, Barr 2016, Ramírez-Echeverry, Olarte Dussán et al. 2016)
	Context and purpose (n=6)	Perform a report according to the context and purpose of the situation	(Wasserman, Schmidt et al. 2003, Flateby and Fehr 2008, Eichelman, Clark et al. 2015, Frank, Kaupp et al. 2015, Barr 2016, Ramírez-Echeverry, Olarte Dussán et al. 2016)
	Audience (n=4)	Adapt the written communication according to the audience	(Wasserman, Schmidt et al. 2003, Flateby and Fehr 2008, Frank, Kaupp et al. 2015, Ramírez-Echeverry, Olarte Dussán et al. 2016)
	Graphical/tables support (n=3)	Use the appropriate graphics and tables to support the text	(Saunders, Glatz et al. 2003, Jones and Abdallah 2013, Mourtos 2014)
Foster communication (n=7)	Self-confidence (n=4)	Act confidently in different situations	(Amante, Lacayo et al. 2010, Lopes, Gerolamo et al. 2015, Ngaile, Wang et al. 2015, Wilkins, Bernstein et al. 2015)

	Achieve/convey ideas (n=3)	Achieve conversation goals, negotiate, persuade and convey ideas in different ways (e.g. graphically, verbally)	(Immekus, Maller et al. 2005, Strauss and Terenzini 2005, Hernandez-Linares, Agudo et al. 2015)
	Self-exposure (n=2)	Self-expose to conversations in different environments	(Lopes, Gerolamo et al. 2015, Wilkins, Bernstein et al. 2015)
Foster interaction (n=4)	Group interaction (n=3)	Interact with all group members and encourage communication between members	(Ater Kranov, Hauser et al. 2008, Uruburu Colsa 2011, Schmeckpeper, Ater Kranov et al. 2014)
	Group self-regulation (n=3)	Work together to find consensus considering perspectives	(Ater Kranov, Hauser et al. 2008, Kaul and Adams 2014, Schmeckpeper, Ater Kranov et al. 2014)
	Client interaction (n=1)	Interact and communicate with clients or instructors	(Uruburu Colsa 2011)
Communication management (n=1)	Conflict resolution (n=1)	Use communication in order to avoid and solve conflicts	(Immekus, Maller et al. 2005)
Reading (n=1)	Reading (n=1)	Read and understand the reading	(Backer 2016)
Listening (n=2)	Listening (n=2)	Listen, understand and react on verbal messages	(Mourtos 2014, Backer 2016)

Appendix B: Description of lifelong learning criteria used in literature.

Category	Criteria	Description	References
Reflection (n=21)	Self-reflection (n=17)	Reflect on current knowledge and to differentiate from what is known or not known	(Mourtos 2003, Ater Kranov, Hauser et al. 2008, Kirby, Knapper et al. 2010, Ater Kranov, Zhang et al. 2011, Lord, Stefanou et al. 2011, Martínez-Mediano and Lord 2012, Ater Kranov, Williams et al. 2013, Chen, Lord et al. 2013, Douglas, Wertz et al. 2014, Kaul and Adams 2014, Mourtos 2014, Schmeckpeper, Ater Kranov et al. 2014, Frank, Kaupp et al. 2015, Ortiz M., Ballesteros Sánchez et al. 2015, Schoepp, Danaher et al. 2016, Zheng, Yin et al. 2016, Ahmed 2017)
	Self-monitoring (n=6)	Monitor learning process and self-assess periodically the performance	(Ater Kranov, Hauser et al. 2008, Ater Kranov, Zhang et al. 2011, Ater Kranov, Williams et al. 2013, Schmeckpeper, Ater Kranov et al. 2014, Schoepp, Danaher et al. 2016, Zheng, Yin et al. 2016)
	Goal setting (n=5)	Set goals for tasks that might be important for the development	(Kirby, Knapper et al. 2010, Lord, Stefanou et al. 2011, Chen, Lord et al. 2013, Ortiz M., Ballesteros Sánchez et al. 2015, Zheng, Yin et al. 2016)
	Responsible for own learning (n=4)	Monitor and evaluate individual and others learning	(Litzinger, Wise et al. 2001, Briedis 2002, Martínez-Mediano and Lord 2012, Ahmed 2017)
	Critical thinking (n=4)	Think carefully about a subject considering various perspectives to arrive at an appropriate solution or conclusion	(Litzinger, Wise et al. 2001, Lord, Stefanou et al. 2011, Villiers, Bondehagen et al. 2013, Wertz, Fosmire et al. 2013)
	Learn from mistakes (n=1)	Learn from mistakes and to practice continuous improvement	(Briedis 2002)
Acquiring (n=20)	Locating and scrutinizing information (n=16)	Locate, examine closely and interpret information	(Ater Kranov, Hauser et al. 2008, Kirby, Knapper et al. 2010, Ater Kranov, Zhang et al. 2011, Lord, Stefanou et al. 2011, Wertz, Ross et al. 2011, Ater Kranov, Williams et al. 2013, Chen, Lord et al. 2013, Villiers, Bondehagen et al. 2013, Wertz, Fosmire et al. 2013, Douglas, Wertz et al. 2014, Scharf 2014, Schmeckpeper, Ater Kranov et al. 2014, Ortiz M., Ballesteros Sánchez et al. 2015, Schoepp, Danaher et al. 2016, Zheng, Yin et al. 2016, Ahmed 2017)
	Source citation (n=4)	Identify and cite correctly quality sources	(Wertz, Ross et al. 2011, Wertz, Fosmire et al. 2013, Douglas, Wertz et al. 2014, Scharf 2014)

	Reading engineering information (n=2)	Take the initiative to read engineering articles or books outside of classes	(Mourtos 2003, Mourtos 2014)
	Apply technology (n=2)	Acquire and apply new technologies	(Strauss and Terenzini 2005, Douglas, Wertz et al. 2014)
Learning (n=14)	Willingness/ motivation/ curiosity to learn (n=11)	Learn new things autonomously	(Litzinger, Wise et al. 2001, Briedis 2002, Mourtos 2003, Strauss and Terenzini 2005, Coşkun and Demirel 2010, Lord, Stefanou et al. 2011, Martínez-Mediano and Lord 2012, Kaul and Adams 2014, Mourtos 2014, Frank, Kaupp et al. 2015, Ortiz M., Ballesteros Sánchez et al. 2015)
	Rehearse and elaborate information (n=3)	Memorize, summarize and paraphrase information	(Lord, Stefanou et al. 2011, Scharf 2014, Frank, Kaupp et al. 2015)
	Adaptation of learning strategies (n=3)	Deal with uncertain and unexpected conditions and to solve problems when they arise	(Kirby, Knapper et al. 2010, Chen, Lord et al. 2013, Ortiz M., Ballesteros Sánchez et al. 2015)
	Creativity (n=1)	Create new ideas	(Litzinger, Wise et al. 2001)
Initiating (n=11)	Create a learning plan (n=10)	Prepare own personal learning development plan to initiate tasks or participate in activities to improve future performance	(Litzinger, Wise et al. 2001, Mourtos 2003, Kirby, Knapper et al. 2010, Martínez-Mediano and Lord 2012, Chen, Lord et al. 2013, Villiers, Bondehagen et al. 2013, Douglas, Wertz et al. 2014, Mourtos 2014, Frank, Kaupp et al. 2015, Ahmed 2017)
	Help-seeking (n=2)	Seek help when needed	(Lord, Stefanou et al. 2011, Frank, Kaupp et al. 2015)
Participating (n=5)	Activity participation (n=4)	Participate in professional activities and learning opportunities	(Litzinger, Wise et al. 2001, Briedis 2002, Mourtos 2003, Mourtos 2014)
	Collaborative work (n=1)	Collaborate in teams to solve complex problems	(Martínez-Mediano and Lord 2012)

Appendix C: Description of teamwork criteria used in literature.

