Transforming Engineering Education in Learning Ecosystems for Resilient Engineers

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Transforming Engineering Education in Learning Ecosystems for Resilient Engineers

Renate G. Klaassen, Hans Hellendoorn, and Linette Bossen

***Abstract*—TU Delft education system is transformed on three levels: 1) new courses and projects in existing B.Sc. and M.Sc. programs for multidisciplinary and reflective learning; 2) new M.Sc. programs focusing on multi and interdisciplinarity, personal development, and professional skills; and 3) central Interdisciplinary Projects for Master Students from different programs. With these steps, the university offers students a learning *ecosystem* where identity-building can occur, fosters interdisciplinary teamwork, and strong interaction with the professional world and government is necessary to finish projects. In this article, the ecosystem will be explained, and results will be shared of surveys among students who experienced learning in the learning ecosystem. The surveys show that students understand their future role in the community as engineers, feel that they have acquired new skills, feel better about framing complex problems, and are more competent to work in the industry.**

***Index Terms*—Curriculum renewal, future engineer.**

I. Introduction

MANY view higher education as currently on the verge of a significant transition. As a result of Covid, digitization has soared to new heights, job security has dramatically changed over the past 20 years, and continuous change, increasing complexity, and information overload require multiple disciplines to be involved in problem-solving situations. These trends require a change in the engineering profile that becomes more urgent every passing year. Engineers should, amongst others, engineer flexible technological solutions but also be able to manage complex-socio technical systems and manage ecological development.

Engineers are no longer trained for lifelong employment with big companies or conglomerates and should focus more on small-scale start-ups. The success of the Slush entrepreneurship events in Europe is a hallmark of this development. Students need to engage in multi, inter, or transdisciplinary teams to solve complex societal problems, requiring them to develop respect for other disciplines and cultures [1]. They need to learn to listen carefully to others and act responsibly and ethically when embedding newly engineered tools. Nowadays, engineering knowledge is critically questioned, and the belief in the engineer as "the problem solver" no longer holds. Finally, emerging technologies, which are often co-engineered, ask for a broad understanding of the impact of these new technologies on society and the respective engineering disciplines.

Some smaller and larger institutes decided to change the education system radically (e.g., High Tech High, San Diego, CA, USA; Olin College, Needham, MA, USA [2], and UCL in the U.K. [3] are for example known for their integrated curriculum. Charles Stuart in Australia [4], Arizona State University work with modular, flexible, and interdisciplinary building blocks [5], while Mexico Monterrey University and TU Eindhoven work with Tec21 [6] and Challenge-Based education [7]. MIT in the U.S. works with project-focused and cross-departmental pathways [8], [9]. Each institution has realized the adaptation to the future differently [10]. In Delft, the focus is on incremental and bottom-up dynamic change. New forms of education are developed based on staff motivation and initiatives and driven by an overarching framework and mission supported by institutional management. The change is not merely within the curriculum but also goes beyond the curriculum, intending to create a learning ecosystem where engineering students might thrive.

At TU Delft, the term "learning ecologies" or "learning ecosystems" describes ecological elements characterizing the educational ambitions: 1) the curriculum has a multi/interdisciplinary or transdisciplinary nature, involving multiple nonscientific and scientific stakeholders and perspectives. Critical criteria for interdisciplinary working are collaboration, reflection, an open mindset, integration of knowledge, and critical thinking [11]. 2) Ideally, the stakeholders become co-creators of knowledge, 3) in authentic and real-life and open learning environments, 4) which engender performance modeling in addition to classic assessment, and 5) involve continuous reflection on task, process, and personal growth [12], [13], [14], [15]. Where possible, these include high-level technological innovations using the latest digitized tools.

The learning elements in the learning ecosystem foster a mediated configuration of formal and informal learning formats, that solve or embed a challenge for meaningful and responsible change (free definition adapted from [16]).

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This work involved human subjects or animals in its research. Approval of all ethical and experimental procedures and protocols was granted by the Human Research Ethics Committee (HREC) of TU Delft.

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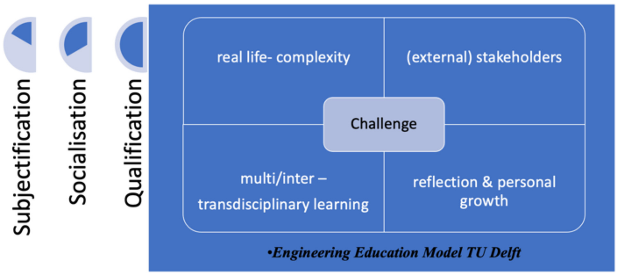

Fig. 1. Engineering education model TU delft.

In Delft, a choice is made to complement the learning ecologies paradigm with society's responsibility toward the learner (Fig. 1). According to Biesta [17], this responsibility implies a pedagogy that allows engineers to become complete/whole human beings and citizens. This pedagogy should involve the tripartite development of qualification, socialization, and subjectification. Qualification is what universities have always been doing, training Engineers to become qualified in theory, knowledge, and application. Today, however, in the face of world-changing events, higher education institutions should also address socialization and subjectification. Socialization in the discipline is important, but more is needed; it should be socialization in relation to the world. Subjectification is knowing who one is as a person and how this knowledge relates to the surroundings to grow as a person. Therefore, engineering education should not only address qualification but a qualification in a context offering the opportunity to practice with the two other elements, socialization and subjectification.

The learning ecosystem is defined as a mediated configuration of formal and informal learning that allows engineering students to define and solve (societally embedded) challenges while building their profile as whole new engineers who have undergone the process of Subjectification, Socialization and Qualification.

With these learning ecosystem elements, identity building can occur, interdisciplinary teamwork is fostered, and intense interaction with the professional world and government is necessary to finish any engineering challenge. While shaping the learning environment, curriculum designers, and educators hold the key to student "Agency." Agency is the capacity to make conscious and reasoned choices about engineering and personal life objectives. This philosophy shapes the guiding principles, shaping the learning eco-system elements.

