A Collaborative Robot in the Classroom: Designing 21st Century Engineering Education Together

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*New and interactive robot arms have found their way to the factory floor: the collaborative robots (cobots). Cobots execute simple and routine tasks with the accuracy and precision of tradional industrial robotics. Although cobots often operate highly autonomous, they require human interferance to function. Both production workers and engineers play an essential role in the creation and maintenance of these 'human-cobot collaborations'. The rising number of cobots in industry increasingly calls for current and future generations of production workers and engineers who are capable of fulfilling their role in human-cobot collaboration. From a development point-of-view, engineering education is a powerful vehicle to prepare production workers and engineers for human-cobot collaboration. However, it is unclear what knowledge, skills, abilities, and other requirements (KSAOs) production workers and engineers need to create and maintain human-cobot collaboration and what engineering education allows the development of these KSAOs. Therefore, our goal was to investigate how engineering education could prepare future production workers and engineers for human-cobot collaboration. We used the O*NET Content Model to deductively analyse 60 interviews about human-cobot collaboration in Dutch industry. Results illustrate how 31 KSAOs were found relevant for the design, programming, operation, and repair of human-cobot collaboration and how these KSAOs were distributed amongst production workers and engineers. Together with a community of practice, we used these insights to design a 240-hour vocational education course on human-cobot collaboration. Key decisions, course content, learning dimensions, and examination compentents are elaborated upon.*

Keywords: collaborative robots, engineering education, course design, KSAOs

INTRODUCTION

European manufacturers are experimenting with a new type of industrial robot: the collaborative robot arm (Broum & Šimon, 2019; El Makrini et al., 2018; Kadir, Borberg & Souza da Conceição, 2018). The collaborative robot arm (cobot) is smaller, weaker, and shorter but also more accurate and easier to program compared to other industrial robots (Gualtieri, Palomba, Wehrle & Vidoni, 2020). Manufacturers use cobots to load and unload machines, pack boxes, glue and weld objects, and assemble products (Bauer et al., 2016; Levratti et al., 2019; Palomba et al., 2021). Although cobots are currently used as (semi) autonomous robots, production workers and engineers will still play a pivotal role in the production system. In these so-called human-cobot collaborations, production workers are increasingly responsible for maintaining the cobot (Wolffgramm, Corporaal & Van Riemsdijk, 2020). They activate the cobot, provide it with products, and process the products handled by the cobot. Furthermore, production workers often solve minor cobot errors. Engineers are responsible for designing the human-cobot collaboration by installing the cobot, integrating it into the production system, and solving errors that could not be solved by the production workers. In addition to its impact on industrial production and engineering, the rise of the cobot also has consequences for engineering education.

Until recently, cobots were not present in engineering education in our local community colleges and university of applied sciences. However, as the number of cobots used in industry rises (Borgue, 2016; International Federation of Robotics, 2020), these local engineering educators want to include cobot education in their programs to prepare their students – the next generation of production workers and engineers – for human-cobot collaboration. They, however, have trouble finding relevant content, since they are unfamiliar with cobot technology and lack clear best practices from industry. Despite the large number of research endeavors being devoted to uncovering relevant capacities for jobs in today’s and tomorrow’s industry, such as 21st century skills (Chu et al., 2021) and futureproof engineering education (Sakhapov & Absalyamova, 2018), these have not yet been specified for human-cobot collaboration (Libert, Mosconi & Cadieux, 2020). As a result, the local engineering educators’ need for engineering education that prepares future production workers and engineers for human-cobot collaboration remains unfulfilled.

Hence, the goal of this paper is to provide input for engineering education by allocating and defining the collection of knowledge, skills, abilities, and other characteristics (KSAOs) production workers and engineers need to create and maintain human-cobot collaboration (Johnson, 2013; Vitalari, 1985). Knowledge refers to all procedural and declarative facts and information that can be memorized (Schou et al., 2018). Skills reflect all work-related and general behaviors that can be enacted (Fleishman & Reilly, 1992). Abilities are the physical, mental and perceptual capacities to enact and sustain a particular skill (Cheney, Hale & Kasper, 1990). Other characteristics refer to actor-related traits, such as personality and interests (Damos, Schwartz & Weissmuller, 2011). The following main question has been formulated: *which KSAOs do production workers and engineers in manufacturing industry need in order to create and maintain successful human-cobot collaboration?*

METHODOLOGY

To discover the KSAOs relevant for creating and maintaining human-cobot collaboration, we used data from our prior research on human-cobot collaboration in Dutch industry (Wolffgramm et al., 2020). The study included 21 manufacturers that have working experience with cobots. Using a semi-structured interview protocol, we asked engineers (N=29), line managers (N=11), and production workers (N=20) what their human-cobot collaboration looked like and how these collaborations were implemented. The interviews were recorded and converted into verbatim transcripts.