Categories	Criteria	Description	References
Team interaction (n=26)	Interacting with others (n=18)	Interact and work with others to accomplish team goals and to solve problems	(Immekus, Maller et al. 2005, Strauss and Terenzini 2005, Besterfield-Sacre, Shuman et al. 2007, Huyck, Ferguson et al. 2007, Pazos, Micari et al. 2010, Gerlick, Davis et al. 2011, Uruburu Colsa 2011, Fini and Mellat-Parast 2012, Zhang 2012, Enszer and Castellanos 2013, Sheridan, Evans et al. 2014, Gerhart and Carpenter 2014, Ortiz M., Ballesteros Sánchez et al. 2015, Valdes-Vasquez and Clevenger 2015, Brake and Curry 2016, Bringardner, Leslie et al. 2016, Pazos, Magpili et al. 2016, Blanco, López-Forniés et al. 2017)
	Contribution of ideas/solutions/ work (n=9)	Contribute with ideas, solutions and effort in a group work	(Besterfield-Sacre, Shuman et al. 2007, Amante, Lacayo et al. 2010, Gerlick, Davis et al. 2011, Fini and Mellat-Parast 2012, Zhang 2012, Enszer and Castellanos 2013, Fagerholm and Vihavainen 2013, Sheridan, Evans et al. 2014, Valdes-Vasquez and Clevenger 2015)
	Problem-solving and decision making (n=8)	Make decisions and solve problems respecting the team consensus	(Saunders, Glatz et al. 2003, Besterfield-Sacre, Shuman et al. 2007, Huyck, Ferguson et al. 2007, Vicent, Margalef et al. 2007, Pazos, Micari et al. 2010, Fini and Mellat-Parast 2012, Kaul and Adams 2014, Mourtos 2014)
	Multidisciplinary work (n=5)	Work in teams of people of a variety of skills and backgrounds	(Strauss and Terenzini 2005, Uruburu Colsa 2011, Kaul and Adams 2014, Mourtos 2014, Blanco, López-Forniés et al. 2017)
	Proactivity to collaborate/ Participate (n=4)	Actively participate and collaborate with team members	(Uruburu Colsa 2011, Zhang 2012, García, Fuentes et al. 2015, Hernandez-Linares, Agudo et al. 2015)
	Prepared for team meetings (n=4)	Attend and be prepared for team meetings	(Saunders, Glatz et al. 2003, Huyck, Ferguson et al. 2007, Zhang 2012, Sheridan, Evans et al. 2014)
	Engineering discipline work (n=1)	Work in teams of people of different engineering disciplines	(Strauss and Terenzini 2005)
Work management (n=20)	Manage team responsibility (n=15)	Define team roles, plan work, assign tasks, distribute work equally among team members and set direction	(Saunders, Glatz et al. 2003, Immekus, Maller et al. 2005, Besterfield-Sacre, Shuman et al. 2007, Huyck, Ferguson et al. 2007, Vicent, Margalef et al. 2007, Pazos, Micari et al. 2010, Gerlick, Davis et al. 2011, Zhang 2012, Fagerholm and Vihavainen 2013, Jones and Abdallah 2013, Sheridan, Evans et al. 2014, Dunai, Prieto et al. 2015, Brake and Curry 2016, Bringardner, Leslie et al. 2016, Pazos, Magpili et al. 2016)

	Monitored and controlled activities (n=6)	Monitor and control team activities to fulfil goals and deadlines	(Saunders, Glatz et al. 2003, Huyck, Ferguson et al. 2007, Mourtos 2014, Garcia, Calvo-Manzano et al. 2015, Valdes-Vasquez and Clevenger 2015, Pazos, Magpili et al. 2016)
	Responsible for team outcomes (n=6)	Display dedication, determination and responsibility on team outcomes and performance	(Huyck, Ferguson et al. 2007, Dolan, Batchelder et al. 2011, Zhang 2012, Fagerholm and Vihavainen 2013, Sheridan, Evans et al. 2014, Bringardner, Leslie et al. 2016)
	Team leadership (n=6)	Demonstrate leadership by taking responsibility for tasks and by motivating and disciplining others	(Dolan, Batchelder et al. 2011, Zhang 2012, Gerhart and Carpenter 2014, Brake and Curry 2016, Bringardner, Leslie et al. 2016, Wu, Huang et al. 2016)
Fostering team climate (n=21)	Team relationship (n=15)	Engage members with respect and listen and respect others' ideas	(Saunders, Glatz et al. 2003, Besterfield-Sacre, Shuman et al. 2007, Dolan, Batchelder et al. 2011, Gerlick, Davis et al. 2011, Fini and Mellat-Parast 2012, Zhang 2012, Fagerholm and Vihavainen 2013, Jones and Abdallah 2013, Sheridan, Evans et al. 2014, Dunai, Prieto et al. 2015, Garcia, Calvo-Manzano et al. 2015, Valdes-Vasquez and Clevenger 2015, Bringardner, Leslie et al. 2016, Heinis, Goller et al. 2016, Blanco, López-Forniés et al. 2017)
	Encourage the group (n=7)	Encourage the group to achieve goals and to contribute to group work	(Huyck, Ferguson et al. 2007, Amante, Lacayo et al. 2010, Gerlick, Davis et al. 2011, Zhang 2012, Enszer and Castellanos 2013, Sheridan, Evans et al. 2014, Valdes-Vasquez and Clevenger 2015)
	Managing conflict (n=5)	Avoid conflict and to solve conflicts	(Gerlick, Davis et al. 2011, Mourtos 2014, Brake and Curry 2016, Bringardner, Leslie et al. 2016, Pazos, Magpili et al. 2016)
Foster interaction (n=13)	Communication with group members/others (n=9)	Communicate actively and constructively between group members and others outside the discipline	(Besterfield-Sacre, Shuman et al. 2007, Ramirez, Jimenez et al. 2007, Amante, Lacayo et al. 2010, Pazos, Micari et al. 2010, Gerlick, Davis et al. 2011, Jones and Abdallah 2013, Dunai, Prieto et al. 2015, Valdes-Vasquez and Clevenger 2015, Pazos, Magpili et al. 2016)
	Stimulate industry's involvement (n=3)	Stimulate the involvement and communication with industry partners	(Gerlick, Davis et al. 2011, Mourtos 2014, Garcia, Calvo-Manzano et al. 2015)