Guiding Principles: These guiding principles have been listed below:

1) They (students) are responsible for their learning (trajectories): they know why they came to the university and agree on what they must learn *(Subjectification—responsibility for their learning).*
2) They learn how to design their engineering profile and life: they have a long-term plan for what they want to be and what they want to become *(Life-long learning subjectification).*
3) They can apply their knowledge in a changing field: in ten years, the world will be different, and in 20 years, it will be changed; students should be able to add value also at that time *(Life-long learning/subjectification).*
4) They show genuine respect for other disciplines: they understand the value of social sciences, management systems, and design *(Socialization).*
5) They can reflect on themselves and their colleagues: they know their team role(s) and weaknesses and are willing to work on them *(Socialization).*
6) They master transferable skills: teamwork, decision making, communication, planning, and prioritization (*Socialization, subjectification, qualification).*
7) They know AI, digital skills, climate, open data, and entrepreneurship, high on the Dutch Higher Education Science Agenda, and embrace the Unesco Sustainable Development Goals *(Qualification, subjectification, socialization).*
8) They learn how to become ethical and responsible engineers (*Subjectification, socialization, qualification*).

In this article, three courses in the curriculum will be shared, including these learning ecosystem elements in different configurations.

The main question is, "What is the contribution of these learning ecosystem elements toward professional behavior defined in this vision?"

This article will share the results of surveys among students in three differently designed and recently developed courses. A five EC Fundamentals course was developed in an existing program a year ago. The 60 EC first year of a master's program was developed three years ago, and a 15EC joint interdisciplinary project (JIP) (1EC = 28 h) was developed five years ago. The course set-up will be described according to these learning ecosystem elements. Successively the student survey methodology, results, and evaluative group interviews will be described.

A. Learning Ecosystem Elements Embedded in Course Design

In general, Delft transforms the education system toward incorporating the learning ecosystem elements. Education is designed around societal challenges, and the three pillars of qualification, socialization, and subjectification are taught in conjunction. This transformation happens through the introduction of:

1) new courses and projects in existing B.Sc. and M.Sc. programs for multi/inter/transdisciplinary and reflective learning;
2) new M.Sc. programs with a focus on multi/inter and transdisciplinary, personal development, and professional skills;
3) and, multiple central interfaculty Interdisciplinary Projects for students from different M.Sc. programs in the elective space of the master's programs.

With these newly developed courses, the university offers students a learning *ecosystem* described above in which identity building can take place, interdisciplinary teamwork is fostered, and intense interaction with the changing society and professional world (like companies, government, and hospitals) necessary to finish projects is stimulated.

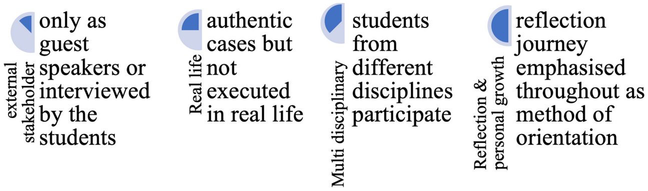

Fig. 2. Dashboard BME course.

One of each of the transformative courses is discussed here. It includes one 1st-year fundamental course in the master's program, one entire 1st-year master program in Robotics, and one 2nd-year Master (Joint) interdisciplinary project(s) (JIP) course. To clarify which elements are embedded in the learning ecosystems configuration, a dashboard is made for each, about the extent to which external stakeholders, real-life cases, multi, inter, transdisciplinary focus, and reflection are incorporated. The amplitude in the dashboard refers to within case distribution of the elements but does not reflect a comparison between the courses. It is equally important to note that the descriptions differ in detail and size, as the focus is on the interventions embedded. Furthermore, a whole 1st year M.Sc. program cannot be described.

The Challenge: In all three "course descriptions," challenges are embedded and are designed with the following ambitions in mind and according to this description: Challenges are (real world) opportunities for problem solving, creating knowledge for scientific discovery, and for SDG solutions in the area of, for example, Health care, Medicine, and Technology. These challenges will likely be performed in multi, inter, or transdisciplinary settings related to engineering.

The challenges are structured based on the principles of challenge-based learning [7].

1) A complex problem with multiple solution options.
2) Stimulating student Agency with autonomy and self-regulated learning elements.
3) Involve the application of different ethical, economic, political, technical, medical, etc.
4) It requires students to determine the problem definition, methods of approach, and stakeholder agreement (not necessarily external stakeholders) on proposed solutions.
5) It includes feedback and reflection and multiple formative/summative feedback moments.

II. Three Courses

A. Course Description—Biomechanical Engineering (5 EC)

In this course, the emphasis is on reflection and positioning oneself to learn to embark on the master's journey. Students from the M.Sc. Biomechanical Engineering start their programme with a fundamentals course, including the elements described in the dashboard of Fig. 2. The course consists of capstone lectures (qualification), a challenge worked on during the course in teams—supported by a debate session and a peer review on the content of the challenge (socialization) and a reflection journey (subjectification) in which students identify their future engineering roles and how they are going

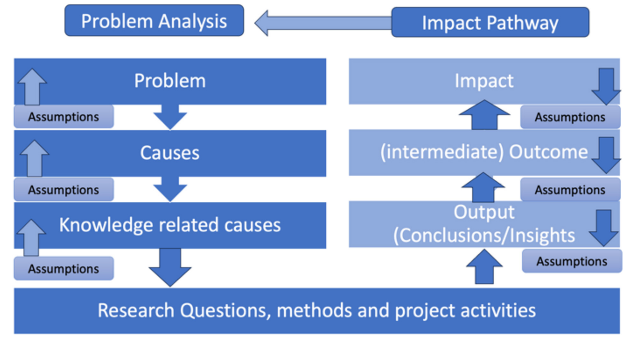

Fig. 3. Dutch science foundation (NWO)-impact model.

to learn from the challenge activity and identification of their future role as a person.

The capstone lectures represent an overview of the topics addressed in the master's program. It is used to level the knowledge of the students with different disciplinary backgrounds enrolled in the program. Students are assessed with a multiple-choice exam (50% of their grade). Mentors and e-portfolios support students.

Particularly in the BME course, the problems exploration is based on steps for "Framing" the problem: 1) historic development; 2) reframing the problem; 3) contextualising the problem; 4) investigation/exploring the problem; 5) using a new framework to come up with solutions; and 6) reflecting on the application and transforming into new knowledge structures.

