Relationships between competences and Lean Automation practices: an exploratory study

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Abstract

Lean Automation (LA) is defined as the combined use of Lean Production (LP) practices and Industry 4.0 (I4.0) technologies. This paper investigates the pairwise relationships between the LA practices and their corresponding implementation competences. A survey-based study with 110 practitioners from manufacturing companies was conducted. Multivariate data techniques were used to analyze the responses, which were categorized according to practitioners' LP experience and I4.0 knowledge. Findings indicate that the relationships between competences and LA practices become more prominent as practitioners' LP experience increases. A contrary trend was observed when I4.0 knowledge increases. Nevertheless, commonalities were found regardless respondents' characteristics, such as: (*i*) the significant relationships between LA practices and competences were all positive; (*ii*) supply chain-related LA practices are more likely to be extensively associated with all competences; and (*iii*) competences related to the ability of identifying, analyzing and solving problems through computer programming and data analytics were the most likely to support LA practices. To the best of our knowledge, this is the first study that empirically verifies the pairwise relationship between competences and LA practices. The understanding of this allows companies to foster and develop the proper competences on the employees, catalyzing the LA implementation.

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Abstract

Lean Automation (LA) is defined as the combined use of Lean Production (LP) practices and Industry 4.0 (I4.0) technologies. This paper investigates the pairwise relationships between the LA practices and their corresponding implementation competences. A survey-based study with 110 practitioners from manufacturing companies was conducted. Multivariate data techniques were used to analyze the responses, which were categorized according to practitioners' LP experience and I4.0 knowledge. Findings indicate that the relationships between competences and LA practices become more prominent as practitioners' LP experience increases. A contrary trend was observed when I4.0 knowledge increases. Nevertheless, commonalities were found regardless respondents' characteristics, such as: (*i*) the significant relationships between LA practices and competences were all positive; (*ii*) supply chain-related LA practices are more likely to be extensively associated with all competences; and (*iii*) competences related to the ability of identifying, analyzing and solving problems through computer programming and data analytics were the most likely to support LA practices. To the best of our knowledge, this is the first study that empirically verifies the pairwise relationship between competences and LA practices. The understanding of this allows companies to foster and develop the proper competences on the employees, catalyzing the LA implementation.

Keywords: Lean Automation, Competences, Lean Production, Industry 4.0.

1. Introduction

Driven by the start of the fourth industrial revolution, many companies have initiated their digital transformation by incorporating disruptive technologies (e.g. Internet-of-Things, cloud computing and big data analytics) into their management processes (Xu et al., 2018). The technology-oriented approach from Industry 4.0 (I4.0) may change not only the way products, processes and services are designed, performed and delivered, but also the required competences of the individuals (Lorenz et al., 2015; Tortorella et al., 2018). Hence, the integration of I4.0 into a company's management approach affects both the technical (e.g. practices, technologies, work routines) and sociocultural (e.g. behaviors, leadership, organizational culture) aspects of the organization (Sony and Naik, 2020).

At the same time, Lean Production (LP) has been acknowledged during the last four decades as a strategic management approach to continuously improve organizations (Stone, 2012; Leite et al., 2020). Due to the reported benefits, LP became very popular among practitioners and researchers, motivating many studies on the aspects that support its successful implementation (Jasti and Kodali, 2015). As LP excels for simple solutions derived from continuous experimentation and problem-solving activities (Womack and Jones, 2003), researchers (e.g. Bortolotti et al., 2015; Tortorella and Fogliatto, 2017; van Dun et al., 2017) have given great emphasis on the behavioral aspects that surround it. More specifically, because individuals' behaviors play a key role for sustaining LP in the long term, the underlying competences of LP have been a point of concern (Parry et al., 2010; Seidel et al., 2017).