	Accept/ask feedback (n=2)	Accept or ask feedback to improve personally or the team performance	(Kaul and Adams 2014, Sheridan, Evans et al. 2014)
	Provide opinions and constructive feedback (n=1)	Provide opinions and constructive feedback to others	(Sheridan, Evans et al. 2014)
Work delivery (n=9)	Work content (n=6)	Develop a team work with quality content	(Gerlick, Davis et al. 2011, Zhang 2012, Enszer and Castellanos 2013, Sheridan, Evans et al. 2014, Valdes-Vasquez and Clevenger 2015, Wu, Huang et al. 2016)
	Proficiency in discipline/topic (n=3)	Show proficiency in the discipline or topic developed	(Zhang 2012, Enszer and Castellanos 2013, Mourtos 2014)
	Homogenous report/ presentation (n=2)	Elaborate a homogenous presentation and report when the individual parts are combined	(Huyck, Ferguson et al. 2007, Ortiz M., Ballesteros Sánchez et al. 2015)
	Presentation and explanation of work (n=2)	Present, explain and defend the work developed	(Huyck, Ferguson et al. 2007, Valdes-Vasquez and Clevenger 2015)

Appendix D: Description of innovation criteria used in literature.

Categories	Criteria	Description	References
Idea generation (n=17)	Flexibility (n=15)	Apply and integrate engineering knowledge, and to use different technologies to generate ideas and solutions	(Ramirez, Jimenez et al. 2007, Shields 2007, Charyton, Jagacinski et al. 2008, Hernández and Ramírez 2008, Robbins and Kegley 2010, Charyton, Jagacinski et al. 2011, Amelink, Watford et al. 2013, Solana-Gutiérrez, Bejarano-Carrión et al. 2014, Hernandez-Linares, Agudo et al. 2015, Clemente, Vieira et al. 2016, Lopez-Malo, Husted et al. 2016, Vila-Parrish, Baldwin et al. 2016, Wu, Huang et al. 2016, Keh, Ismail et al. 2017, Saorín, Melian-Díaz et al. 2017)
	Originality (n=13)	Produce unique or unusual ideas in a given context	(Shields 2007, Charyton, Jagacinski et al. 2008, Robbins and Kegley 2010, Charyton, Jagacinski et al. 2011, Eppes, Milanovic et al. 2012, Fila and Purzer 2012, Solana-Gutiérrez, Bejarano-Carrión et al. 2014, Clemente, Vieira et al. 2016, Lopez-Malo, Husted et al. 2016, Vila-Parrish, Baldwin et al. 2016, Wu, Huang et al. 2016, Keh, Ismail et al. 2017, Saorín, Melian-Díaz et al. 2017)
	Fluency (n=7)	Produce a great number of ideas and solutions	(Shields 2007, Charyton, Jagacinski et al. 2008, Robbins and Kegley 2010, Charyton, Jagacinski et al. 2011, Solana-Gutiérrez, Bejarano-Carrión et al. 2014, Wu, Huang et al. 2016, Keh, Ismail et al. 2017)
	Elaboration (n=7)	Pull information together, add details, and explain and polish information	(Amelink, Watford et al. 2013, Solana-Gutiérrez, Bejarano-Carrión et al. 2014, Clemente, Vieira et al. 2016, Lopez-Malo, Husted et al. 2016, Vila-Parrish, Baldwin et al. 2016, Wu, Huang et al. 2016, Saorín, Melian-Díaz et al. 2017)
Product generation (n=10)	Connectivity (n=4)	Connect and integrate different ideas and solutions into new creative forms	(Eppes, Milanovic et al. 2012, Garcia Garcia, Gonzalez Garcia et al. 2014, Clemente, Vieira et al. 2016, Saorín, Melian-Díaz et al. 2017)
	Implementing solutions (n=3)	Work with team members to design and implement innovative solutions	(Ramirez, Jimenez et al. 2007, Hernández and Ramírez 2008, Amelink, Watford et al. 2013)
	Usefulness (n=3)	Develop a product or system that fulfils the given design problem	(Charyton, Jagacinski et al. 2011, Fila and Purzer 2012, Lopez-Malo, Husted et al. 2016)
	Viability (n=1)	Develop a product or system that can be maintained and sustained	(Fila and Purzer 2012)

	Feasibility (n=1)	Develop a product or system that can be implemented	(Fila and Purzer 2012)
	Desirability (n=1)	Develop a product that is accepted by consumers and users	(Fila and Purzer 2012)
Thinking (n=9)	Scaling information (n=4)	Identify, organize and synthesize information, elements and ideas	(Eppes, Milanovic et al. 2012, Amelink, Watford et al. 2013, Hernandez-Linares, Agudo et al. 2015, Lopez-Malo, Husted et al. 2016)
	Critical thinking (n=2)	Think carefully, explore and evaluate ideas considering various perspectives to arrive an appropriate solution or conclusion	(Amelink, Watford et al. 2013, Vila-Parrish, Baldwin et al. 2016)
	Problem-solving (n=2)	Develop a logical and consistent plan to solve problems and to implement it effectively	(Eppes, Milanovic et al. 2012, Lopez-Malo, Husted et al. 2016)
	Abstract thinking (n=1)	Think in terms of concepts and general principals	(Garcia Garcia, Gonzalez Garcia et al. 2014)
Communication (n=3)	Graph ability (n=2)	Express graphically	(Clemente, Vieira et al. 2016, Saorín, Melian-Díaz et al. 2017)
	Communicate innovation (n=1)	Communicate innovative designs and solutions	(Amelink, Watford et al. 2013)
Risk (n=3)	Risk-taking (n=3)	Take personal risk or risk of product failure	(Eppes, Milanovic et al. 2012, Lopez-Malo, Husted et al. 2016, Vila-Parrish, Baldwin et al. 2016)
Contradiction (n=3)	Embracing contradiction (n=3)	Recognize the value of divergent or contradictory perspectives and to integrate them	(Eppes, Milanovic et al. 2012, Lopez-Malo, Husted et al. 2016, Vila-Parrish, Baldwin et al. 2016)

Active learning (n=3)	Acquiring competencies (n=2)	Attain strategies and skills within a particular domain	(Eppes, Milanovic et al. 2012, Lopez-Malo, Husted et al. 2016)
	Self-initiated exploration (n=1)	Direct monitor own learning and knowledge	(Amelink, Watford et al. 2013)
Diffusion (n=2)	Diffusion (n=2)	Explore the resources that lead to participation in innovative activities or development of innovation	(Amelink, Watford et al. 2013, Hernandez-Linares, Agudo et al. 2015)
Collaboration (n=1)	Collaboration (n=1)	Work with others to generate ideas	(Amelink, Watford et al. 2013)

Appendix E: Reliability and Validity evidence of the measurement methods (IRR indicates interrater reliability; ICC - intra-class correlation coefficient; r - Pearson correlation coefficient; EFA - exploratory factor analysis; CFA - confirmatory factor analysis; ρ - Spearman correlation; PA - percentage agreement; KMO - Kaiser Meyer Olkin).