Students write an individual essay on a thematic topic which calls for controversial opinions and reactions, such as personalized healthcare and the use of AI data to improve healthcare services or a ban on homoeopathy treatments. Students can choose from two different topics presented to them by the teachers. Students are assigned to teams based on their engineering role of choice (which is also related to their personal reflection journey). This team explores the best problem definition based on the impact pathway model Fig. 3 and presents it to the entire group. The teams define stakeholders and causes. Successively, they propose a solution to the problem according to engineering principles and the impact pathway, which is then subjected to a peer review and a debate. In the debate, students represent one stakeholder party and reflect from this stakeholder position on the impact of their solutions. Guest stakeholders are invited to present their stories to frame the challenges. The challenge report is graded 50%.

The structure of the activities to solve the challenge is based on the impact pathways model of the Dutch Committee for Science Education.

Reflection: The reflection Journey addresses the personal development of students and consists of three reflection assignments guided by an engineering role framework addressing the question Who am I/do I want to be in the future? And helps recognisee motivation, approaches, and ambitions toward the self, others, and the learning material. These include reflections on the challenges in relation to individual behavior and are graded with a pass/fail mark. Some examples of the reflection questions are listed in the following bullets.

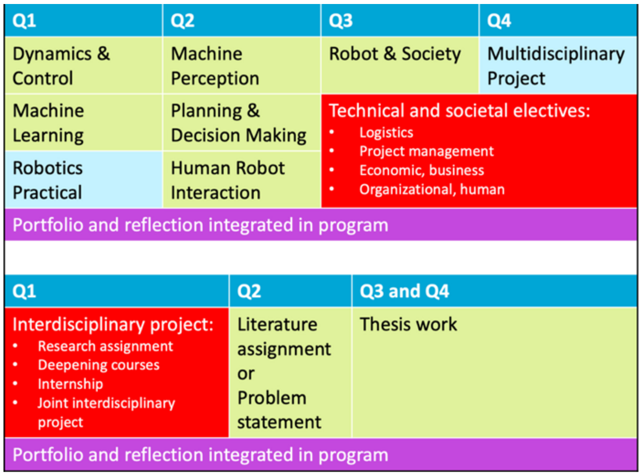

Fig. 4. Robotics curriculum.

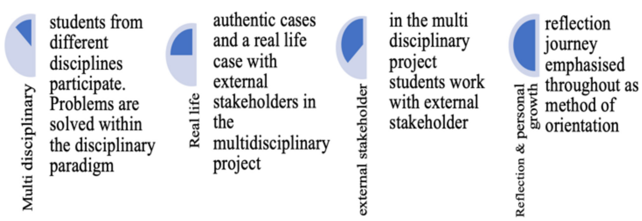

Fig. 5. Dashboard robotics program.

1) What role as an engineer do I want to play in society?
2) Who am I, and how can I shape who I want to become?

B. First-Year M.Sc. Robotics (RO, 60EC)

M.Sc. programs focused on multidisciplinarity, personal development, and professional skills have been developed: 1) Robotics and 2) Quantum Information Systems and Technology. The Robotics Programme depicted in Fig. 4 started in 2020. The program combines mechanical engineering and artificial intelligence; its goal is to respond to the rapidly changing society that changes people's lives, work, and economy. Students must be prepared for the increasing and changing demands of the new field. The "Holistic Engineer" is trusted to make essential decisions in solving complex problems and taking on nontechnological tasks of leadership. The robotics engineer understands industrial and logistics processes and can advise on the use of robots. Similarly, the Quantum engineer understands industrial and logistics processes and can advise on using quantum computing.

The robotics program is an entire year; and heavily emphasizes reflection, like the biomedical course. In terms of challenges, it includes a multidisciplinary project of 5 EC. In Fig. 5 the robotics dashboard is shown with the predominant elements.

Multidisciplinary Project (5EC) (Challenge) and Integrated Curriculum (Socialization and Quantification): The multidisciplinary project is an open project and not structured. In the multidisciplinary project, students specifically work with four Robot (driven) companies (Lely, Ahold Delhaize, Festo, and SamXL) on real-life cases to find a robot-integrated solution. Students have to apply for a case and write a motivation.

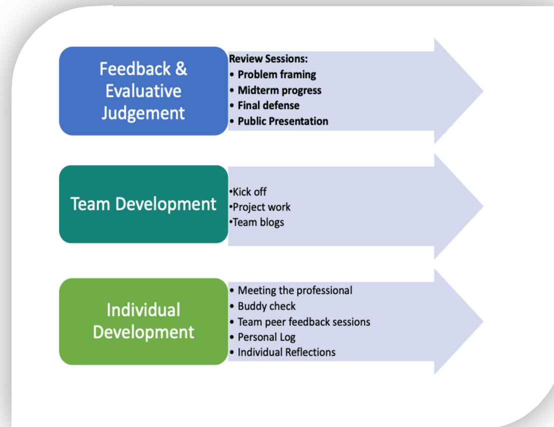

Fig. 6. Course design elements JIP.

Then they are added to a team, and they have to define the problem in teams of four and consider the company's expectations when generating ideas and creating solutions for the company. They have to convince the companies of their "best" solutions. Practically, each student team develops a complete integrated software package for a complex robot system, integrates the package on the robot and lets it function. Development and testing are realized in a simulated environment. Students successively implement the package in a real robot at the end of the course. All teams (within one year) will work with the same robot components, but each is assigned a different task. The robot components and application field may differ from year to year. Examples include agriculture robots, drones, and self-driving cars. The common denominator is that, in each case, the students have to integrate the following robot capabilities, which have been taught in previous courses.

1) Perception-Navigation and planning.
2) Motion control.
3) Human–robot interaction.

The course is obligatory and supported by individual development courses and assignments.

