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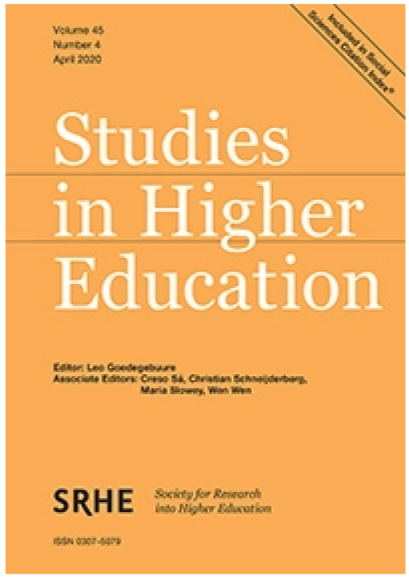

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The digitalization of operations requires frontline workers to develop new competencies and become increasingly involved in innovation processes, but companies and technical schools are facing challenges in providing the necessary upskilling. The aim of this research was to isolate the contribution that technical universities can make in this middle-skills 'gray area' without incurring an unwarranted academization of these professions, i.e. not conceiving new degrees but rather collaborating to strengthen upper secondary technical education. An extensive field research was conducted in the empirical setting of a leading Italian electric-power distribution company, to investigate how the advent of smart grids is transforming its electrical grid workers' work environment. On the basis of the new competency needs that emerged, a Challenge-Based-Learning intervention was co-designed with the company, and carried out with two classes of students involved in its school-based apprenticeship program. The findings contribute to literatures on knowledge creation and transformation by university academics, showing how technical universities can design effective challenge-based activities thanks to elements such as cutting-edge laboratories, multidisciplinary research, diverse teaching domains, and a stimulating environment. An empirical extension to the emerging literature stream of 'developmental university' is also provided, showing the role that technical universities can play to help bridge the middle-skills gap by transferring innovative research-based teaching methods to technical schools, thereby restoring their socio-economic attractiveness and that of technical middle-skill professions. A major policy implication that emerges is the urgent need to foster initiatives aimed at a deeper integration between upper secondary and higher education systems.

Keywords: Academization; Challenge-Based Learning; Developmental Universities; Digitalization; Vocational Education and Training

Introduction

Middle-skill jobs – for which one needs 'more than a high school diploma but less than a bachelor degree' (Holzer and Lerman 2007) – represent a gray area between upper secondary and post-secondary education, in which technological change affects the work practices and competency requirements (Kochan, Finegold, and Osterman 2012; Fuller et al. 2014). Examples of middle-skill workers are skilled trades such as computer support or biotechnology technicians, but also skilled blue-collar workers (Osterman and Shulman 2011). Indeed, in such process industries as chemicals, oil and gas or food and beverages (Woodward 1965), and in network-based sectors such as electric power and telecommunications, frontline workers are in charge of operating and maintaining complex machinery, and therefore require a technical diploma and/or additional on-the-job training. Now that digitization technologies – related to computing, communication, connectivity, information processing capabilities (Bharadwaj et al. 2013) – are largely available to control and optimize the assets and production processes of companies, operational activities are increasingly linked to information processing tasks. This 'digital transformation' of firms has been even accelerated by the COVID-19 pandemic, which has required an increasingly higher remote control of service operations (Rapaccini et al. 2020). As a result, middle-skill workers are witnessing rapid evolutions of their jobs, which are characterized by higher task variety and complexity, therefore requiring new sets of competencies.

On the other hand, upper secondary Vocational Education and Training (VET) systems are proving unable to keep up with such an increase in complexity (Cedefop 2018), and thus the middle-skills gap is widening. Companies try to realign the schools' curricula to their competency needs through school-based VET programs or dual apprenticeships (Solga et al. 2014); however, 'dual vocational trainees can no longer meet the complexity of digital work' (Gebhardt, Grimm, and Neugebauer 2015, p. 128), and such a technological change requires a new approach to higher education and new training models for middle-skill workers (Fuller et al. 2014). An alternative approach would be to require university degrees to access these jobs; however, this trend of 'academization' has received several criticisms, above all that of inducing inefficiencies on the labor market as a result of unneeded over-education (Bøje 2012).

In this article, we analyze a third way, i.e. an intensified collaboration between technical universities and technical schools. Despite the increasing interest observed in education literature, there is still a scant amount of empirical research on 'developmental university' initiatives – i.e. those directed toward tackling the social and development challenges faced by society – aimed at strengthening upper secondary educational systems. This work also aims to contribute to the literature on knowledge creation and transformation by university academics, by exploring the role that a technical university might play as a result of actively intervening in technical schools (rather than embracing academization and passively attracting new students) and realigning their goals to the needs brought about by technological innovation. Our research questions are: How are digitalization and academization widening the middle-skills gap? What are the assets that could allow technical universities to take on a role in tackling the middle-skills gap issue?

The rest of the article is organized as follows. First, we examine previous literature concerning the new competency needs induced by digitalization and the actors in charge of developing them for middle-skill workers. We then outline the two cycles of our research, through which we first explored the specific competency needs of smart grid workers, and then co-designed and developed a competency-based intervention – structured on Challenge-Based Learning principles – together with a company and two technical schools. The findings are structured around the benefits that future middle-skill workers, firms, technical schools, and the universities themselves can obtain from the involvement of technical universities. The results are then discussed, and practical implications are drawn up for organizations, educational institutions and policy makers in light of the developmental role that technical universities can play in tackling the middle-skills gap issue.

Middle-skills gap, digitalization and academization

To investigate the middle-skills gap issue, generated in the 'gray area' between upper secondary technical education and the labor market, and widened by digitalization and academization, we drew from literatures on skill-biased technological change, knowledge creation and transfer, and education.