The recent integration between I4.0 and LP has been denoted as Lean Automation (LA). The term LA was first proposed in mid 1990s, but its utilization has gained more prominence after the advent of I4.0 (Kolberg et al., 2017; Ma et al., 2017). LA represents an integrated approach that combines the technological enablers from I4.0 with the practices and principles from LP. It is noteworthy that other terms have also been used to refer to this integration between I4.0 and LP, such as 'Lean 4.0' and 'Digital Lean'. The former expresses in the broadest sense how the combination of the principles of LP with I4.0 are implemented together at different levels of the organization, in terms of process optimization, strategy implementation, technology adoption and organizational change (Mayr et al., 2018; Arcidiacono and Pieroni, 2018; Perico and Mattioli, 2020; Bittencourt et al., 2020). The latter indicates a new way to understand the concept of production according to which, the use of new digital technologies enhances access, analyzes and interprets massive amounts of data to detect, corrects, predicts and prevents production process behavior, thus avoiding the generation of waste and inefficiency (Powell et al., 2018; Romero et al., 2019a; 2019b; Raweewan and Kojima, 2020). The difference between LA, Digital Lean and Lean 4.0 is blurred, and the terms are often considered synonymous by practitioners and researchers. Indeed, the core idea of combining I4.0 and LP is shared by the studies that use these terms.

The investigation of how companies can benefit from such combination has been a growing research topic (Buer et al., 2018a; Tortorella and Fettermann, 2018; Bittencourt et al., 2020). Nevertheless, most studies have focused on the technical side of LA (e.g. synergy between technologies and management practices), neglecting the social implications (Pagliosa et al., 2019; Villalba-Diez et al., 2019) such as the required implementation competences. Similarly to LP, LA implementation requires certain individual competences. However, the relationship between LA practices and their corresponding competences has not yet been explored in the literature. Furthermore, as LA encompasses technological aspects derived from I4.0, there might be additional competences to be considered besides the usual LP competences which reinforces the relevance of the research gap.

To fulfil this gap, this study aims at examining how the LA practices are related to their implementation competences, which are interpreted as those arising from the joint use of LP and I4.0. We surveyed 110 Brazilian practitioners who were experienced in LP and aware of I4.0. They were asked to indicate the adoption level of LA practices (Tortorella et al., 2020a) and the perceived level of the competences of LP (Seidel et al., 2017) and I4.0 (Hecklau et al., 2016; Grzybowska and Łupicka, 2017; Łupicka and Grzybowska, 2018) on middle managers of their corresponding companies. Because the identification of this relationship is highly dependent on respondents' perception and expertise, we categorized them according to their LP experience and I4.0 knowledge. Responses were then analyzed through multivariate data techniques, and communalities among the analyses were sought to grasp the most relevant pairwise relationships. The contribution of this research is two-fold. First, it provides initial evidence on the competences that support the LA implementation, which is a social aspect under explored in the literature. Second, the identification of the pairwise relationships between competences and LA practices allows companies to establish training and development plans for their leaders.

2. Literature review

2.1. Lean Automation

The notion of LA first emerged by combining LP practices to Computer Integrated Manufacturing technologies (Kolberg et al., 2017). However, even if the idea of integrating automation with LP is inherent in the lean thinking fundamentals - as clearly demonstrated by the concept of autonomation (Ohno 1988) - not much attention has been paid to it (Bortolotti and Romano, 2012; Kolberg and Zühlke, 2015) until the acknowledgement of the Fourth Industrial Revolution. I4.0 has given renewed relevance to LA, whose implications are still under investigation (Yamazaki et al., 2016; Tortorella and Fettermann, 2018).

Many conceptualizations of LA are found in the literature (e.g. Yamazaki et al., 2017; Shigematsu et al., 2018; Pantano et al., 2020). Jackson et al. (2011) defined LA as the application of automation to a given activity or process, stressing robust and reliable components and minimizing overly complicated solutions. LA favors decentralized management, aiming at modular and simple arrangements (Ma et al., 2017) with higher changeability and shorter information flows (Kolberg et al., 2017). Furthermore, most of the developed LA solutions are proprietary and as such they need to be customized to individual needs (Kolberg et al., 2017).

Several theoretical (Buer et al., 2018b) and empirical LA applications (Powell et al., 2017) have been proposed, both covering different dimensions of LP, including but not limited to JIT (Chen and Lin, 2017), Jidoka (Romero et al. 2019b) and Human Resource Management (Romero et al., 2020). An example of application is found in Spenhoff et al. (2020), which adapted the production levelling (a.k.a. *heijunka*) to the semi-process industry combining it with cyber-physical systems technologies. This allowed scheduling the production system as efficiently as possible, providing the necessary flexibility and minimum schedule perturbation. Another instance of application is shown in Pozzi et al. (2021), which conducted case studies in companies implementing I4.0 as a support for their continuous improvement initiatives.