Reflection (Subjectification): Students partly determine their learning paths based on the formulation of learning goals at the beginning of the 1st year, and they have 20 EC electives to choose from to specialize in a chosen direction. At the beginning of the first year, in the introduction week, the students describe their goals and ambitions, interests and networks, and design a picture of their future role as a robotics engineer, including the required competencies. Students work on individual portfolios throughout the program to reflect on their acquired skills and ambitions. In the portfolio, they describe how they develop their personal goals in the courses and projects. Peer group reflections, which give input to the portfolio, occur in the courses and the Multidisciplinary Project. In the second year, students finish their portfolios before they are allowed to start with their thesis work.

Fig. 6, the M.Sc. Robotics curriculum, the top line is a mentor-driven activity, in the 2nd year student-driven.

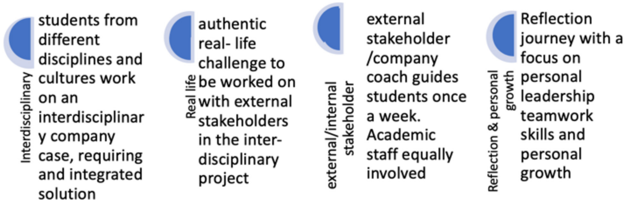

Fig. 7. Dashboard JIP.

C. Joint Interdisciplinary Project

The last course discussed in the learning ecosystem is the JIP. The 2nd year master course is offered yearly in Q1 to 200+ students. In the JIP project, four or five students from different M.Sc. programs and with different gender and cultural backgrounds collaborate in a 10-week full-time engineering or design project.

Challenge: The students address real-life problems companies need help to solve. Companies should expect that an interdisciplinary team of young scientists can provide a novel solution approach. A company representative is available one or two days a week for the student team, and regular or frequent company visits are part of the project. All the elements (Fig. 7 dashboard JIP) of the learning ecosystem are embedded in the course configuration.

The TU Delft provides academic support, but student teams must search for the right experts for their projects. The TU and the involved companies organize project management, business development, teamwork, and other courses to arm the students for the intensive project. This part of the project is mainly about qualifications. Students' capacity to use their disciplinary knowledge for complex problem solving is tested to the max and reflected in a report, often with prototype/concept and other types of deliverables, in which the integration of knowledge becomes visible in the activities and deliverables for the students (Fig. 6).

Socialization: Interdisciplinary teamwork and intense interaction with the professional world are at the heart of the project and give rise to new and out-of-the-box solutions. The students spent much time working in the team and meeting with people who provided input to socialize in interfaculty engineering and the professional domain of interest, such as energy, smart industry, or other societal challenges. Teams keep up a blog/vlog during the process to share with all the stakeholders and get feedback from other teams. TAs monitor these to help guide the students.

Subjectification: For personal growth, there is a series of reflections and 360° feedback from team members to grow one's skills over time. Teams do regularly provide each other feedback on personal growth goals.

TABLE I
CONSTRUCTS USED TO MEASURE PROFESSIONAL CAPABILITIES

Part I – Personal Development (Trede, 2019/2022)	
Vision: Subjectification point 1/2	
Self	Discovering who I am
Emotional Reflexivity	Dealing with emotions
Resilience	Bouncing back from setbacks
Part II Agency	
Subjectification, Socialisation (and qualification) point 3 in the vision	
Evaluating Information	Judgement against professional quality criteria/standards, also known as evaluative judgement. Davies & Stevens (2019)
Critical Stance	Critical thinking and taking a position concerning professional topics. Davies & Stevens (2019)
Part III Collaboration	
Socialisation point 4/5 and 6 in the vision	
Communication	Being able to collaborate with peers within the community (team/group work) (Picard et al., year)
Interprofessional Competence	Being able to communicate across domains/professional boundaries. (Picard et al., 2021)
Part IV Contextual insight	
Socialisation and Qualification point 6 and 7 in the vision	
Informed Vision	Being aware of the wider developments and one's (organizational) roles therein. (Trede (2019/2022))
Ethical Sensitivity	Ethical behaviour in complex and sensitive situations. (Picard et al., 2021)

III. SURVEY STUDY AND GROUP INTERVIEW

A. Methods

A questionnaire is created with validated questions and 5-point Likert scale answering categories to determine what the students are learning from these courses concerning professional competencies. A construct description of the questionnaire is provided in Table I. An extensive description of how this questionnaire was constructed can be found in the Sefi 2022 paper [18]. Here, the same data and additional data from a second round of data collection this academic year are used. Across both data moments, ethical clearance has been obtained from the Human Research Ethics Committee (HREC) of TU Delft.

The questionnaire mainly focuses on subjectification and socialization (lifelong skills) as, following the vision set out, qualification is well covered in all these courses and in general at TU Delft.

Cronbach's alpha of the first round of data collection is included in the 3rd column, and the second-round data is in the last column of Table II. In the first study, Cronbach's alpha is slightly lower on Communication and Informed Vision. The second study is slightly lower and insufficient on Self and Communication. As the aggregated alpha is still above 0.70 on the Parts I–IV levels, it is decided to still report on the subconstruct level.

Response rates were in total BME $N = 28$ out of 100 is 28%, Robotics $N = 47 + 32 = 79$ out of 230 is 34%, and JIP $N = 54 + 57 = 111$ out of 350 is 31% across two measure moments for Robotics and JIP and one measure moment of BME. Furthermore, these amount to similar response rates across the two data collection rounds. New data are included in this article. The data in the subgroups needed to be more extensive for major comparative statistical procedures and still

TABLE II
CRONBACHS' ALPHA CONSTRUCTS

	Items Version1	Cronbach's alpha	Items version 2	Cronbach's alpha
Part I – Personal Development		**.90**		**.88**
Self	N = 4	.75	N = 4	.69
Emotional Reflexivity	N = 6	.79	N = 6	.76
Resilience	N = 8	.79	N = 7	.77
Part II Agency		.85		**.81**
Evaluating Information	N = 5	.78	N = 5	.71
Critical Stance	N = 4	.77	N = 4	.72
Part III Collaboration		.86		**.79**
Communication	N = 5	.69	N = 5	.62
Interprofessional Competence	N = 5	.81	N = 5	.73
Part IV Contextual insight		**.80**		**.73**
Informed Vision	N = 7	.67	N = 7	.68
Ethical Sensitivity	N = 4	.83	N = 3	.77

are too small for the BME course. Therefore, reporting will be on each group's aggregate averages of a construct (continuous variable). The ideal sample size with a 0.95 confidence interval would be 177. The current sample size is $N = 218$, meaning the results can be reported at a 0.95 confidence interval. However, note that in the first round, $N = 126$, which meant the data from the first round were at an 85% confidence level, taking an error margin of around 5% into account while at the same time not discarding relevant findings [23].