Digitalization and the upskilling of frontline workers

Whereas automation had a substitution effect on low-skill occupations, digitalization is now having a major – albeit different – impact on middle-skill frontline workers. With the application of data-driven approaches to operational decisions (e.g. predictive maintenance, remote troubleshooting), enabled by 'machine-based digital technologies' like the Internet of Things (Balsmeier and Woerter 2019), the everyday tasks of middle-skill frontline workers are becoming increasingly varied and complex, characterized by interaction, creativity and problem solving, Therefore, despite the claims about a possible 'job polarization' (Acemoglu and Autor 2011), digital technologies could struggle to substitute them (Brynjolfsson and McAfee 2014). Instead, these workers now need new knowledge, analytical and interpersonal skills, and attitudes to process data and communicate with engineers (Helper and Kuan 2018). In this context, recent studies have shown the contribution that may be derived from the tacit experiential knowledge of frontline workers, who therefore need to be more involved in continuous improvement processes as operational decisions become more data-driven (Lam et al. 2017). A key precondition necessary to make the involvement of frontline workers effective is their ability to assimilate and exploit new knowledge, i.e. their individual absorptive capacity (Cohen and Levinthal 1990), whose antecedents are prior-based knowledge, breadth of knowledge, communication, learning behaviors, problem-solving capabilities, and attitudinal elements such as motivation and organizational citizenship (Ellis 1965; Cohen and Levinthal 1990; Yao and Chang 2015) – the more things are known, the easier it is to link them and boost the learning process in motivated individuals. Firms can invest in their employees' individual absorptive capacity through advanced technical training (Cohen and Levinthal 1990) and school-based apprenticeships, as on-the-job training is needed to develop competencies through learning by doing, using and interacting (Lundvall 2010). Furthermore, the experiential learning theory (Kolb 1984) highlights the need for applied settings to foster students' engagement and motivation. School-based VET programs go into this direction, as they bring education closer to the labor market needs and parallelize the development of knowledge, skills and attitudes (Baartman and De Bruijn, 2011). However, occupation-specific training programs might be short sighted in constantly evolving contexts, as they fail to provide the general knowledge needed by workers to adapt to further technological progress (Jacob and Solga 2015). It is therefore unclear who should provide such new competencies, and how (Gebhardt, Grimm, and Neugebauer 2015).

Academization and the need for a breakthrough in technical education

Well established in several European countries, upper secondary VET programs are carried out in technical or vocational high schools, and deliver technical education, professional education, or technician professional diplomas (OECD 2013). However, as technological change is happening at an unprecedented speed, these programs do not have the means to keep up the pace with such increases in complexity (Cedefop 2018), and the need for upskilling remains unmet.

To address this skills gap, one option has been to combine vocational training and academic education in hybrid programs, issued by both university and non-university institutions (Graf 2013). Since a wide range of cognitive skills is only emphasized in higher education (Baethge and Wolter 2015), these occupation-specific programs can be practical for the non-generalized training of higher-skilled trades. However, abusing of them as a 'standard' extension of upper secondary school could have negative social implications for those socio-economic groups needing access to the job market with a diploma and no further involvement in years of higher studies. In this vein, requiring a degree to perform every middle-skill job that needs partial upskilling would mean incurring the controversies implied by the so-called 'academization', the trend for which individuals increasingly aspire to obtain the highest possible academic qualification, also found in recent literature (e.g. Kopatz and Pilz 2015) as 'academic drift' (not to be confused with the same term used by Neave [1979] to describe non-university institutions acting like universities with emphasis on advanced work and research). An uncontrolled approach to academization is being criticized a great deal, as it could lead to a lack of practical sense, a 'loss of nobleness' of technical jobs, and over-education, with costs for both individuals and firms (Bøje 2012; Kopatz and Pilz 2015; McGuinness 2006) due to the inefficiencies of the mismatch it brings in the labor market (Cappelli 2015). One reason is that technical students are often unaware that the labor market needs more middle-skill workers than graduates (Figueiredo et al. 2017), and believe that only a university career guarantee them employment. In developed countries as the USA and Germany, higher education entrants equalled the number of new VET entrants (Baethge and Wolter 2015) in the same period – the early 2000s – when 47% of job openings were expected to be for middle-skill jobs (Kochan, Finegold, and Osterman 2012) and only 23% required a degree (Osterman and Shulman 2011).

Given the above, a dichotomous view of upper secondary and higher education is probably not the most appropriate for addressing the middle-skills gap issue. In this vein, a third way – that integrates both systems in a new educational order – has begun to be discussed (e.g. Baethge and Wolter 2015; Polidano and Tabasso 2016). Indeed, upper secondary VET programs do have the potential of matching the demand of middle-skill workers through an extensive use of school-based VET and apprenticeship schemes (Solga et al. 2014). With firms already involved, technical universities might be the missing actor needed to take these programs to the next level. Their involvement is in line with the trends of learning and training practices, which – in a context of rapidly changing technology and a continuously evolving work environment – benefit from being research-based (Hasanefendic, Heitor, and Horta 2016; Giesenbauer and Müller-Christ 2020). Innovative approaches to learning, such as 'living labs' or 'teaching factories', are examples of how research, innovation and education can converge (Mavrikios et al. 2013). Thanks above all to their sources of knowledge and facilities (e.g. Piqué, Berbegal-Mirabent, and Etzkowitz 2020), universities have the resources and competencies necessary to play a developmental role in society and collaborate with other stakeholders to create living labs, science shops and communities of practice where accumulated knowledge can be spread (Bayuo, Chaminade, and Göransson 2020). Isolated interventions of academics in upper secondary VET programs – through such practices as Challenge-Based Learning (e.g. Johnson et al. 2009, Shuptrine 2013) – can produce benefits in terms of promoting a scientific approach (e.g. Hammond, Karlin, and Thimonier 2010; Venville and Dawson 2010), critical thinking and problem solving skills, and even increasing academic performance (Yang 2015; Polidano and Tabasso 2016). University-affiliated high schools are already a reality in several countries throughout the world (Devedjiev et al. 2019; Ilomäki, Vasileva, and Stefanova 2020). In this vein, supporting upper secondary VET programs might constitute an expansion of scope for 'developmental universities' (see, for example, Arocena and Sutz 2007), which are needed not only in developing countries (Göransson, Sutz, and Arocena 2018), but also wherever stronger and more inclusive systems need to be built to include marginalized groups with a weak or un-articulated demand for innovation (Arocena, Göransson, and Sutz 2015). With the advent of digitalization, upper secondary VET systems – which struggle to prepare middle-skill workers for their future – are a perfect match to this description.