Instrument, Dimensions, Scale	Competency	Reliability	Validity	Reference
Rubric 14 dimensions 3-point Likert scale	Communication (Oral)	Internal consistency (2 raters): Cronbach's $\alpha=0.86$ and 0.74 IRR (2 raters): $r=0.68$ ($p<0.001$) and Cohen's kappa statistic (strict criterion=0.33 and lax criterion=0.40)	Content validity: literature and expert review Tested as pilot study	(Galván-Sánchez, Verano-Tacoronte et al. 2017)
Social Skill Inventory (SSI-Del-Prette) 38 dimensions	Communication	Internal consistency: Cronbach's $\alpha=0.75$ Test-retest reliability: $r=0.90$ ($p<0.001$)	Pre and post-assessment	(Lopes, Gerolamo et al. 2015)
Science, Technology, Engineering and Math Interpersonal Communication Skills Assessment Battery (STEM ICSAB): 3 instruments of 20, 12 and 5 dimensions	Communication	Internal consistency: EFA: Cronbach's $\alpha=0.96$, 0.92 and 0.85 CFA: Cronbach's $\alpha=0.93$, 0.94 and 0.66	Content validity: expert review Construct validity: EFA: 1 factor solution VarExp: 53%, 57%, 46% FL≥0.60, 0.60, 0.60 CFA: 1 factor solution FL≥0.55, 0.54, 0.38	(Wilkins, Bernstein et al. 2015)
Cognitive Level and Quality of Writing Assessment, CLAQWA	Communication (Written)	IRR: Correlations above 0.80	Content validity: Expert review/validation 6-year study	(Flateby and Fehr 2008)
Written VALUE rubric 4 Likert scale Elevator Pitch 5 Likert scale	Communication (Written)	IRR (2 raters) ICC(VALUE rubric)=0.73 (individual dimensions - 0.56 to 0.73) ICC(Elevator Pitch)=0.59 (individual dimensions - from 0.64 to 0.75)	Control and experimental groups Construct validity: correlation between students grades and their perception questionnaire of communication improvement (for experimental group $r=-0.11$, $\rho=-0.04$, $p=0.86$, and for control group $r=0.04$, $\rho=0.04$, $p=0.88$)	(Eichelman, Clark et al. 2015)

Collegiate Learning Assessment, CLA+	Communication (Written)	Internal consistency: Stratified α=0.85 and 0.87	Face validity: students self-report on what skills they perceived the test measured Construct validity: correlation with 2 measures (CLA Performance Task r=0.73-0.83 and CLA Critique an Argument r=0.73-0.94)	(Frank, Kaupp et al. 2015)
Written VALUE rubric 5 dimensions 4 Likert scale	Communication (Written)	IRR (2 raters): Kappa statistics >90%	Face validity	(Frank, Kaupp et al. 2015)
Post-questionnaire 36 dimensions (CM 4 items, TW 3 items, and LLL 3 items) 5 Likert scale	Communication Lifelong learning Teamwork	Internal consistency: Cronbach's $\alpha(CM)=0.86$, $\alpha(LLL)=0.78$, and $\alpha(TW)=0.86$	Tested as pilot test Content validity: Review of literature and available instruments, and experts and students review of item and content Construct validity: EFA 9 factors $FL(CM)\geq0.60$, $FL(LLL)\geq0.73$, $FL(TW)\geq0.65$ ExpVar: 72.2%	(Strauss and Terenzini 2005)
Questionnaire 23 dimensions 5 Likert scale	Communication Teamwork	Internal consistency: Cronbach's $\alpha(TW)= 0.905$ and 0.94, $\alpha(CM)=0.857$ and 0.651	Pre and post-questionnaire 5 factors	(Fini and Mellat-Parast 2012)
Self-report CM 26 items, and TW 15 items) 5 Likert scale	Communication Teamwork	Internal consistency: Cronbach's $\alpha(TW)= 0.94$, $\alpha(CM)=0.95$	Pilot study is described Content validity: review of literature and items Construct validity: CFA $FL(TW)>0.22$ and $FL(CM)>0.20$	(Immekus, Maller et al. 2005)
Questionnaire of 45 dimensions (CM - 5 items, IC - 3 items for creativity, and TW - 1 item) 5 Likert scale	Communication Innovation	Internal consistency: Cronbach's $\alpha=0.968$ $\alpha(CM)= 0.823$, $\alpha(I)=0.663$	Validated in previous work Construct validity: EFA (previous work) and CFA 9 factors ExpVar: 74.109%	(Hernandez-Linares, Agudo et al. 2015)
Abreaction Test for Evaluating Creativity, TAEC	Creativity	Equivalent forms: Wilcoxon ($p<0.01$ for experimental group)	Pre and post-intervention Control and experimental groups	(Clemente, Vieira et al. 2016)

Modified Strategies for Learning Questionnaire, MSLQ 5 dimensions 5 Likert scale	Innovation	Internal consistency (calculated in previous study): Moderate Cronbach's $\alpha<0.70$	Predicted validity: scales related to academic performance	(Lord, Stefanou et al. 2011, Amelink, Watford et al. 2013)
Creative Thinking VALUE rubric 6 dimensions 4 Likert scale	Creative Thinking	IRR (2 raters): 0.85 and 0.79		(Lopez-Malo, Husted et al. 2016)
Abreaction Test of Creativity 12 dimensions 5 Likert scale	Innovation	Internal consistency: Cronbach's $\alpha=0.71$		(Saorín, Melian-Díaz et al. 2017)
Critical Thinking Assessment Test, CAT	Critical and creative thinking	IRR: average score=0.82	Face and criterion validity (correlation between 5 measurements) Pre and post-test	(Vila-Parrish, Baldwin et al. 2016)
Scoring rubric 5 dimensions 5 Likert scale	Innovation	IRR(2 raters): ρ ($p<0.05$ for all 4 dimensions)	Content validity (literature review)	(Fila and Purzer 2012)
Index of Learning Styles, ILS 4 dimensions	Creativity	Internal consistency: Cronbach's α of moderate effect (calculated in previous studies)	Pre and post-assessment Convergent validity	(Waychal 2014)
Torrance Tests of Creativity Thinking 4 dimensions	Innovation	Reliability assessed in previous studies	Predicted validity	(Shields 2007, Robbins and Kegley 2010, Wu, Huang et al. 2016)
Creative engineering Design Assessment, CEDA 4 dimensions	Creativity	IRR (2 raters): $r=0.98$ Consistency of pre and post-test reliability: $r=0.563$ CEDA was moderately correlated with the PCT ($r=0.39$, $p<0.01$) and slightly correlated with the PVST-R ($r=0.19$, $p<0.05$)	Convergent validity (correlation between 3 instruments) Discriminant validity	(Charyton, Jagacinski et al. 2008, Charyton, Jagacinski et al. 2011)