B. Data Analysis

In this analysis, three groups are compared, of which two have had two measure moments. The measure moments will be reported separately. Constructs have been aggregated for a continuous variable. Almost all the assumptions for a One-way ANOVA are met, with no outliers and normal distribution (Shapiro Wilks), apart from Levine's test of homogeneity of variance. The Welch–Anova test is used to correct for differences in homogeneity and a post-hoc Games–Howell test for group differences. Significant differences have been found between all the groups and each construct at $p < 0.001$. The results section; reports significance levels between groups and measure moment on subconstructs.

IV. RESULTS

In the results section, each Parts I to IV, as listed in Table I, of the professional development survey with respect to each response group BME, Robotics 1 and 2 and JIPs 1 and 2 are presented.

A. Part I—Subjectification: Goal—Purpose—Designing Your Life

The three constructions, *Self, Emotional Reflexivity, and Resilience*, mainly focus on whether students can set goals,

TABLE III
SIGNIFICANCE OF PERSONAL DEVELOPMENT/SUBJECTIFICATION

	Jip 1	Robotics 1	BME	Robotics 2	JIP2
Self					
BME	.001	.001	-	.006	.001
Emotional Reflexivity					
BME	.001	.015	-	.039	.001
Robotics 1	.001	-	.015	-	-
Robotics 2	.010		.039		
Resilience					
BME	.001	.007		-	.005
Robotics 1			.007		
Robotics 2	.062				

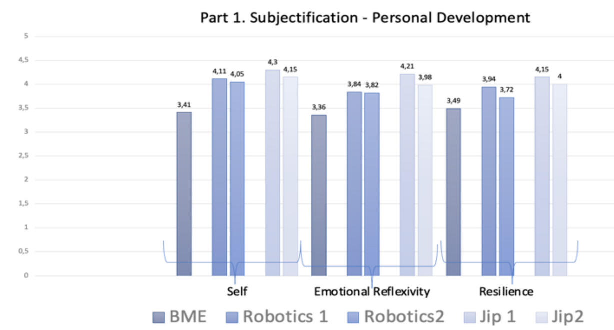

Fig. 8. Aggregated means Part I.

handle their life, and bounce back from adversity; hopefully, they will be able to address the following two "guiding principles" introduced at the beginning of this article.

1) They are responsible for their learning (trajectories): they know why they came to the university and agree on what they must learn. *(Subjectification—responsibility for their learning)*
2) They learn how to design their engineering profile and life: they have a long-term plan for what they want to be and what they want to become. *(Life-long learning-subjectification)*

In Table III, significant differences are reported in a matrix format. Groups compare from the Left Column and top Row across the three constructs Self, Emotional Reflexivity, and Resilience.

Despite the slight differences in average means (Fig. 8), the JIP and BME groups have significant differences for each subconstruct: Self, Emotional Reflexivity, and Resilience smaller than < 0.001 for the first and second measurement moment of JIP (Table III). The Robotics 1/2 and BME also differ significantly, $p = 0.001$ and $p = 0.006$, respectively. They are showing the apparent discrepancy between 1st-year master students just starting with reflection and second-year master students being more mature and being confronted with reflection. The JIP and Robotics groups on the subconstruct *Self* do not significantly differ in the first or the second moment of measurement.

On the subconstruct *Emotional Reflexivity (Table III)*, there was a significant difference between JIP 1 and BME ($p = 0.001$), Robotics 1 ($p = 0.001$), and Robotics 2 (0.010). However, this significance has disappeared in the JIP 2 measure moment. Despite higher mean averages (Fig. 8), the finding is also cohort dependent. Furthermore, on the subconstruct Emotional Reflexivity, for the Robotics/BME group, it was found that Robotics 1 scored significant ($p = 0.015$) and Robotics 2 scored significant ($p = 0.039$).

On the subconstruct *Resilience (Table III)*, Significant differences were found between JIP2 and BME (0.005), Robotics 1 and BME (0.007). There was no significant difference between Robotics2 and BME. An almost significant difference was found between JIP 1 and Robotics 2. $p = 0.062$. For JIP 2, there was no significant difference between JIP 1, Robotics 1, or Robotics 2.

Personal Development: The Mean average distances between JIP 1, JIP2, and BME in Fig. 8 are noteworthy differences, suggesting more impact of the ecosystem elements and more maturity of students. The average means (Fig. 8) Robotics 1, 2, and JIP 1/2 are more similar than the averages between Robotics 1, 2, and BME, suggesting again maturation and more substantial challenges play a role.

The estimated medium effect sizes eta squared are Self 0.30, Emotional Reflexivity 0.30, and Resilience 0.21 for JIP 1 compared to BME. Eta squared being lowered to Self 0.22, Emotional Reflexivity 0.19, and Resilience.12 for JIP 2 and BME. The numbers show a large effect size as they are almost all higher than 0.14, meaning a more significant proportion of the variance can be attributed to personal development than expected based on the variance standards. Therefore, Self, Emotional Reflexivity, and Resilience are considered vital to knowing who one is. At the course level, some elements still need to be strengthened. The BME course still needs to strengthen the reflection and the creation of more challenging opportunities, whereas the Robotics program and JIP courses already have well-embedded elements. The trends in these graphs show that personal reflection is growing with practice and maturation. Students are investing in a reflection cycle that is relevant and paying off.

B. Part II: Agency—Subjectification/Socialization and Lifelong Learning Skills

The second aspect of subjectification and socialization is Agency, where one can take a critical stance and evaluate information against professional standards and make an informed decision based on those skills. It is a primary lifelong learning skill expressed in the visionary-guiding principle 3.