Research setting and methods

The empirical setting of this research is the Italian education system. At upper secondary level, technical education is provided by technical schools (*'Istituti Tecnici'*) in five-year programs that combine general and technical subjects and prepare students for either employment or higher education, to which they allow access (Cedefop 2019). Recent technological advances have led to the upskilling of technical professions, calling for new educational needs in the gray area between the *Istituti Tecnici* and the *'Politecnici'*, i.e. the technical universities that carry out advanced work and research – both theoretical and applied, in cutting-edge laboratories – in such sectors as engineering, design and architecture, and provide bachelor's, master's, and doctoral courses and degrees.

To match the new competency needs of firms, two main initiatives have been put in place: (i) the establishment, in 2008, of post-secondary technical colleges (non-university and non-research-based) inspired by the German *Fachhochschulen*, called *'ITS'* (*'Istituti Tecnici Superiori'*) issuing two- or three-year vocational programs; and (ii) the introduction, in 2015, of mandatory school-work alternation in the last triennium of upper secondary school.

In order to explore the role that a university can have in this gray area, and with a focus on the second initiative described, our research involved: (i) 'the University', a large Italian technical university, (ii) 'the Company', a leading Italian electric-power distribution firm that heavily invested in the school-work alternation of (iii) 'the School', i.e. two Italian technical schools with a path in electrotechnics. Due to strong upskilling needs, the Company has considerably increased its educational requirements for its electrical grid workers: not even a technical diploma was required before 2007, while now they undergo a three-year paid apprenticeship based on: (a) two years of school-based VET (one day a week in the last biennium, plus a full in-company training in the summer period halfway the two years) at selected technical schools, and (b) one year of work-based apprenticeship after the diploma.

The School and the Company – both interested in enhancing their education and training practices – were active participants in the research. Participatory Action Research allows one to collaborate with participants, co-produce practical solutions, and generalize implications (Conroy and Mccarthy 2019). By actively involving practitioners in the research process, this approach allows them to understand their practices 'from within', create a shared vocabulary among the participants, develop interactions and communities of practice, and transform their conduct accordingly (Kemmis, McTaggart, and Nixon 2014). The research followed a multi-method, qualitative and quantitative approach based on two action research cycles (Lewin 1946) (Figure 1).

[Figure 1 near here]

The first cycle consisted of a case study conducted at the Company, with its grid workers being the unit of analysis. This represents a convenient setting, since the heavy digitalization faced by the electric-power sector with the advent of smart grids urgently requires further upskilling of these frontline workers dealing with grid maintenance and operations. This research cycle was aimed at exploring the gap, brought about by digitalization, between the Company's new training needs and the school-based part of its apprenticeship (hereafter: 'school-based apprenticeship'). To converge lines of inquiry (Yin 2009), multiple sources of evidence were triangulated: site visits, focus groups, structured and open-ended interviews – coded inductively into categories and second-order themes (Gioia, Corley, and Hamilton 2013) – with the school-based apprenticeship's tutors (teachers from the School, operating unit manager from the Company), and reserved documentation.

The results of Cycle 1 were the starting point of the second research cycle, concerning the intervention conducted at the University. The objective was to develop and test, together with the other participants, a Challenge-Based Learning (CBL) method aimed at providing the missing pieces of competencies needed for the evolution from 'grid workers' to 'smart-grid workers'. Company managers and University researchers collaborated, in the planning phase, on the co-designing of the contents of the intervention. This collaboration involved the departments of management, computer science and electronics, to exploit – through an interdisciplinary approach – their knowledge on HRM and digital transformation, computer science, and ICTs. In line with CBL principles (Johnson et al. 2009), the activities were developed to challenge students to innovate work processes through the exploitation of new technologies (IoT sensors and data management), in order to solve real-world problems (monitoring and the prevention of breakdowns of secondary cabins). University-level theoretical lessons (data architectures and management, innovation design processes, psychology for teamwork, cost-benefit analysis of an innovation) were included as 'guiding activities' to ensure a breadth of knowledge, and University researchers were deployed as near-mentors ('guiding resources').

Two interventions were executed with thirty-four students of the classes involved in the Company's school-based apprenticeship: class A underwent the intervention at the end of year 4, and class B at the beginning of year 5. The objective of this research design choice was to disentangle the effects of the full-time on-the-job training carried out halfway the last biennium of school-work alternation. In each intervention, the students were brought to the University's innovation lab for five consecutive days and divided into four teams to face the challenges through activities such as design thinking, cost-benefit analysis, development of IoT-based demonstrators, data collection and analysis. A mid-week assessment and a final presentation were used to foster reflection and trace the progress of skill development through the application of new knowledge. The evaluation of the findings followed a number of steps throughout the two-year research, with data being collected in both cycles (Table 1).

[Table 1 near here]

In order to avoid response bias and reflexivity (Yin 2009), the interviewed tutors did not know about the results of the student survey, nor did the students know anything about the tutor interviews. The two classes were comparable: same age and educational level, and with no statistically significant differences in personality traits or preliminary knowledge gaps, assessed before the interventions. We investigated the perceived impacts on knowledge, skills, and attitudes using a 1-5 Likert scale. Five constructs were identified for attitudes and were validated through a factor analysis. The benefits of involving a university were triangulated by drawing on open comments in the surveys, participant observations during the interventions, physical artifacts (demonstrator models), and final presentations. Moreover, – as 'some of the learning resulting from experiential designs can often be delayed or tacit and will only become evident in the light of subsequent experience' (Lizzio and Wilson 2004, p. 485) – the interview with the School tutor was conducted a few months after the intervention.

Findings

The findings are organized according to the two research cycles: firstly, a characterization of the new competency needs – and relative gaps – is carried out, then the benefits of the intervention and the role of the University are outlined.