Lifelong Learning Scale, LLS 14 dimensions	Lifelong Learning	Internal consistency: Cronbach's $\alpha(LLL)=0.71$ 57% factor loadings > 0.4		(Kirby, Knapper et al. 2010, Chen, Lord et al. 2013)
Engineering Professional Skills Assessment, EPSA	Lifelong Learning	IRR: inter-rater agreement	Literature review and expert review of content, construct and criterion validity Pilot study Control group	(Ater Kranov, Hauser et al. 2008, Ater Kranov, Zhang et al. 2011, Ater Kranov, Williams et al. 2013, Schmeckpeper, Ater Kranov et al. 2014)
Scharf Diagnostic Essay Prompt 5 dimensions	Lifelong Learning	IRR: high inter-item correlation matrix Internal consistency: Cronbach's $\alpha=0.959$	Predicted validity (the overall grades correlate with pre and post-essay scores)	(Scharf 2014)
Self-Assessment of Problem Solving Strategies, SAPSS 20 dimensions	Lifelong Learning	Internal consistency: Cronbach's $\alpha=0.92$ Factor loadings≥0.34	Content validity: literature review Construct validity (EFA)	(Douglas, Wertz et al. 2014)
Critical Engineering Literacy Test, CELT, 28 dimensions	Lifelong Learning	Internal consistency: Cronbach's $\alpha(LLL)=0.67$; $r=0.47$ ($p<0.01$)	Construct validity (Correlation between CELT and Critical Assessment Test)	(Wertz, Fosmire et al. 2013)
Lifelong Tendency Scale, LLTS 27 dimensions	Lifelong Learning	Internal consistency: Cronbach's $\alpha=0.89$ KMO=0.89 Factor loadings≥0.32	Content validity (literature review, then students and lecturers review, and test correlation with Index Curiosity) Construct validity: KMO coefficient, Barlett test and EFA	(Coşkun and Demirel 2010)
Instrument 10 dimensions	Teamwork	IRR: inter-class correlation coefficient = 0.93 Internal consistency: Cronbach's $\alpha\geq0.76$ for 80% of the factors and $\alpha\geq0.61$ for 20% of items	Content validity (literature review) Construct validity (EFA and CFA) Pilot study	(Pazos, Micari et al. 2010)
Questionnaire 18 dimensions	Teamwork	Internal consistency: Cronbach's $\alpha(TW)\geq0.92$ for all the factors $\alpha\geq0.50$ for all the factors	Content validity (Literature review) CFA (all factor loadings > 0.5)	(Zhang 2012)

Team-Effective Inventory 27 dimensions	Teamwork	IRR (inter-class correlation)	Content validity (literature and items review, and experts review)	(Sheridan, Evans et al. 2014)
Rubric 7 dimensions	Teamwork	IRR (4 raters): r≥0.4 for 4 dimensions and PA	Content validity (Experts and students review)	(Gerlick, Davis et al. 2011)
Questionnaire 8 dimensions	Teamwork	Internal consistency: Cronbach's α= 0.78	Pre and post-assessment Group comparison	(Bringardner, Leslie et al. 2016)
Work sampling observation	Teamwork	IRR	Valid	(Besterfield-Sacre, Shuman et al. 2007)

*According to Field (2009):

- The values of the factor loadings should be > 0.40 or Kaiser-Meyer-Olkin > 0.5, and the eigenvalues > 1.0.
- IRR is assessed by intra-class correlation coefficient (ICC > 0 show similarities) and Pearson or Spearman rho correlation (absolute values closer to 1 indicate higher correlation).
- Cronbach-α values around 0.80 are good for cognitive tests, around 0.70 for ability tests and in social sciences values below 0.7 can even be expected because of the diversity of the construct.

Appendix F: Transversal Competencies Perceptions Instrument (COMπ)

Entrepreneurial competencies				
	1- Technology benchmarking: Demonstrates awareness of market drivers, emerging technologies, competitions, pricing and customer needs, regulations and standards.			
	Absent Not aware of market drivers, emerging technologies, competitions, pricing and customer needs, regulations and standards	**Basic** Little awareness of market drivers, emerging technologies, competitions, pricing and customer needs, regulations and standards	**Advanced** Awareness of market drivers and emerging technologies, but little awareness of competitions, pricing and customer needs, regulations and standards	**Expert** Awareness of market drivers, emerging technologies, competitions, pricing and customer needs, regulations and standards
	2- Financial awareness: Demonstrates awareness of financial capital (funding, cash flow, taxes, wages, etc.).			
	Absent Not aware of financial capital (funding, cash flow, taxes, wages, etc.)	**Basic** Little awareness of financial capital (funding, cash flow, taxes, wages, etc.)	**Advanced** Awareness of financial capital (funding, cash flow, taxes, wages, etc.)	**Expert** Deep awareness of financial capital (funding, cash flow, taxes, wages, etc.)
	3- Business acumen: Identifies business opportunities and applies business modelling and problem solving to implement strategic responses.			
	Absent Not able to identify business opportunities nor to apply business modelling and problem solving to implement strategic responses	**Basic** Difficulties with identifying business opportunities and applying business modelling and problem solving to implement strategic responses	**Advanced** Identifies business opportunities but has difficulties with applying business modelling and problem solving to implement strategic responses	**Expert** Identifies business opportunities and applies business modelling and problem solving to implement strategic responses
	4- Negotiation skills: Demonstrates knowledge of negotiation methods and negotiates under risk, long-term and international business environments.			
	Absent No knowledge of basic negotiation methods nor the ability to negotiate in low-risk business environments	**Basic** Knowledge of basic negotiation methods but no ability to negotiate in low-risk business environments	**Advanced** Knowledge of negotiation methods and ability to negotiate in low-risk business environments	**Expert** Knowledge of negotiation methods and ability to negotiate in medium-high risk, long-term and international business environments
	5- Project management: Plans, controls and orients strategies, and instructs and coordinates people.			
	Absent Not able to plan, monitor and orient strategies, and instruct and coordinate subordinates	**Basic** Difficulties with planning, monitoring and orienting strategies, and instructing and co-ordinating people	**Advanced** Plans, monitors and orients strategies, but has difficulties with instructing and co-ordinating people	**Expert** Plans, monitors and orients strategies, and instructs and co-ordinates people
	6- Leadership: Provides guidance, instruction, direction, and leadership to a group and is considered charismatic among members.			
	Absent Not able to provide guidance, instruction, direction and leadership to a group	**Basic** Difficulties with providing guidance, instruction, direction and leadership to a group	**Advanced** Provides guidance, instruction, direction and leadership to a group	**Expert** Provides guidance, instruction, direction and leadership to a group and is considered charismatic among members
	7- Risk tolerance: Withstands risk and overcomes failure learning from it.			
	Absent Not able to withstand risk nor to overcome failure	**Basic** Difficulties withstanding risk and overcoming failure	**Advanced** Withstands risk but has difficulties overcoming failure	**Expert** Withstands risk and overcomes failure learning from it