Vision Ambition:

3) They can apply their knowledge in a changing field: in ten years, the world will be different, and in 20 years, it will be changed; students should be able to add value also at that time *(life-long learning/subjectification).*

In Table IV, significant differences are found in Evaluating Information between Jip 1 on the one hand and BME $p = 0.006$, Robotics 1 $p < 0.001$, Robotics 2 and JIP 2 $p = 0.008$ on the other hand. All the other groups do not have significant between-group differences. Suggesting the JIP1 group might have been exceptional.

The construct Critical Thinking skills are shown in Table IV; again, significant differences between JIP 1, and BME $p = 0.001$, Robotics 1 $p = 0.001$, and JIP 2 $p = 0.011$ are found. All the other between-group scores are nonsignificant.

TABLE IV
SIGNIFICANCE PART II AGENCY—SUBJECTIFICATION/SOCIALIZATION

	JIP 1	Robotics 1	BME	Robotics 2	Jip 2
Evaluating Information					
BME	.006				
Robotics 1	.001				
Robotics 2	.008				
JIP2	.008				
Critical Thinking					
BME	.001	-	-	.090	
Robotics 1	.001	-	-	-	-
Jip 2	.011				

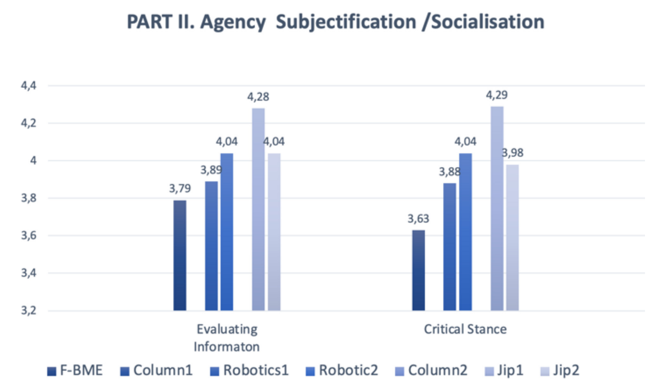

Fig. 9. Aggregate averages for agency; evaluating information and critical thinking.

Effect sizes being large again for Evaluating Information eta squared is 0.21, and for Critical Thinking, the eta squared is 0.20. for the first measure moments of Jip1/BME/Robotics1. Moreover, the effect size is moderate, 0.12 on Evaluating Information and 0.14 on Critical Thinking on the second measure moment for robotics and Jip2. This finding suggests the JIP 1 cohort took maximum advantage of the educational situation regarding socializing. Indeed, the weekly meetings being the only meeting moments and socializing moments in covid times allowed for maximum guidance and interaction.

Agency: When all the curricular elements are added to the mix, a potential for better results in Evaluating Information against professional standards and critical thinking training is present. In Fig. 9, the aggregate averages are higher for JIP1 and Robotics2/Jip2. Even though Robotics 1 is higher than BME, the significant gap with JIP 1 remained in the first measure moment. However, note that Robotics 2 is moving and on par with JIP 2. This development may suggest that the impact of the learning-ecosystem elements becomes comparable in each situation and beneficial after more exposure to the learning ecosystem elements.

C. Part III: Socialization

The two constructions Communication, and Interprofessional Competence, mainly focus on whether students can communicate and collaborate in multi or interdisciplinary teams and with external and internal academic

TABLE V
SIGNIFICANCE PART III
COLLABORATION—SOCIALIZATION/QUALIFICATION

	JIP 1	Robotics 1	BME	Robotics 2	JIP 2
Communication					
BME	.001				.058
Robotics 1	.049				
Robotics 2	.027				
Interprofessional Competence					
BME	.002	-	-	-	.075
Robotics 1	.003	-	-	-	-
Robotics 2	.002				

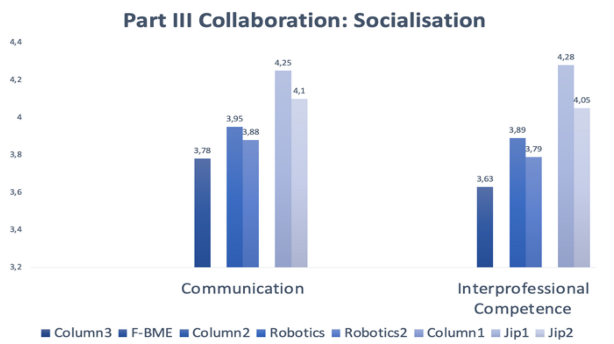

Fig. 10. Aggregated means of collaboration: communication and interprofessional competence.

TABLE VI
SIGNIFICANCE PART IV CONTEXTUAL
INSIGHT—SOCIALIZATION/QUALIFICATION

	JIP 1	Robotics 1	BME	Robotics 2	JIP 2
Informed Vision					
BME	.001				.061
Robotics 1	.002				
Robotics 2	.005				
Ethical Sensitivity					
BME	.003	-	-	-	.-
Robotics 1	.007	-	-	-	-
Robotics 2	.001				
JIP 2	.013				

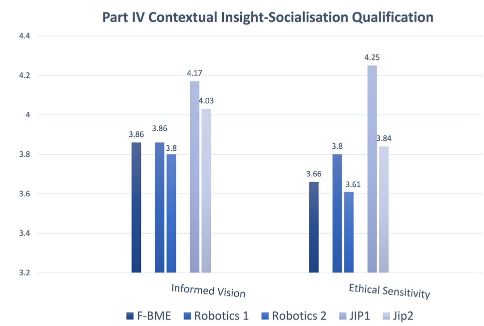

Fig. 11. Aggregate mean average contextual insight: informed vision and ethical sensitivity.

stakeholders. These are embedded in the three visionary guiding principles 4–6.

4) They show genuine respect for other disciplines: they understand the value of social sciences, management systems, and design (socialization).
5) They can reflect on themselves and their colleagues: they know their team roles and weaknesses and are willing to work on them (socialization).
6) They master transferable skills: teamwork, decision making, communication, planning, and prioritization (socialization – subjectification, qualification).

Socialization deals with becoming aware of whom you are within one's discipline and in relation to the interactions conducted with the outside world, including peers, professionals, and academics. Here, the effect of the different courses on the aspects of collaboration and socialization is surveyed; captured in the construct Communication and Interprofessional Competence.