The new competency gap brought about by digitalization (Cycle 1)

The Company is turning grids into smart grids, and transforming the way inspections, maintenance and the use of the electrical grid and cabins can be conducted by frontline workers using IoT and digital technologies. As these workers are in direct contact with the work environment from which data are extracted, they are required to collaborate with engineers for both the operational remote control of the grid and for the design of innovative solutions to problems of the secondary cabins, for which vertical interaction and innovation-related competencies are increasingly being needed. According to senior grid workers involved in the focus groups, the aspects of competency that are becoming more important with digitalization are data analysis and statistical interpretations (92% of the participants), the ability to use IT applications (92%), and team-working skills (75%). Based on findings, we were able to structure the required competency profile of smart grid workers into domain, transversal and digital components of knowledge, skills and attitudes in Table 2.

[Table 2 near here]

Higher quality, motivation and discipline were observed for the students involved in school-based apprenticeships. In particular, a strengthening effect on deep learning approaches was observed:

> I noticed that the way they are studying now is no longer to simply obtain good marks (School tutor interview 1)

> With the apprenticeship, the absence rate fell. They no longer try to copy during tests, they understood that evaluation is a moment to make them aware of the stage at which they are […] and they now accept innovative teaching methods more than before (School tutor interview 2)

The other findings from the interviews with the tutors are summarized in Table 3.

[Table 3 near here]

Overall, although the domain component of competency showed only a few gaps (domain knowledge was provided in class, skills and attitudes through on-the-job training), the desired transversal and digital components of competency still appeared to be lacking to a great extent.

Benefits and success factors of the challenge-based intervention (Cycle 2)

The University and the Company co-designed the intervention with a main learning objective: to provide students with knowledge, skills and attitudes needed to collaborate with senior workers, participate in innovation processes, and understand how data flow and need to be managed remotely by engineers and data scientists. This was reflected on the learning outcomes perceived by the students, which are summarized in Table 4.

[Table 4 near here]

The additional on-the-job training made the students from Class B see theory from a different point of view during the challenges, and better contextualize the theoretical aspects they had observed at school. A correlation was observed between more training and the ability to learn more about secondary cabins and carry out an economic analysis of their innovation, thus suggesting that the domain knowledge of frontline workers is needed to foster participation in innovation processes. Moreover, the stronger attitude toward deep learning is an impact that was enabled by several weeks of on-the-job training, thus confirming the findings of Cycle 1.

Concerning the direct perceptions about the intervention itself, Figure 2 shows the positive aspects reported by the students' open comments, that can be clustered in two main categories: skill development (benefits) and university environment (success factors).

[Figure 2 near here]

The majority of comments were focused on the specific effects of being involved in a university environment, as confirmed by the subsequent interview with the school tutor. Having professors and mentors from different departments allowed the students to appreciate and look for breadth in knowledge and skills, while neutrality and the absence of any formal evaluation provided the students with a higher orientation toward learning and continuous improvement:

> [I liked] the organization, the relationship with the university professors and tutors with different skills (Student survey)

> Having different teachers talking about different trends and transferring knowledge and skills allowed them to see that the world of technology is multifaceted. (School tutor interview 3)

> The students perceived that we were trying to give them knowledge and skills, regardless of whether they were Company apprentices or School students. At the University, they were both and neither. This left them free to manage their own learning, and made them feel more involved in the design process (School tutor interview 3)

By working side by side with engineering professors and researchers as near-mentors, and having access to laboratories and edge technologies, the students acquired a great motivation and a renewed vocation for technical jobs:

> [I liked] the use of technologies side by side with engineers (Student survey)

> [I liked to] propose non-trivial ideas and combine personal ideas with the advice of tutors and professors (Student survey)

> Participating in person in the University environment and laboratories made the students experience something more than merely visiting the laboratories, but rather take advantage of their potential. It made them see that things can also be studied at a higher level, thanks to synergies between different education sectors (School tutor interview 3)

> Those who were unsure about whether to undertake an academic career understood that being engineers implies a higher level of commitment, skills and knowledge. Those who did not want to go to university now take comfort in saying 'I'm done with studying, it's time to work: tell me what to do and I'll do it well. Then, if I advance I will become a shift manager, team leader, head of unit' (School tutor interview 3)

Last, the intervention showed promising results in terms of a higher integration between universities and technical schools, which could at the same time constitute a sort of 'active guidance' toward higher studies and 'give a meaning' to technical schools:

> We gave a low-social-class student, who had to go to a technical institute instead of general high school […] the opportunity to see that there is more. He saw this for just a week, but will remember it for a lifetime (School tutor interview 3)

> Other classes from our School conduct 'orientation' by talking to the students and taking them to see a university, but neither the university nor the students understand anything about each other […] Instead, through what you did here, twenty students have had true guidance in this sector (School tutor interview 3)

> This is the direction which, sooner or later, should be taken to show that the public technical school has a meaning (School tutor interview 3)

Discussion

The education and training of middle-skill workers fall into a gray area, which – with the advent of digitalization – urgently needs to be demystified. Our results go in the same direction as many other studies that stress the importance of reinforcing upper secondary schools, and of making them able to develop 21st century skills instead of delegating such task to universities (e.g. Doppelt 2007; Goode 2007; Venville and Dawson 2010; Yang 2015; Gaskins et al. 2015; Ilomäki, Vasileva, and Stefanova 2020). Other recent studies have instead supported the academization of professions concerning e.g. healthcare or hotel management; however, as they themselves acknowledge, such researches often lack empirical evidence from the stakeholders involved in the education and training process (e.g. Kälble 2013; Gardini 2018). An in-depth analysis of such stakeholders' roles and perspectives has allowed this study to disentangle how universities can contribute through logics that are profoundly different from envisaging ad-hoc undergraduate programs for middle-skill profiles. Specifically, our study has highlighted the value added associated with involving technical universities that can count on multidisciplinary attitudes and capabilities to carry out research and short education initiatives as Challenge-Based Learning interventions.