8- Stakeholder management: Demonstrates knowledge about stakeholders' needs, concerns, and desires.			
Absent No knowledge about stakeholders' needs, concerns and desires	**Basic** Little knowledge about stakeholders' needs, concerns and desires	**Advanced** Knowledge about stakeholders' needs, concerns and desires	**Expert** In-depth knowledge about stakeholders' needs, concerns and desires
9-Value/cost-consciousness: Demonstrates awareness of project values and costs when creating, designing, implementing and operating it.			
Absent Not aware of project values and costs when creating, designing, implementing and operating it	**Basic** Little awareness of project values and costs when creating, designing, implementing and operating it	**Advanced** Awareness of project values and costs when creating, designing, implementing and operating it	**Expert** Manages project values and costs
10- Curious for innovation: Demonstrates curiosity to identify and to explore innovative ideas/products/services which give market value.			
Absent No curiosity to identify and to explore innovative ideas/products/services which give market value	**Basic** Little curiosity to identify and to explore innovative ideas/products/ services which give market value	**Advanced** Curious to identify and to explore innovative ideas/products/ services which give market value	**Expert** Besides being curious, motivates others to identify and explore innovative ideas/products/services which give market value
11- Problem-solving: Identifies problems and estimates risks, evaluates the different options and weights the alternatives.			
Absent Not able to identify problems, generate and evaluate the risk of alternatives	**Basic** Difficulties with identifying problems, and with generating and evaluating the risk of alternatives	**Advanced** Identifies problems in the real world but requires help to generate and evaluate the risk of alternatives	**Expert** Identifies problems and estimates risks, evaluates the different options and weighs the solutions
12- Critical thinking: Considers issues, develops strategies to overcome obstacles, estimates their risk, and implement solutions.			
Absent Not able to consider issues, develop strategies to overcome obstacles, estimate risks and implement solutions	**Basic** Difficulties with considering issues, developing strategies to overcome obstacles, estimating risks and implementing solutions	**Advanced** Considers issues, develops strategies to overcome obstacles, but requires help to estimate risks and to implement solutions	**Expert** Considers issues, develops strategies to overcome obstacles, estimates risks and implement solutions
13- Ideation: Uses creative tools and processes, and others' advice to create functional new ideas or to improve existing ideas.			
Absent Lacks creativity tools and processes and others' advice to create functional new ideas or to improve existing ideas	**Basic** Uses little creative tools and processes and others' advice to create functional new ideas or to improve existing ideas	**Advanced** Uses creativity tools and processes, and others' advice to create functional new ideas or to improve existing ideas	**Expert** Besides being creative, encourages others to come up with new functional ideas by applying their creativity and innovation methods
14- Idea implementation: Implements activities which enable creative ideas to move from the design to the marketplace.			
Absent Not able to implement activities which enable creative ideas to move from the design to the marketplace	**Basic** Little ability to implement activities which enable creative ideas to move from the design to the marketplace	**Advanced** Implements activities which enable creative ideas to move from the design to the marketplace	**Expert** Manages the implementation of activities which enable creative ideas to move from the design to the marketplace

Communication competencies

15- Presentation method: Develops presentation methods and mediums depending on topic and target group.			
Absent Not able to use a presentation method and medium	**Basic** Uses the same presentation method and medium without adaption to topic and target group	**Advanced** Uses the appropriate presentation methods and medium depending on topic and target group	**Expert** Develops innovative presentation methods and mediums depending on topic and target group
16- Presentation skills: Gives a clear, organized and logical speech and answers questions adequately and with elaboration.			
Absent Gives unclear, disorganized and monotonous speech and does not answer questions from the audience	**Basic** Gives clear, organized and logical but monotonous speech and answers questions rudimentary	**Advanced** Gives clear, organized and logical speech and answers all questions adequately but without elaboration	**Expert** Gives clear, organized and logical speech and answers all questions adequately and with elaboration
17- Adaptive communication style: Communicates properly, adapting style and language to the purpose, context, and environment.			
Absent Not able to communicate properly, adapting style and language to the purpose, context and environment	**Basic** Difficulties communicating, adapting style and language to the purpose, context and environment	**Advanced** Communicates properly, adapting style and language to the purpose, context and environment	**Expert** Masters communication, adapting style and language to the purpose, context and environment with ease
18- Self-confidence: Possesses confidence in formal and informal settings and maintains eye contact with the audiences.			
Absent No confidence when talking in formal or informal settings and maintains no eye contact with the audience	**Basic** Confidence requires development when talking in informal settings and little eye contact is maintained, only with part of the audience	**Advanced** Has confidence in talking in informal settings but little in formal settings, maintaining eye contact with part of the audience	**Expert** Has confidence in all situations both in formal and informal settings and easily maintains eye contact with the whole audience
19- English language skills: Has fluency in the English language.			
Absent No fluency in the English language (B1<)	**Basic** Basic English language fluency (B2)	**Advanced** English language requires minor corrections (C1)	**Expert** Fluent ability in the English language (C2 or native)
20- Listening skills: Listens and understand verbal messages, and consequently acts on what someone says or does.			
Absent Does not pay attention nor acts on what someone says or does	**Basic** Is sometimes not paying attention and not acting on what someone says or does	**Advanced** Listens and understands verbal messages, but hardly acts on what someone says or does	**Expert** Listens and understands verbal messages, and consequently acts on what someone says or does
21- Writing skills: Develops a logical, accurate, detailed, and organized report/paper without grammar mistakes and with accurate references.			
Absent Not able to develop a logical and accurate report/paper and lacks organization and details, and has few grammar errors and missing/inaccurate references	**Basic** Develops a logical and accurate report/paper but lacks organization and details, and has few grammar errors and inaccurate references	**Advanced** Develops a logical, accurate, detailed, and organized report/paper without grammar mistakes but with missing or inaccurate references	**Expert** Develops a logical, accurate, detailed, and organized report/paper without grammar mistakes and with accurate references