The O*NET Content Model (Mumford & Peterson, 1999) was used to code the transcripts. The model uses a number of theories, such as Theory of Work Adjustment (Dawis & Lofquist, 1984), to describe occupations and workers. We found the O*NET Content Model to be comprehensive and suitable for this research as it has already been used for describing over 1,000 occupations and workers in industry and beyond. In this research, we focused on the O*NET Content Model’s worker-oriented descriptors: worker characteristics and worker requirements – we excluded worker experience since we had insufficient data to determine interviewees' experiential backgrounds. The work characteristics and worker requirement descriptors comprise eight variables (e.g., knowledge). The variables comprise a total of 30 sub-variables (e.g., manufacturing and production). The sub-variables comprise a total of 70 indicators (e.g., production and processing).

Since well-operationalized KSAO variables, sub-variables, and indicators were provided by the O*NET Content Model, we used a deductive coding method to analyze the data (Fereday & Muir-Cochrane, 2006). Prior to the analyses, a coding structure was created using the above-mentioned variables, sub-variables, and indicators. The data was rich enough to allow a clear distinction between production worker KSAOs and engineer KSAOs. The coding structure was imported into the coding software tool Atlas.TI. Three researchers used the coding structure to analyze the transcripts individually. The focus was on the tasks production workers and engineers executed to create and maintain a human-cobot collaboration. In line with thematic analysis (Fereday & Muir-Cochrane, 2006), the transcripts were analyzed in three steps. First, the variables under study were used to deduct relevant quotes from the transcripts (e.g., "… production workers should have basic understanding of the cobot's movement" was linked to 'Knowledge'). Second, the quotations were linked per variable to the sub-variables (e.g., 'Engineering and Technology'). Third, the quotations were linked per sub-variable to an indicator (e.g., 'Mechanical Knowledge'). The researchers compared their outcomes to determine the production worker KSAOs and engineer KSAOs.

RESULTS

In total, 31 KSAOs relevant to the creation and maintenance of human-cobot collaboration were found. These 31 KSAOs were clustered into four groups of characteristics: design characteristics, program characteristics, operation characteristics, and repair characteristics. Table 1 (next page) provides an overview.

Cluster 1: Design Characteristics

This cluster covers all KSAOs relevant for a human-cobot collaboration design. Engineers used their *production and processing knowledge* and *operations analysis skills* to thoroughly analyze the production system where the cobot would be introduced. Furthermore, they used their *engineering and technology knowledge* to understand cobots and accompanying tooling specifications and how both can be used in practice (e.g., by searching for online use-cases). Based on the analyses, engineers used their *ability of originality* to come up with feasible human-cobot collaboration designs. They used their *equipment selection skills* to select the cobot tooling most suitable to their designs. Once the design was ready, engineers presented the designs to production workers using their *speaking skills* (e.g., through images or videos). Production workers were asked to review the design and propose alternatives. Production workers used their *ability of fluency of ideas* to come up with a number of preferred human-cobot collaborations. Engineers used their *active listening skills* to understand the production workers' input.

Cluster 2: Program Characteristics

This cluster covers all KSAOs to install and program human-cobot collaboration. Since only engineers installed the cobot and wrote the software programs, this cluster is only relevant for engineers. Engineers used their *engineering and technology knowledge* of cobot hardware and machine programming to install and program the cobot. By using their *installation skills*, they unboxed the cobot, its transformer and controller, and connected these to the workstation. Next, they attached the tooling to the cobot, wired it to the cobot and transformer, installed the software, and centered the cobot. Once installed, they wrote the program underlying the cobot application using their *programming skills*. During the installation and programming, complex cobot errors occurred (e.g., miscommunication between the cobot and a CNC machine), engineers had to use their *complex problem-solving skills* and the *ability of inductive reasoning* to give meaning to these errors, search for their cause, and come up with a solution. Once programmed, engineers trained production workers for their role (Cluster 3) in the human-cobot collaboration using their *instructing skills*.