Building Challenge-Based Learning upon research and workplace training

With the advent of smart grids, electrical grid operators will increasingly need to deal with a large variety and high cognitive complexity of tasks. Technical universities can add some unique elements necessary to complement the school-based apprenticeship programs created by firms and technical schools.

First, technical universities have the capability of recombining distant knowledge domains to create Challenge-Based Learning (CBL) activities, an ability that technical upper secondary schools lack – since this knowledge transformation is an outcome of applied research programs and greater resources devoted to cutting-edge technologies, innovation labs, and the experimentation of new pedagogical approaches. In this case, the University contributed to transferring transversal and digital knowledge (e.g. innovation design, data and information management) to the students, complementing their domain knowledge in electrotechnics.

Second, research universities can count on more hierarchical roles than technical schools, and deploy all the different levels of researchers in both the design of CBL activities (built on a logic of recombining the above-mentioned different complementary knowledge domains) and their pedagogy: from PhD fellows and research assistants, involved as near-mentors in the interventions, to associate and full professors, involved in teaching.

Third, universities can trigger motivational mechanisms in CBL programs, which can play roles in creating such attitudes as proactivity and propensity to ask for feedbacks, fundamental for a 'high-road' integration of competencies (Baartman and De Bruijn 2011), and in fostering the learning orientation needed by frontline workers whose cognitive involvement becomes more and more important. Teamwork and informal moments, enabled by the neutrality of the University environment, stimulated a student-peer social interaction (similarly to the findings of van Herpen et al. 2020). The theoretical lectures and the mid-week and final reviews were essential parts of the formal approach needed for the assimilation, sharing and transformation ('recombination'; see Savino, Messeni Petruzzelli, and Albino 2017) of new knowledge. The University environment made the students understand how technologies are involved in processes, through a challenging teaching method that made them feel engaged, a similar result to the findings of Shuptrine (2013). Involving diverse professionals (experienced workers, engineers, HR managers) of the Company as active participants in both of the research cycles made it possible to emulate work-related innovation processes, that – together with the division into teams, the use of new technologies to solve real-world problems, and the final presentation – generated the experiential learning advanced outcomes that are typical of CBL (Johnson et al. 2009), such as collaboration, communication, and real-world problem-solving skills. The interventions accelerated the improvement of argumentation skills and rational informal reasoning (supporting the findings of Venville and Dawson 2010) needed for the knowledge transformation process. These points show that the involvement of technical universities in CBL programs can contribute to building the micro-foundations of the absorptive capacity needed by frontline workers to be actively involved in the process of innovation and continuous improvement of their data-rich working environment.

Such an absorptive capacity is built on previous working experience and, in this vein, the higher impacts that Class B perceived on recombining their domain knowledge with new knowledge showed that school-based apprenticeships are able to foster this process. In addition to the generation of a 'deep' approach to learning, opposed to the surface approach that is typical of upper secondary students (Richardson 1994), the on-the-job training provided operational knowledge, willingness to learn, resistance to stress, and additional manual dexterity, thus confirming the advantages of direct interaction with the real world of operations described by Gebhardt, Grimm, and Neugebauer (2015). The school-based apprenticeship constituted a 'contextually rich' concrete experience phase of the experiential learning cycle (Morris 2019), which is fundamental to contextualize domain knowledge and generate an individual absorptive capacity, both of which are enablers of such an experiential approach as CBL. This evidence brings new light to previous research (e.g. Smith 2002), confirming the complementarity between on-the-job training and off-the-job interventions. Figure 3 synthetizes how school-based apprenticeships can enable and be complemented by CBL, a hands-on approach that allows to complete the experiential learning cycle (Kolb 1984) in innovation labs of technical universities. The latter not only have the right environment and people to carry out CBL activities, but also the competency to design them based on multidisciplinary academic research.

[Figure 3 near here]

We argue that the lack of research activity in technical schools is one reason why they might fall short in effectively designing this kind of CBL interventions. This also applies to those post-secondary institutions, such as the Italian ITS, that have not followed the example of the *Fachochschulen*, which in 2016 started offering doctoral programs and carrying out research activities. As 'transdisciplinary research and research-based learning will increasingly be needed to tackle societal issues' (Giesenbauer and Müller-Christ 2020, p.1), an academic drift – as in Neave (1979) – of upper secondary and tertiary VET programs acquires greater importance. However, concerning execution, thanks to their regional proliferation both technical schools (for generalized upskilling of frontline workers) and ITS (for specific training of higher-skilled trades) can be key actors in bridging the gaps brought about by digitalization, as long as they engage in structured school-based apprenticeships and embrace the support of technical universities. A major implication that emerges with regard to middle-skill frontline workers, focus of this article, is the need to foster integration between technical universities and technical schools (e.g. Devedjiev et al. 2019; Ilomäki, Vasileva, and Stefanova 2020), creating bonds that ensure the employability of middle-skill entrants to the labor market not only in the current digital transformation, but in any future technological wave.

A new developmental role for technical universities

This study has allowed the authors to show how universities can contribute to society by transferring best practices and attractiveness to technical schools and middle-skill jobs. The initiative was fostered by a university to match specific skill and social needs that fall outside its boundaries, thereby constituting an example of the developmental role of the university (Gunasekara 2006). The intervention, carried out by researchers and professors who did 'a socially valuable use of their specific capabilities' and resources (e.g. the innovation lab) to help develop the weaker – i.e., smaller and less funded – technical schools, met all the 'developmental university' features listed by Arocena and Sutz (2007).

Carrying out participatory action research allowed the University to transfer research capabilities to the Company and the School, thereby increasing their ability to 'do research for themselves' (Kemmis, McTaggart, and Nixon 2014). In particular, transferring expertise on CBL to technical schools represented a further occasion of development: confirming the findings of Gaskins et al. (2015) and Ilomäki, Vasileva, and Stefanova (2020), we found that teachers need professional development and practical guidelines concerning the principles required to develop CBL activities and carry them out independently after the first practice transfer.