22- Interconnection/interrelation ability: Builds and retains formal and informal relationships or networks.			
Absent Not able to understand the importance of networking nor how to get the knowledge to interconnect and create links among individuals	**Basic** Understands the importance of networking but has little knowledge of how to interconnect and create links among individuals	**Advanced** Understands the importance of networking and pays attention to building formal and informal relationships	**Expert** Builds and retains formal and informal relationships naturally and fosters others' networking
23- Pitching skills: Conveys and persuades audiences within a short time speech (1-3 minutes).			
Absent Not able to convey and persuade an audience with a short time speech (1-3 min)	**Basic** Difficulties with conveying and persuading an audience with a short time speech (1-3 min)	**Advanced** Able to convey and persuade an audience with a prepared short time speech (1-3 min)	**Expert** Able to convey and persuade an audience with a spontaneous short time speech (1-3 min)
24- Cross-cultural understanding: Understand cultural differences, recognizes their importance or benefit and stimulates cooperative teamwork among people of different cultures.			
Absent Not able to understand cultural differences, recognise their importance/ benefit nor stimulates teamwork among different cultures	**Basic** Understands cultural differences but does not recognise their importance/ benefit nor stimulates teamwork among different cultures	**Advanced** Understands cultural differences and recognises their importance/ benefit but does not stimulate teamwork among different cultures	**Expert** Understands cultural differences and recognises their importance/ benefit and stimulates cooperative teamwork among different cultures
25- Interdisciplinary thinking: Collaborates with team members of engineering disciplines and of other disciplines, and clients.			
Absent Not able to collaborate interdisciplinarily with team members of engineering disciplines and of other disciplines, and clients	**Basic** Difficulties collaborating interdisciplinarily with team members of engineering disciplines and of other disciplines, and clients	**Advanced** Collaborates interdisciplinarily with team members of engineering disciplines, but not with members of other disciplines nor clients	**Expert** Collaborates interdisciplinarily with team members of engineering disciplines and other disciplines, and clients
26- Goal setting: Establishes goals balancing self and team interests.			
Absent Not able to establish goals taking into account team interests	**Basic** Difficulties establishing goals taking into account team interests	**Advanced** Establishes small goals for the group or group members considering some other's perspectives	**Expert** Establishes challenging collective goals balancing self and team interests
27- Collaborative goal-oriented: Demonstrates a collaborative working spirit towards common goals.			
Absent Not able to collaborate with team members to achieve common goals	**Basic** Difficulties of collaboration with team members to achieve common goals	**Advanced** Demonstrates a collaborative working spirit towards common goals	**Expert** Collaborates, inspires and motivates others to contribute to common goals and to step out of comfort zones

28- Engagement in teamwork: Shares information and knowledge with team members and shows engagement with teamwork.			
Absent Not able to share ideas and knowledge with team members nor show engagement with teamwork	**Basic** Shares some ideas and knowledge with team members but shows little engagement with team work	**Advanced** Shares information and ideas with team members and shows engagement with team work	**Expert** Fosters sharing of information and knowledge and encourages members to be engaged with team work
29- Giving constructive feedback: Gives constructive feedback to improve team members' performance.			
Absent Not able to give feedback to improve team member performance when asked	**Basic** Difficulties giving constructive feedback to improve team member performance when asked	**Advanced** Gives constructive feedback to improve team member performance when asked	**Expert** Gives constructive feedback to improve team member performance even without being asked
30- Time management: Prioritizes, determines tasks, schedules appointments, allocates team roles and meets deadlines.			
Absent Not able to prioritize, determine tasks, schedule appointments, allocate team roles and meet deadlines	**Basic** Difficulties in prioritizing, determining tasks, scheduling appointments and meeting deadlines	**Advanced** Prioritizes, determines tasks and schedules appointments, but sometimes has difficulty to meet deadlines	**Expert** Prioritizes, determines tasks, schedules appointments, allocates team roles and meets deadlines
31- Managing conflict: Manages conflicts between team members by stimulating healthy debates to reach agreements.			
Absent Not able to accept others' opinions generating conflicts between team members	**Basic** Difficulties accepting others opinions generating some conflicts between team members	**Advanced** Accepts and respects others opinions but has difficulties managing conflicts between other team members	**Expert** Manages effectively conflicts between team members by prompting healthy debates to reach agreements
32- Strengths and Weaknesses awareness: Possesses awareness of strengths and weaknesses, and seeks constant self-knowledge.			
Absent Not aware of own strengths and weaknesses and no interest in getting more self-knowledge	**Basic** Little awareness of own strengths and weaknesses and no interest in getting more self-knowledge	**Advanced** Awareness of some strengths and weaknesses but no interest in getting more self-knowledge	**Expert** Awareness of some strengths and weaknesses and interest in getting constant self-knowledge
33- Professional role awareness: Possesses awareness of personal and professional needs and of professional engineering roles.			
Absent Not aware of personal and professional needs and engineering professional roles	**Basic** Limited awareness of personal and professional needs and engineering professional roles	**Advanced** Concrete personal and professional needs but little awareness of engineering professional roles	**Expert** Concrete personal and professional needs and awareness of engineering professional roles
34- Actively seeking learning: Recognizes responsibility for own learning and seeks and develops strategies and practices to increase learning.			
Absent No responsibility for own learning and no proactivity to develop learning strategies and practices	**Basic** Little responsibility for own learning and little proactivity to develop learning strategies and practices	**Advanced** Recognises responsibility for own learning but has little proactivity to develop learning strategies and practices	**Expert** Recognises responsibility for own learning and continuously seeks and develops strategies and practices to improve the learning process

35- Autonomous work: Works and studies with autonomy, has responsibility for tasks, manages projects and supervises people.			
Absent No autonomy when working and studying, no responsibility for simple tasks, and does not manage projects nor supervises people	**Basic** Works and studies with little autonomy, has little responsibility for simple tasks, and does not manage projects nor supervises people	**Advanced** Works and studies with autonomy, has responsibility for routine tasks, manages simple projects and supervises people	**Expert** Works and studies with autonomy, has responsibility for complex tasks, manages complex projects, and supervises people
36- Extracurricular activity participation: Participates in volunteering activity or paid work (non-credit giving) which involve responsibility			
Absent No participation in volunteering activity or paid work (non-credit giving)	**Basic** Participation in volunteering activity or paid work (non-credit giving) with no responsibility	**Advanced** Participation in volunteering activity or paid work (non-credit giving) with limited responsibility	**Expert** Participation in volunteering activity or paid work (non-credit giving) with extensive responsibility

Appendix G: Drawing scores, assessed using the rubric, of the groups who score between 50% and 75% of the points. The maximum possible score was 43 points (Mo - Monday, Tu - Tuesday, We - Wednesday, Th - Thursday and Fr - Friday).