TABLE 1
OVERVIEW OF CHARACTERISTIC CLUSTERS AND KSAOS

Cluster 1: Design Characteristics			
KSAO	*Sub-Variable*	*Relevant to Engineers*	*Relevant to Production Workers*
Knowledge	Production and Processing	X	-
Knowledge	Engineering and Technology	X	-
Skills	Operations Analysis	X	-
Skills	Equipment Selection	X	-
Skills	Speaking	X	-
Skills	Active Listening	X	-
Abilities	Originality	X	-
Abilities	Fluency of Ideas	-	X
Cluster 2: Program Characteristics			
KSAO	*Sub-Variable*	*Relevant to Engineers*	*Relevant to Production Workers*
Knowledge	Engineering and Technology	X	-
Skills	Complex Problem Solving	X	-
Skills	Installation	X	-
Skills	Programming	X	-
Skills	Instructing	X	-
Abilities	Inductive Reasoning	X	-
Cluster 3: Operating Characteristics			
KSAO	*Sub-Variable*	*Relevant to Engineers*	*Relevant to Production Workers*
Knowledge	Mechanical	-	X
Skills	Operation and Control	-	X
Skills	Time Management	-	X
Abilities	Reaction Time	-	X
Abilities	Visualization	-	X
Abilities	Problem Sensitivity	-	X
Abilities	Spatial Orientation	-	X
Abilities	Manual Dexterity	-	X
Other Characteristics	Self-Control	-	X
Cluster 4: Repair Characteristics			
KSAO	*Sub-Variable*	*Relevant to Engineers*	*Relevant to Production Workers*
Knowledge	Engineering and Technology	X	-
Knowledge	Mechanical	-	X
Skills	Complex Problem Solving	XX[2]	X
Skills	Troubleshooting	XX[2]	X
Skills	Repairing	XX[2]	X
Abilities	Reaction Time	-	X
Abilities	Deductive Reasoning	-	X
Abilities	Inductive Reasoning	X	-

[2] XX = Engineers should master this KSAO at a more advanced level compared to production workers.

Cluster 3: Operating Characteristics

This cluster covers all KSAOs needed to operate the human-cobot collaboration and prevent it from coming to a standstill due to malfunction. These operating characteristics relate to production workers only. They used their *mechanical knowledge* to operate the cobot, supply the cobot with materials, and determine what a well-functioning cobot looks like (e.g., movements, appearance). They used their *ability of manual dexterity* to place materials for the cobot to handle in a designated pick-up area. Once handled, the production worker used the same skill to collect the products from the drop-off area. Using their *operation and control skills*, production workers switched-on the cobot, used the controller to select one of the prewritten programs, and press the start button. Since most cobots in this study only used one of a few programs, production workers rarely had to change programs.

To prevent the cobot from coming to a standstill, production workers had to load and unload the cobot at the right time, using their *ability of reaction time*. Furthermore, they used their *ability of spatial orientation* to prevent themselves from colliding with the cobot. To monitor the performance, they used their *mechanical knowledge, operation and control skills*, and *ability of visualization* to create a mental image telling them when the cobot was functioning well. Their *ability of problem sensibility* helped production workers to predict whether the cobot would stop working. In addition, since most production workers ran parallel tasks when the cobot was running its program, they had to use their *time management skills* to plan when they would perform their cobot and parallel tasks without doing one at the expense of the other. Finally, production workers had to exhibit *self-control* when working with the cobot. They had to perceive the cobot as a tool that would help them perform their job more effectively.

Cluster 4: Repair Characteristics

This cluster covers all KSAOs needed to reactivate the cobot after it has stopped working. Production workers used their *ability of reaction time* to troubleshoot and, when possible, repair the cobot as soon as an error occurred. They used their *mechanical knowledge* to follow the prescribed troubleshooting and repair procedures. With their *troubleshooting skill* they would visually inspect the state of the cobot, the tooling, and parts being handled. Their *ability of deductive reasoning* and *complex problem-solving skills* allowed production workers to define the cause of the problem and apply standardized repair duties accordingly. The production workers' *repair skills* included two basic degrees of freedom: rebooting the cobot using its power switch and reselecting the program. When these repair efforts did not resolve the issue, the engineers would be called to the scene to take over.

The engineers would use their in-depth *engineering and technology knowledge* to troubleshoot and solve cobot errors that could not be solved by production workers. Engineers would inspect the scene visually and digitally (e.g., reading the history on the controller and checking the program). Since engineers faced a wide variety of more complex errors that often went beyond general rules, procedures, and guidelines, they had to rely heavily on their *ability of inductive reasoning* to solve these issues. In addition, the complexity of the errors also required the engineers to have more complex problem-solving and repair skills compared to production workers.