Through such an active participation in the final stage of technical upper secondary education, universities can play another developmental role for society: that of guidance, which could fix the mismatches between the workforce and the labor market. By allowing students to become familiar with the university environment (Veen et al. 2005), the intervention acted as a 'transition program' (e.g. Torenbeek, Jansen, and Hofman 2010), offered clearer expectations to talented lower-class students (Hilliger et al. 2018), and provided them with transferable skills to integrate and succeed at university (Georg 2009). This increased their awareness concerning the flexibility to either pursue higher-level studies or be prepared for employment (see Polidano and Tabasso 2016). In fact, some students confirmed their intention to work as smart-grid operators in the Company, and – thanks to insightful contacts with academics and technologies – the vocational path also regained attractiveness for those who did not intend pursuing a university career. Stronger technical schools, in step with latest research and truly aligned with a middle-level segment of the job market demand, could allow low-achieving VET students (see Jacob and Solga 2015) to start working at the end of high school (Haasler 2020) and make the pursue of a university path not mandatory to stay in the middle class – one of the pitfalls of academization. By means of such an integration with universities, technical schools can regain appeal and play an active role in society.

In summary, universities can review their developmental role by fostering the dissemination in technical schools of short-term, isolated and targeted CBL interventions, based on specific upskilling needs in the labor market. Involving technical universities in the 'gray area' between upper secondary and post-secondary technical education has benefits for companies, technical schools, and the universities themselves (Table 5).

[Table 5 near here]

Conclusions

Digitalization requires an upskilling of frontline workers, who now need greater digital literacy and interaction skills to perform their tasks and co-design innovation together with engineers and data scientists. Building such complex competency profiles in technical schools is a hard task, as updates of teachers, labs and technology are slower than in industry. However, a university degree is still unnecessary for middle-skill frontline workers and, on some occasions, even unwanted: companies need to balance their aging and retiring workforce with rapidly-available new workers, and lower socio-economic classes reclaim the possibility of being involved in fulfilling jobs with no further engagement in higher studies.

However, technical universities can still play a role in the middle-skills 'gray area', deploying their resources and research capabilities to strengthen upper secondary VET programs. Such a role is supported by two main considerations that contribute to literatures on knowledge creation and transfer by academics, and developmental university, respectively. First, education and training practices for middle-skill workers benefit from being increasingly based on technology and research, which is where non-university post-secondary VET providers might be failing. Through their wide range of multidisciplinary human and technological resources, technical universities can recombine diverse research-based knowledge to design effective CBL interventions. Second, universities can play an active developmental role in the middle-skills question – rather than engaging in a passive counterproductive academization – by interacting and integrating with technical schools and firms in order to transfer them new knowledge, teaching methods, and research capabilities. Such an integration can, in turn, be beneficial for the actors involved, as it can reduce competency gaps on the labor market, renew attractiveness for technical schools and occupations, and rationalize transitions toward higher education. This will need to be confirmed by extending the research through longitudinal studies on other students or employees. Indeed, a limitation of the work presented in this article is that of not having observed the long-term effects of this kind of intervention, and future research could test the potential of such formats not only for the upskilling of new entrants, but also for the reskilling of senior middle-skill workers.

In conclusion, the centrality of frontline middle-skill workers in the ongoing digital transformation is calling for innovation systems composed of firms, technical schools and technical universities, in which the latter can play a fundamental role in helping to close the middle-skills gap. With the increasing complexity brought about by digitalization, middle-skill workers will probably not need a degree. However, they might still need a university.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Table 1. Data collection stages.

	What	Date	Purpose
Cycle 1	School tutor interview 1	11/2018	Exploration of the Company's school-based apprenticeship
	Site visits and talks with HR	Between 11/2018 and 05/2019	Exploration of school-based apprenticeship and new competency needs
	Focus groups with HR managers and grid workers	06/2019	Investigation of the daily work transformations caused by digitalization
	Company tutor interview	06/2019	Investigation of competency needs
	School tutor interview 2	06/2019	Investigation of educational gaps
Cycle 2	Participant observation during the intervention	07/2019 09/2019	Understanding of the interaction with the university environment and the potential effects on knowledge, skills and attitudes
	Student survey (last day of each intervention)	07/2019 09/2019	Assessment of the perceived impacts on knowledge, skills, and attitudes, as well as on the value extracted from university resources
	School tutor interview 3	04/2020	Investigation of the medium-term impacts of the intervention

Note: the school tutor had a working experience of 20+ years, HR managers and grid workers 10-15 years.

Table 2. The emerging competency profile of smart-grid workers.

	Competency dimensions		
	Domain	**Transversal**	**Digital**
Knowledge	• Domain theory (automated systems, electrical machines and systems, electrotechnics) • Breakdown causes, functioning and equipment of secondary cabins	• Dynamics of innovation design processes • Economics of an innovation project (fundamentals)	• Fundamentals of IoT architectures • Basic statistics for data management
Skills	• Installation and inspections for network maintenance and repairs • Fast technical/operative decision making • Manual dexterity (assembly of IoT measurement tools) • Troubleshooting • Written technical communication	• Cost-benefit analysis • Creative problem solving • Interpersonal skills (e.g. effective communication with senior workers, persuasive communication of ideas and projects) • Team working	• Data interpretation and management (e.g. design of information flows) • IoT devices programming
Attitudes	• Conduct and organizational citizenship • Resilience to deal with stress and tight schedules • Sensitivity to safety issues	• Attitude toward deep and continuous learning • Eagerness of feedbacks • Proactivity • Propensity toward continuous improvement	• Being data-driven • Second-guessing and critical spirit on algorithm outcomes

Table 3. Coding of the interviews with the school-based apprenticeship tutors.

Limitations and opportunities for upper secondary VET programs	Facilities and technologies	• Companies need external laboratories and technologies • Digital technologies and the related competencies need to be updated in schools
	Stakeholders can shape the curricula	• Companies need new knowledge to be transferred • Schools have freedom to act on the curricula
Students' competencies	Benefits of the school-based apprenticeship	• Firm-specific knowledge and skills are provided • Students show more self-awareness, maturity, better conduct and a deeper learning approach compared to other students of the same age
	Skill gap	• No gaps on domain knowledge • Manual skills are not developed in the class • Weak analytical capabilities for troubleshooting • No statistics or digital skills are taught, only computer science; some IoT, but no specific skills on smart grids

Table 4. Perceived impacts of the two CBL interventions.