In Table V, the significant difference in the construct Communication between Jip 1 and BME ($p = 0.001$), Robotics 1 ($p = 0.049$), and Robotics 2 ($p = 0.027$) are reported. Almost significant differences are found in Communication for BME and JIP2 ($p = 0.058$) and Interprofessional Competence ($p = 0.075$). No significant differences between Robotics 1 and 2 on the one hand and JIP 2 on the other hand on these constructs, despite higher mean averages (Fig. 10).

With moderate 0.12 eta squared and large 0.17 eta squared, effect sizes for Communication and Interprofessional Competence in the first measure moment, are reasonable. The second measure moment they have decreased to Communication 0.09 (small) and 0.13 (moderate) for Interprofessional Competence. When introducing challenges, reflection, and working with external stakeholders, Interprofessional Competence becomes moderately important for the socialization of the students.

Collaboration: Furthermore, the more curricular elements (such as a real-life case, external stakeholders, and multi, inter, or transdisciplinary ways of working (including reflection)), the better socialization competencies are acquired. This professional skill is particularly shown for teamworking and interacting with external stakeholders for the challenge or project and reflection at the first measurement moment.

D. Socialization and Qualification; Contextual Insight

The fourth aspect of socialization and qualification is contextual insight. Contextual Insight consists of having an Informed Vision of the (inter)disciplinary context and Ethical Sensitivity. These skills allow for contextualization and determining one's role(s), while flexibly adapting these roles based on individual values, responsible behavior, and moral judgment relevant to the investigated SDGs. This contextualization is expressed in the vision-guiding principles 7 and 8.

7) They learn how to become ethical and responsible engineers (*Socialization–Qualification*).
8) They know and apply AI, digital skills, climate, open data, and entrepreneurship; (awareness/knowledge of societal challenge themes relevant to solve the sustainable development goals *(Socialization–Qualification)*.

In Table VI, the subconstruct Informed Vision showed significant differences for JIP1 on the one hand and BME ($p = <0.001$)/Robotics 1 ($p= 0.002$)/Robotics 2 (0.005) on the other hand. JIP 2 almost significantly differs from BME ($p = 0.061$). Ethical Sensitivity gives a significant difference on Jip 1 on the one hand and BME (p=0.003)/Robotics 1 ($p = 0.007$)/Robotics 2 (p=0.001), JIP 2 ($p = 0.013$) on the other. Effect sizes are large at 0.17 on Informed Vision and moderate at 0.12 for Ethical Sensitivity at the first measurement, becoming small, 0.11 on Informed Vision, and 0.10 on Ethical Sensitivity in the second round.

According to the aggregated averages (Fig. 11), Informed Vision is the differentiating factor in creating contextual insight. Context awareness and socialization occur more profoundly when students are confronted with external stakeholders and real-life cases. The relatively strong score on informed vision suggests that only when companies are involved do students get the opportunity to get a broader vision of their field.

E. Evaluative Interview Results

Evaluative group meetings were held with students and Mentors of BME and Robotics. In total, nine students/mentors from BME participated in these meetings, and 2 of the Robotics and JIP students left testimonials.

A journey map with touchpoints on engineering roles, guidance, the course structure, reflection, and challenges has been used to discuss the likes and dislikes of the learning ecosystem. Some of the students' quotes on each element of Subjectification, Socialization, and Qualification are included. One of the questions asked from the student related to the journey map touchpoints is: "What they acquired in terms of professional skills during the BME and Robotics program?"

Subjectification:

BME-Students: "It is a good course to help the students understand their role as engineers and direct them to future choices."

"Looking back, I can say that it was good to think about my role in society and I have learned a lot from the self-reflection assignments."

BME-Mentors: "Thought of role, they were never confronted with before, which may help them for the future."

"I liked that the course forced participants to think of engineering in a social context. It is an area often overlooked, or secondary to professional development, but ultimately it holds great importance and is key to the success of the individual."

Robotics-Students: "Providing feedback and taking feedback in a constructive and valuable way."

"The portfolio was hard to set up in the beginning but helped me in my personal development, and I think it was very good to have, by design, spread out over the 1.5 years."

JIP—Students: "One of the leadership skills that I could gain during JIP was relationship-building among the team members. In my point of view, the team members must have an effective and respectful relationship with each other, specifically when they are from various cultural back-grounds. Regarding the core values which I endorse, I think that we must try to prioritize the team's final goals over our personal benefit while working on such interdisciplinary group projects."

Socialization—Lifelong Learning:

BME-Students: "Some workshops, e.g., on the debate, were really appreciated."

Robotics Students: "Communicating with many different backgrounds and being open-minded."

"I like the variety of the assignments and the connection to developments in the outside world; it always felt like we were working on contemporary topics."

JIP Students: "The course assisted me with being more familiar with the professional environment, such as what are the rules and regulations in these companies, and how do the financial and legal procedures work, etc. This was a great opportunity for me to be able to work at the company office and experience the working atmosphere at that type of company and observe whether this suits my personal expectations for my future possible working area."

Qualification-Engineering Knowledge:

Robotics Students: "It is always important to go back to the general question and not to get lost in details."

"Breaking down the problem helps with developing a solution."

JIP Students: "Together with my other colleague (from the same studies), we wrote the institutional analysis chapter of the report which further helped with the evolution of the methodology and the generation of alternative solutions. I can thoroughly state that I could play a significant role in the whole methodology section of our project."

The BME students were well aware of the relevance of interaction with external stakeholders and real-life challenges. They were eager to engage and develop a stronger focus on personal development. The Robotics students pointed out that mentor guidance and continuous reflection helped them to become more autonomous learners. In JIP, more transformative learning experiences are seen in which students quickly need to become interdependent and autonomous learners. Pushed out of their comfort zone, they need to recognisee that many assumptions concerning subjectification/socialization behavior no longer hold. They must adapt to the challenges they meet in the course. This adaptation only sometimes yields the same beneficial results. As is shown in the 2nd JIP course, it can be overwhelming for students having to develop all three aspects of subjectification, socialization, and qualification at once. Available staffing and support are essential in making this work.