CONCLUSION

The goal of this study was to investigate how engineering education could prepare future production workers and engineers for effective human-cobot collaboration. Since it is unclear which KSAOs production workers and engineers should master in order to create and maintain a successful human-cobot collaboration, we used the O*NET Content Model (Mumford et al., 1999) to analyze 60 transcripts concerning cobot implementation in the Dutch manufacturing industry. We found 31 KSAOs relevant to the creation and maintenance of human-cobot collaboration. We were able to group the KSAOs into four categories and indicate which ones are relevant for production workers, engineers, or both. Our results revealed a classic distinction between production worker and engineer responsibilities: the engineer (together with management) determines the technology's application, implements the technology, and solves complex errors; the production worker operates the technology and solves errors using detailed instructions (O*NET, 2020a; O*NET, 2020b; Wurhofer, Meneweger, Fuchsberger & Tscheligi, 2018). The distinctions encountered between production worker and engineering KSAOs also have consequences for engineering education provided to these groups.

Engineering education provided to future production workers should help them develop into *cobot operators*. These operators need to be willing to work with the cobot and be able to think along with engineers about its application, as well as preparing and maintaining the cobot and its workstation according to instructions, being able to solve and communicate cobot errors and being capable of managing multiple production systems. The operators should learn the following: the use of the cobots' control panel, cobot functioning and malfunctioning, loading and unloading, and basic cobot troubleshooting.

Cobot education provided to future engineers should prepare them to become *cobot programmers*. These programmers need to be able to determine which cobot application and tooling are best in relation to the state of the production system, be able to build accompanying programs from scratch, integrate the cobot with other machines and devices, develop the social skills to engage and instruct cobot operators, and solve complex cobot errors. The cobot programmers should learn about cobot and tooling specifications, the programming language, cobot input and output management, and expert cobot troubleshooting. In addition, they should learn how to thoroughly analyze a production system and conduct professional conversations.

In the following section we will illustrate how we, together with educators and practitioners, used our insights to develop an engineering education course that prepares technical, vocational education students, the next generation of production workers (cobot operators), for human-cobot collaboration.

Designing 21st Century Engineering Education Together

To structure the development of the engineering education course for cobot operators, we used the educational design model by McKenney and Reeves (2018). The model uses an *iterative* process consisting of three stages, namely: 1) exploration, 2) design, and 3) evaluation. The exploration stage involves having a thorough understanding of the current situation and setting a long-term goal. The design stage is aimed at systematically creating ideas and constructing solutions. The evaluation stage is characterized by reviewing pilots and try-outs of the constructed solutions.

In order to successfully translate the KSAOs for cobot operators into suitable vocational education practices, we formed a *community of practice*. This community of practice consisted of six vocational education teachers from two different community colleges with different technical backgrounds (mechatronics, ICT, laser technology), four researchers from research groups specialized in HRM, industrial design, and mechatronics, two educational designers, three practitioners from technical companies, and a cobot integrator. The diversity of expertise in this community of practice allowed us to embed all required KSAOs in a vocational engineering education program that is related to industrial practice. This approach is in line with suggestions made by Niman and Chagnon (2021) who state that effective customized learning experiences can be created by embedding the expertise and experiences of field professionals in classroom settings. Our community of practice also meets Chen's (2020) request for increased incorporation of state-of-the-art technology in education to better meet the nature of knowledge in a digital era. In the upcoming paragraphs, we will elaborate on how we used the educational design model by McKenney et al. (2018) to structure the development process.

Phase 1: Exploration of the Current Situation

During the first community of practice meetings, we reflected on the 16 KSAOs relevant to cobot operators. We asked the community of practice members to elaborate on two questions: how do these KSAOs compare with the prior knowledge of students and how should we educate the missing KSAOs? Most vocational education teachers had no working experience with cobots, but had expertise with similar technologies (e.g., industrial robots). In response to the desired effectuation of cobot education, vocational education teachers stressed that they wanted to embed cobot education into their engineering education curricula. Since creating a new course and redesigning all community colleges' engineering education curricula was considered as too time-consuming by the entire community of practice, an existing 240-hour elective module called ‘Working with an Industrial Robot’ was selected. Selecting an existing elective module had two key advantages. First, the elective module was already certified and was equipped with clear learning goals and exam criteria. This saved the community of practice an administrative burden and allowed it to focus on developing course content instead. Second, the elective module’s learning goals and exam criteria were in line with the KSAOs relevant to cobot operators. This alignment permitted the uncompromised development of course content that could, on the one hand, prepare students for human-cobot collaboration and, on the other, respect the elective module’s goals and criteria.