		Mean	St. Dev.	Mean A	Mean B	Difference
Knowledge (the students feel they know more about…)	Dynamics of innovation design processes	4.35	.73	4.20	4.57	.37
	Basic statistics for data management	4.12	.69	4.10	4.14	.04
	Economics of an innovation project	4.00	.78	3.85	4.21	.36
	The breakdown phenomena of secondary cabins	3.91	.83	3.75	4.14	.39
	'The challenge made me see the domain theory from a different point of view'	3.71	.76	3.45	4.07	.62**
	Functioning and equipment of secondary cabins	3.68	.84	3.35	4.14	.79***
	Fundamentals of IoT architectures	3.68	1.12	3.65	3.71	.06
	'The challenge made me better contextualize what I saw at school'	3.09	.83	2.75	3.57	.82***
Skills (the students feel they are better at…)	Effective communication with experienced people	4.24	.74	4.20	4.29	.09
	Team working	4.21	.73	4.20	4.21	.01
	Creative problem solving	3.97	.94	3.85	4.14	.29
	Fast technical/operative decision making	3.97	.67	3.85	4.14	.29
	Troubleshooting	3.91	.71	3.75	4.14	.39
	Written technical communication	3.79	.84	3.75	3.86	.11
	Persuasive communication of ideas	3.71	.72	3.75	3.64	-.11
	Interpretation and management of data from measurement tools	3.71	.76	3.75	3.64	-.11
	Oral project presentations	3.71	.91	3.60	3.86	.26
	Cost-benefit analysis	3.41	.89	3.20	3.71	.51*
	Manual dexterity with IoT measurement tools	3.38	.85	3.45	3.29	-.16
	IoT device programming	3.03	1.17	2.80	3.36	.56
Attitudes (the students express an increased…)	Proactivity	3.85	.71	3.73	4.04	.31
	Eagerness of feedbacks	3.82	.80	3.90	3.71	-.19
	Propensity toward continuous improvement	3.75	.59	3.64	3.91	.27
	Learning orientation	3.58	.71	3.40	3.84	.44*
	Resilience to deal with stress and tight schedules	3.44	.93	3.25	3.71	.46

Note: the values are expressed in a 1-5 scale (1 = strongly disagree, 5 = strongly agree). ANOVA *(p<0.01), **(p<0.05), ***(p<0.10).

Table 5. Benefits of active involvement of technical universities in the 'gray area'.

Stakeholder	Main benefits for each stakeholder
Companies	• Regained attractiveness of middle-skill jobs • Frontline workers ready for the digital transformation • Acquisition of innovative training methods
Technical schools	• Regained attractiveness of upper secondary VET • Empowerment of VET low-achievers • Acquisition of innovative teaching methods and technologies
Technical universities	• More 'informed' enrolments of motivated VET high-achievers • Less 'uninformed' enrolments potentially destined to dropouts • Testing the practicality of innovative teaching methods

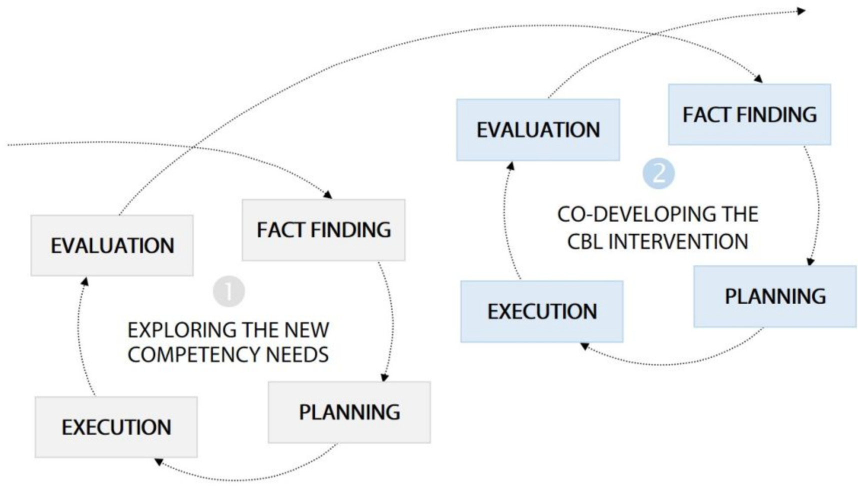

Figure 1. The two cycles of participatory action research.

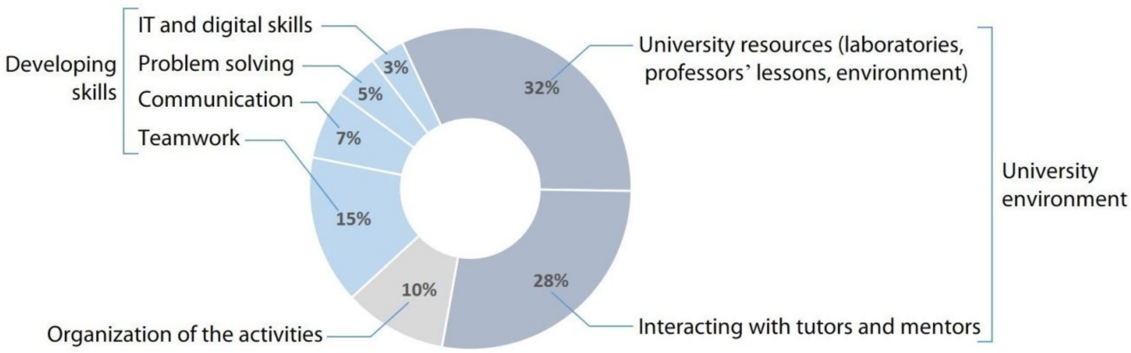

Figure 2. Positive aspects of the intervention (student survey open comments).