V. Conclusion

Based on the survey results and feedback, the following assumptions are made.

1) If the instructional design caters equally for all the elements embedded in the learning ecosystem, students' perceived subjectification/socialization capacities increase over time.
2) Reflection and confrontation with the self, in particular, contribute to subjectification, creating a foundation to

TABLE VII
PROPOSED LEARNING OBJECTIVES

LO 1. The ability to integrate (scientific and practical technological) knowledge from different disciplines to solve complex problems.
LO 2. The capacity to evaluate the ethical, scientific, and societal consequences of the proposed innovation.
LO 3. The ability to create reasonable and relevant research or design according to the academic and technological standards of the involved disciplines.
LO 4. Demonstrate behavioural competencies and skills relevant to teamwork and effective communication with different stakeholders.
LO 5. To carry out regular reflections on professional and personal development and be able to improve upon those reflections.
LO 6. Understand contemporary and societal issues in their work.

question both self and others. Agency helps students take responsibility for their actions in relation to others.

3) Peer-review activities and benchmarking with team members and the professional field support the socialization process, developing interprofessional competence and informed vision.

The essence is that students are developed in the three pedagogical components of Biesta's model of subjectification, socialization, and qualification within the educational space created in these courses. However, confronting students with real-life cases, external stakeholders, complex challenges, and a diverse student population only works if sufficient guidance is offered.

The different courses/programs showed the expected growth aimed for in the first measure moment. In the second measure moment, the robotics program, which has further improved upon its program, scored much higher. The JIP 2 has shown a decline as student numbers grew, staffing remained the same, and coaching moments were fewer for students; this may have influenced student perceptions. However, with all the scores being reasonably high on the 5-point Likert scale, it is assumed this is the right direction for the university's education.

Therefore, Delft recommends focusing on six learning objectives (Table VII) in support of this type of overall learning ecosystem, providing a basis for relevant future engineering profiles which meet the pedagogical goals of Biesta (2017). Becoming a responsible engineer should be a constant dialogue with the world's stakeholders, society, and its technological artefacts, to help acquire these objectives.

Interdisciplinary/Transdisciplinary Learning: Academic teaching has a vital socialization component. As Biesta [17] describes it, the university acquaints students with professional traditions (e.g., of Aerospace Engineering or Industrial Design) and lets them reflect on the meaning, norms, and values of engineering. In the B.Sc. program, staff has guided students on a path with a particular way of thinking and approaching problems fitting to their discipline. However, the first learning goal of the courses and program in a learning ecosystem should be collaborating, valuing, and appreciating other disciplines, particularly beyond the engineering domain. Ideally, under the guidance of facilitators, this will lead to integrating knowledge and creating new innovative knowledge.

Scientific and Intellectual Development—Embedded in Challenges: Engineering students are, in general, bad at engaging. Their program usually consists of common problems they must solve [24]. There is some freedom in approaches and solutions that reveals the capabilities of individual students or student teams, but there is no ownership of the problem. Usually, it is optional to be engaged in the problem in these courses and programs. In the Learning Ecosystem, students are asked to reflect on how the world becomes a better place when they solve their problems. Furthermore, students have to write an ethical essay about their program or solution, where they are encouraged to identify possible problems that may occur when their solutions are implemented on a larger scale.

Research and Design Capabilities—Embedded in Real-Life Challenges: Many engineers need to become acquainted with a rigid design methodology comprising a problem statement, research question, stakeholder analysis, value proposition, and analysis of the scope and limitations. Currently, engineering students, who are solution-focused, jump too quickly to the first available solution without critically questioning their assumptions and exploration of different "solution" routes. Therefore, lectures should provide a rigorous design process and business value proposition methodology in these learning ecosystems courses and programs. Colloquia should then be dedicated to overarching themes such that solutions are also related to the problems humanity needs to solve.

Communication and Collaboration in Teamwork—Socialization: Most engineering programs in the university do not require interviews with experts or customer surveys. Engineering students tend to be hesitant to approach experts from companies or academia, sometimes have yet to learn to give proper feedback to team members and are too focused on details in their communication. In the courses and programs from the Learning Ecosystems, students have to call or visit experts, define their team role, and present at a higher level of authority and expertise. Therewith, students are challenged on how they relate to the world and their professional environment.

Reflections on Personal Development and Adjustment (Resilience)—Portfolio (Peer) Reflections: Students follow the curriculum and fulfil the requirements of the program. Traditionally, there is little room for reflection on why the curriculum is shaped as it is. In evaluations after courses, students can express their criticism or praise about courses. In the courses and programs from the Learning-Ecosystem, students have to write a motivation letter to participate, make a plan with their team before starting the work, and write a blog about their experiences and possible frustrations. They must reflect on whom they want to become in the long term. This reflection process makes them aware of what they are doing in education and why they are doing it in interaction with the world around them. It improves the learning curve as students become more focused learners.

Reflection and Contextual Awareness—Confrontation With Professional Life: Sustainable development goals (SDGs) are useful to let students think about the greater goal of their project and take a more global and responsible perspective. Students study the 17 goals and discuss which fit their projects. It is motivating for them to see, sometimes for the first time, that engineering can serve a greater good. Also, in the ethics essay, they evaluate possible threats to society that may accompany their proposed solutions locally and at an ecological level.

VI. Limitations of This Study

It should be noted that the issue of learning ecosystems requires additional study. A more detailed overview of the learning ecosystem elements composing a constellation in which the pedagogical component of Biesta gets a place, and the effect of those elements on the professional capabilities is a complexity level which cannot be studied in one go. As embedding these professional capabilities elements becomes more necessary today in higher engineering education, this seems an essential task.

Whether a survey questionnaire on perceptions with a limited response rate and evaluative group interviews is enough to talk of evidence-informed curriculum construction is questionable. This study made us aware of the difficulties involved in the many variables affecting the perceptions in an already dynamic and complex system. It certainly, makes for a problem space [25] that is a moving target. Dynamic system approaches in longitudinal data collection may offer a more robust way of going about this task [26]. However, the study gave droplets of insights that support assumptions made toward a more robust model building of the learning ecosystem, which benefits all engineering students.

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