Phase 2: Designing Cobot Education Content

We created the content for the elective course based on the insights obtained in the exploration phase (phase 1). Since both knowledge and practical KSAOs were found to be relevant for cobot operators, a hybrid learning environment was considered optimal. A hybrid learning environment is both authentic and situated (Zitter & De Bruijn, 2016) and combines the advantages of school-based and workplace learning arrangements by binding these intersecting practices together. A hybrid learning environment combines two learning dimensions. The first dimension is the learning processes that are to be embedded in vocational education and varies from *acquisition* (where knowledge is considered to be a commodity that can be acquired, transferred and shared) to *participation* (learning through growth to become a full member of a professional community). The second dimension concerns the conditions under which the learning process takes place in vocational education and varies from *constructed* (near work exercises such as cases and simulations) to *realistic* (how novices participate in authentic work). The dimensions of a hybrid learning environment were used to structure the elective module. The elective comes with three sequential parts: A, B, and C. The knowledge-related KSAOs are embedded in parts A and B. The skills, abilities, and other characteristics are embedded in parts B and C.

In *part A*, aimed at constructed acquisition, students gain an initial understanding of the concepts of cobot and human-cobot collaboration and what these concepts entail in the context of modern manufacturing. Students learn about the technical specification differences between robots and cobots, the different types of cobots and their tooling, and how cobots are being used in industrial practice. The lessons for part A all take place in the classroom. The mechanical knowledge will be transferred by showing cobot images, discussing application videos, reviewing specification overviews, explaining company-specific use cases, and through storytelling by guest speakers who have experience with cobots.

In *part B*, focused on realistic acquisition, students will learn about and effectuate the basics of cobot operation and cobot repair. In an integrated series of classroom and workshop lessons concentrated around three sequential assignments, students will learn how to operate and repair a cobot. Students execute the assignments and their underlying exercises in pairs or threesomes – the content of the assignments and exercises are explained in the upcoming paragraphs. Prior to the assignments, students receive an educator-lead demonstration of cobot activation and cobot safety. Cobot activation is about switching the cobot on and off, activating the tooling, and using the tech pendant. Cobot safety comprises the activation of safety settings, the use of the emergency stop, and basic workplace safety regulations.

The three assignments following on from the demonstrations each capture a unique cobot feature. Assignment 1 is about cobot movements. Students learn about the different types of cobot movement, such as linear or joint movements. Furthermore, they learn what these movements look like and how these are programmed in the tablet. Through ‘follow the pattern’ exercises, such as shapes and letters, students are challenged to operate the cobot. Assignment 2 is about operating a cobot for picking-up products and placing these in a designated area. In four exercises, students will operate the cobot to pick-up simple Lego Duplo parts and complex metal parts and place these on smooth and precision plateaus (e.g., a mold). Assignment 3 is about operating a cobot using remote control commands and condition functions. In three exercises, students will operate the cobot through building wait functions, by activating and deactivating parts of the program structure, and through if-then-else statements being activated by the remote control. By using these commands students learn how to operate an automated cobot system and how to maintain this system based on input-throughput-output logics. All three assignments finish with a repair exercise. In the exercise, a suboptimal program needs to be resolved. Students need to be capable of recognizing the suboptimality, execute troubleshooting, communicate the suboptimality, and determine whether this should be solved by the cobot operator or cobot programmer.

Part B's classroom sessions facilitate the assignments and their underlying exercises through demonstrations and knowledge-transfer. The classroom content is about cobot features (including their program build-up), the principle of product flow, the looking up and documentation of cobot performance, error recognition, role division between cobot operators and cobot programmers, and repair practices. Through roleplay, students learn how to communicate malfunctions and suggested repairs.

In *part C*, focusing on realistic participation, students apply their learnings from part A and part B by operating and maintaining workstations equipped with a cobot. In line with this objective, part C completely takes place in the workshop. Part C entails two assignments. In assignment 1, students operate and maintain a packing workstation (i.e., the cobot must successfully fill trays with the right cans). In assignment 2, students operate, maintain, and participate in an assembly workstation (i.e., the students and cobot are assembling products together [Image 1]). By following the taught standards, repairing malfunctions and resolving suboptimalities, students should be able to demonstrate a safe and functional human-cobot collaboration. To assure the collaborations are not only output-driven but also humanly maintainable (Parker, Andrei & Van den Broeck, 2019), both assignments last around 30 to 45 minutes.