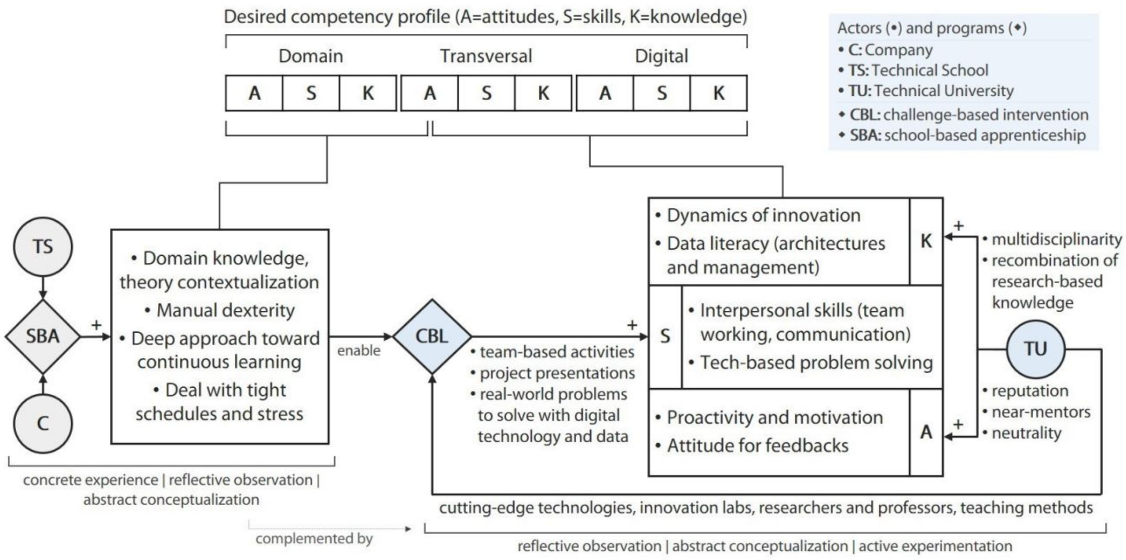

Figure 3. The challenge-based intervention: complementarity with on-the-job training and the role of the university.

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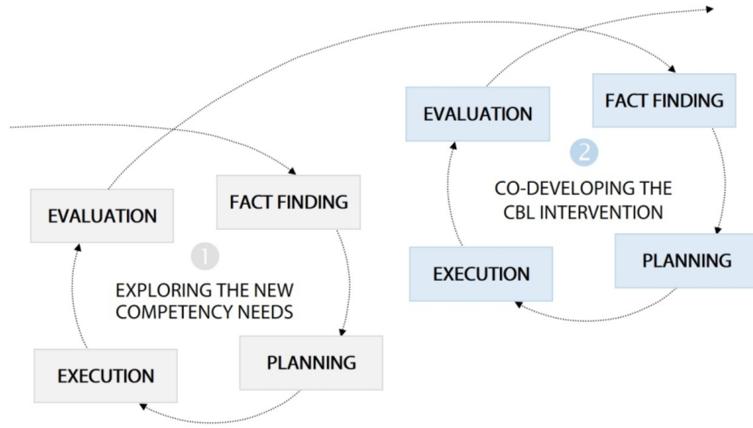

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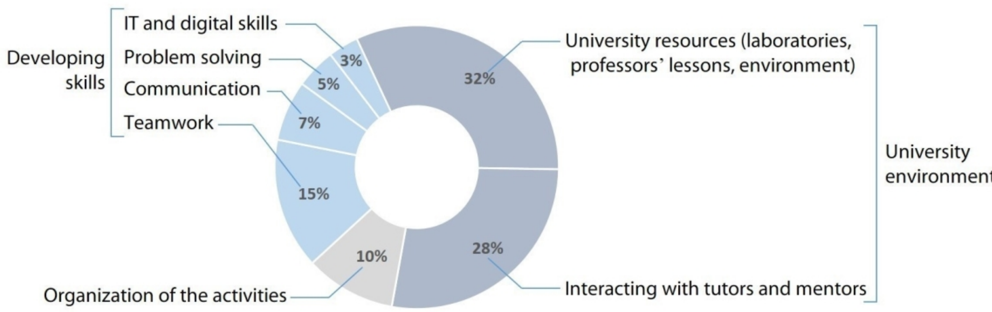

Figure 2. Positive aspects of the intervention (student survey open comments).

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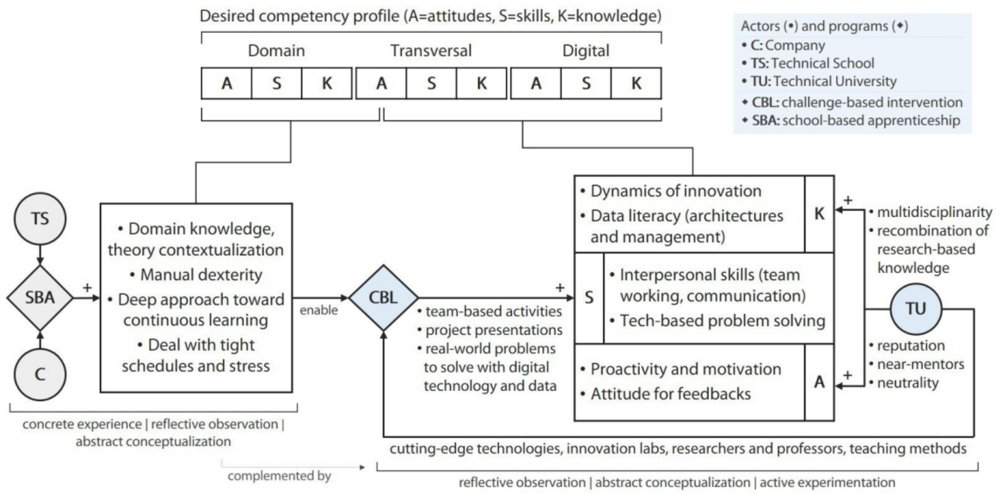

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425x214mm (96 x 96 DPI)