University	Year	Group ID	Rubric Scores					
			Objects	Amount	Colour	Position	Details	Group total
TU Delft	2019	5	7	4	6	4	11	32
IST	2019	3 Th3	7	3	6	6	8	30
TU Delft	2019	6	7	3	6	4	9	29
IST	2019	1 Tu1	7	4	4	6	8	29
TU Delft	2019	3	7	4	3	7	7	28
UMinho	2019	2	7	5	4	4	8	28
IST	2019	1 Mo1	6	4	5	4	9	28
IST	2019	4 Mo1	6	4	3	4	11	28
IST	2019	6 Mo1	7	3	3	5	10	28
IST	2019	4 Mo3	5	5	5	5	8	28
IST	2019	1 Tu2	6	4	4	5	9	28
IST	2019	3 Tu2	6	4	4	5	9	28
IST	2019	5 Th3	6	3	4	4	11	28
TU Delft	2018	1	6	4	6	4	7	27
IST	2019	1 Th1	6	4	5	5	7	27
IST	2019	6 Th1	6	4	5	4	8	27
TU Delft	2019	2	6	4	5	5	6	26
TU Delft	2019	4	7	5	2	6	6	26
IST	2019	6 Mo2	6	4	4	4	8	26
IST	2019	1 Th2	6	3	2	5	10	26
TU Delft	2019	1	6	4	6	4	5	25
KU Leuven	2018	1	6	4	2	4	9	25
KU Leuven	2019	1	6	3	6	4	7	25
IST	2019	3 Mo1	6	3	2	5	9	25
IST	2019	3 Tu1	6	3	4	5	7	25
IST	2019	7 Tu1	6	3	4	4	8	25
IST	2019	5 Tu2	6	4	4	3	8	25
IST	2019	6 Tu2	6	4	3	4	8	25
KU Leuven	2019	3	6	4	3	3	8	24
IST	2019	2 Mo4	6	3	4	5	6	24
IST	2019	4 Tu2	6	3	4	3	8	24
IST	2019	5 Th2	5	4	4	3	8	24
IST	2019	7 Th3	6	4	0	5	9	24
TU Delft	2018	3	6	4	1	4	8	23
KU Leuven	2019	2	5	4	4	3	7	23
IST	2019	2 Mo1	5	4	2	4	8	23
IST	2019	1 Mo3	6	4	0	4	9	23
IST	2019	5 Mo4	5	4	3	3	8	23
IST	2019	6 Mo4	6	3	5	5	4	23
IST	2019	2 Th2	7	5	0	6	5	23
IST	2019	2 Th3	6	4	4	2	7	23
IST	2019	1 Fr1	5	3	4	4	7	23
IST	2019	2 Fr1	5	3	4	4	7	23

IST	2019	4 Fr1	5	3	4	3	8	23
TU Delft	2018	2	5	4	4	4	5	22
IST	2019	3 Mo2	6	4	3	3	6	22
IST	2019	7 Tu2	6	4	0	5	7	22
IST	2019	5 Th1	4	3	3	4	8	22
IST	2019	6 Th3	4	4	1	4	9	22
Total per rubric			**7**	**5**	**7**	**7**	**17**	**43**

ABOUT THE AUTHOR

Curriculum Vitae

Mariana Leandro Cruz was born in Porto, Portugal on 2 March 1992. She grew up near Lisbon. She moved to Portugal capital city to do her Bachelor and Master degrees in Biomedical Engineering at Instituto Superior Técnico (IST) – University of Lisbon (from 2011 to 2016). During her master, Mariana went to the Netherlands as an Erasmus exchange student with an Erasmus+ placement grant to study at Delft University of Technology (TU Delft) for 6 months in 2015. During this period, she also worked as a supervisor at the Kavli Nanolab Delft. She returned to the Netherlands in 2016 with an Erasmus+ work placement scholarship to do her master thesis at the orthopaedics department of Erasmus Medical Centre in Rotterdam. She studied the factors that stimulate in situ cartilage regeneration through endogenous stem cell recruitment. In April 2017, she started her PhD research in Engineering Education at TU Delft. This research project was part of the European project called Professional Roles and Employability of Future EngineeRs (PREFER) and focused on addressing the transversal competency mismatch in the field of engineering. During her PhD, together with her co-authors she was awarded the best student paper at SEFI 2019 and research paper at SEFI 2020.

Publications

Articles in peer-reviewed journals

Leandro Cruz, M. and Saunders-Smits, G. N. Exploring the effectiveness and the transversal competency retention of a game-based learning activity one year after student participation. *Journal on Teaching Engineering*. 1(1): 94-112.

Leandro Cruz, M. Sá, S., Mesquita, D., Lima, R., and Saunders-Smits, G. N. (2021). The effectiveness of an activity to practise communication competencies: A case study across five European engineering universities. *International Journal of Mechanical Engineering Education*. DOI: 10.1177/03064190211014458

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Conference contributions

Sá, S., and Leandro Cruz, M. (2021). *"Using a valid game-based learning activity to practice communication competencies online."* Presented at the 4th International Conference of the Portuguese Society for Engineering Education, Lisbon, Portugal, 21-23 June.

Leandro Cruz, M., Sá, S., Mesquita, D., Lima, R., and Saunders-Smits, G. N. (2020). *"The effectiveness of a simple tool to practice communication skills: A case study across five European Engineering Universities."* Presented at the 1st International Conference on Science and Technology Education, Porto, Portugal, 15-16 October.

Saunders-Smits, G. N., and Leandro Cruz, M. (2019). *"Towards A Typology In Literature Studies & Reviews In Engineering Education Research."* Presented at the 48th SEFI Annual Conference, Twente, The Netherlands, 20-24 September. Best Research Paper Award.

Leandro Cruz, M., and Saunders-Smits, G. N. (2019). *"Transversal Competency Level of Engineering Graduates Dictated by European Industry."* Presented at the 126th ASEE Annual Conference & Exposition, Tampa, Florida, 16-19 June.

Leandro Cruz, M., Carthy, D., and Craps, S. Communication Activity Implementation over 3 Engineering Universities: Values and Challenges. Presented at the 47th SEFI Annual Conference, Budapest, Hungary, 16-19 September 2019. Best Student Paper Award.

Leandro Cruz, M., and Saunders-Smits, G. N. (2018). *"Pilot study boot camp: professional engineering roles experienced in a week."* Presented at the 6th Annual symposium of the United Kingdom & Ireland Engineering Education Research Network, Portsmouth, United Kingdom, 1-2 November, p. 21-30.

Leandro Cruz, M., and Saunders-Smits, G. N. (2018) *"Design and Implementation of New Communication and Lifelong Learning elements in a Master Engineering Course."* Presented at the 46th SEFI Annual Conference, Copenhagen, Denmark, 17-21 September.

Leandro Cruz, M., and Saunders-Smits, G. N. (2017). *”Comparison of Transversal Competence Levels of Engineering Students with Labour Market Requirements.”* Presented at the 5th Annual symposium of the United Kingdom & Ireland Engineering Education Research Network, London, United Kingdom, 23-24 November, p. 64-67.

Craps, S., Pinxten, M., Saunders-Smits, G., Leandro Cruz, M., Gaughan, K. and Langie, G. (2017) *“Professional Roles and Employability of Future Engineers.”* Presented at the 45th SEFI Annual Conference, Azores, Portugal, 18-21 September.

Poster presentations

Leandro Cruz, M., Saunders-Smits, G. N., and Groen, P. (2018). *“Employability of Future Engineers: curriculum elements.*” Presented at the Aerospace PhD Poster Day 2018, Delft, The Netherlands, 16 March.

Leandro Cruz, M., Saunders-Smits, G. N., and Groen, P. (2019). “*PREFER: Professional Roles and Employability for Future EngineeRs*.” Presented at the Aerospace PhD Poster Day 2019, Delft, The Netherlands, 8 March.

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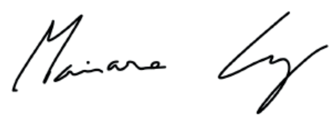


SUCCESS
$E=mc^2$
$F=ma$