FIGURE 1
BUILD-UP ASSEMBLY WORKSTATION

For the sake of optimally preparing the students for working with cobots in their future profession, the community of practice attempted to achieve constructed participation by incorporating as much industrial reality as possible throughout parts A, B, and C. For instance, through realistic examples in the classroom and through field-inspired cobot applications in the workshop. Furthermore, the examination of the elective comprises three components: a written exam that accounts for 30%, an assessment that accounts for 50%, and an interview that accounts for 20%. The written exam covers all knowledge components mentioned in part A and part B. The assessment is a slightly manipulated version of part C's exercise 2. The interview is meant for reflection on the course content, lessons learned, and the students' participation. An overview of the elective is shown in Table 2 (next page).

TABLE 2
OVERVIEW DEVELOPED ELECTIVE ‘WORKING WITH AN INDUSTRIAL ROBOT’

	Part A: An introduction to human-cobot collaboration	**Part B: Functionalities of a cobot**	**Part C: Working with a cobot in human-cobot workstations**
Description Cobot Education	Basic knowledge of the (kinds of) cobots, introduction to smart industry, differences between a robot/cobot, ethical issues, and impact of work	Introduction to working with a cobot, basic application of cobot operation practices, safety precautions, and managing malfunctions and suboptimalities	Working with human-cobot collaboration in realistic workstations and recognizing and correcting cobot malfunctions
Learning Dimension Hybrid Learning Environment (Zitter et al., 2016)	**Constructed acquisition** Illustrating theoretical concepts; contextualization of concepts in the form of examples in textbooks by using pictures of videos. *Example: e-learning about the knowledge needed, i.e. industrial application and parts of the cobot.*	**Realistic acquisition** Learning processes under realistic conditions, to make work process knowledge explicit (reflective practice). *Example: small assignments about operating a (malfunctioning) cobot, in which theory is translated to practice.*	**Realistic participation** Learning through work experience or on-the-job learning; at school grounds or at the workplace. *Example: final assignment based on a realistic workplace example; solving a problem in human-cobot collaboration.*
	Constructed participation Elements from the varied reality of professional practice are present, but not in entirety. For example parts have been omitted, simplified or simulated. *Example: (digital) simulations to practice working with a cobot or semi-structured assignments.*		
Examination	• Written exam (30%) • Assessment (50%) • Interview (20%)		

Phase 3: Improving the Design

Designing an elective course on human-cobot collaboration was an iterative process which relied heavily on members of the community of practice. The network meetings served as moments to reflect on the designed content. During the design process, five vocational education students tested the designed content, assignments, and applications with cobots. The goal was to gain a first understanding on how vocational education students react to the course content and to learn what kind of support they needed from their educators.

It seemed that – most of the time – students found it quite simple to work with basic aspects of the cobot (e.g., activating a program). We also learned that it is important to include in the assignments in part B a more complex exercise in order to challenge all students. Furthermore, the occurrence of cobot-related errors and suboptimalities proved to be a great opportunity for students to translate their learned knowledge about cobots into practice. It also seemed to stimulated their fluency of ideas as they provided suggestions for optimizing their human-cobot collaboration. An important point for improvement was not to cluster part B’s repair exercises into a separate fourth assignment. Not only was it difficult to organize an assignment on movement, pick-and-place, and command repair; it also added little to the students’ learning process since they had already encountered most of these issues during part B. Another aspect which seemed to be very important to the development of the elective, was to have a digital platform accessible to all members of the community of practice. Such a platform was in our case needed to share expertise and course content across institutions. The design process resulted in long-term partnerships between education, practice, and research.

With this study, we have contributed to the engineering education community and industrial practice by specifying the KSAOs production workers and engineers need to work with a collaborative robot. Furthermore, together with two community colleges, three manufacturers, a system integrator and two research groups, we have developed a 240-hour vocational education course on human-cobot collaboration. Co-creating education and a pioneering mindset have proved to be of great value and a necessity in keeping engineering education up-to-date. We are looking forward to launching our cobot education in the Fall of 2021 and reporting on our findings in a follow-up contribution.

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