The technological choices facing manufacturers are multiple and non-trivial as the industry contemplates the increasing levels of digitization and automation in readiness for the modern competitive age (Hughes et al., 2020). However, not only do the applications refer to the shopfloor but they are also extended to the supply chain level. For instance, Sony (2018) indicated the role LA plays in the vertical, horizontal and end-to-end integration of companies, suggesting a theoretical framework based on the main LP principles and I4.0 technologies. Fatorachian and Kazemi (2021) explored the impact of I4.0 on supply chain performance, while Kucukaltan et al. (2020) indicated possible changes in the logistics industry from the operational, financial, and human resources aspects. Based on a cross-sector survey performed with 147 manufacturers, Tortorella et al. (2020a) proposed a framework for LA implementation with 31 practices (see Table 1). This framework resulted from the empirical identification of significant pairwise relationships between Shah and Ward's (2007) LP measures and I4.0 technologies (National Confederation of Industry Brazil, 2016).

Another point of interest for research concerns the evolutionary process undertaken by companies implementing LA. These companies seem to initially present a more LP-oriented approach and, as the implementation advances, the focus shifts to merging technological solutions to LP practices (Chiarini and Kumar, 2020; Tortorella et al., 2021a). Mora et al. (2017) highlight how companies that undertake LA progressively shift their focus from hard to soft LP practices, moving from the automation of assets to automated systems supporting production and logistics processes, as well as employee training, involvement and problem-solving support.

Table 1 – LA practices (adapted from Tortorella et al., 2020a)

2.2. LP and I4.0 competences

Boyatzsis (2008) defines a competency as a capability and describes it as a set of related but different behaviors organized around intentions. Behaviors are manifestations of the intent, as appropriate in various situations. Marrelli (1998) adds that a competence involves measurable knowledge, skills, traits and behaviors that allow an individual to effectively perform a task. While skills are the specific learned abilities that you need to perform a given job well, competences, on the other hand, are the person's knowledge and behaviors that lead them to be successful in a job (McNeill, 2019).

LP competences are those required for the implementation of lean systems (Parry et al., 2010). These competences are particularly important to those professionals holding formal or informal leadership roles, as these may coach others in the company and facilitate the dissemination of the expected behaviors and mental models (Bortolotti et al., 2015; Camuffo and Gerli, 2018). According to Yukl (2010), the acquisition and deployment of competences depend on three main factors: personal attributes, management systems that allow for the use of the competences, and organizational context. Seidel et al. (2019) discuss how these three factors play out in lean leadership. For instance, personal attributes of lean leaders include humility, honesty, and discipline. An example of mechanism of influence adopted in lean systems refers to shop floor daily management meetings supported by visual devices. In turn, relevant organizational context can account for the level of education of the workforce and company's size. Seidel et al. (2017) identified, based on a literature review and interviews with experts, key competences of lean leaders. Those authors carried out a survey with 91 companies and found that the use of those competences was positively associated with the development stage of the lean system.

With regards to I4.0, a few works have explored the required competences to cope with the challenges related to its new technologies and processes. Hecklau et al. (2016) developed an I4.0 competence model composed of four categories of competences: (*i*) technical, (*ii*) methodological, (*iii*) social and (*iv*) personal. Grzybowska and Łupicka (2017) proposed eight core managerial competences to support I4.0 adoption. Łupicka and Grzybowska (2018) refined the study by re-classifying those competences in three categories (social, technical and managerial) and comparing the expectations of practitioners, scientists, and students. Pinzone et al. (2017) focused on the evolution of technical skills in the I4.0 context, providing qualitative insights raised from a variety of manufacturers in Northern Italy.

LP and I4.0 competences present a certain level of overlap, especially with respect to social competences. In turn, there are relevant differences on the technical competences, since I4.0 literature emphasizes data analytics competences. For the purpose of assessing the relationships between the LA practices and competences, we adapted and consolidated in Table 2 the competences of LP, proposed by Seidel et al. (2017) and Camuffo and Gerli (2018), and I4.0, derived from Hecklau et al. (2016), Grzybowska and Łupicka (2017) and Łupicka and Grzybowska (2018). These 14 competences provide the basis for our study, whose theoretical model is displayed in Figure 1. It is worth noting that these 14 competences were combined into one main dimension, namely LA competences, following the rationale that LA integrates I4.0 technologies into LP practices (Tortorella et al., 2021b).

Table 2 – LP and I4.0 competences

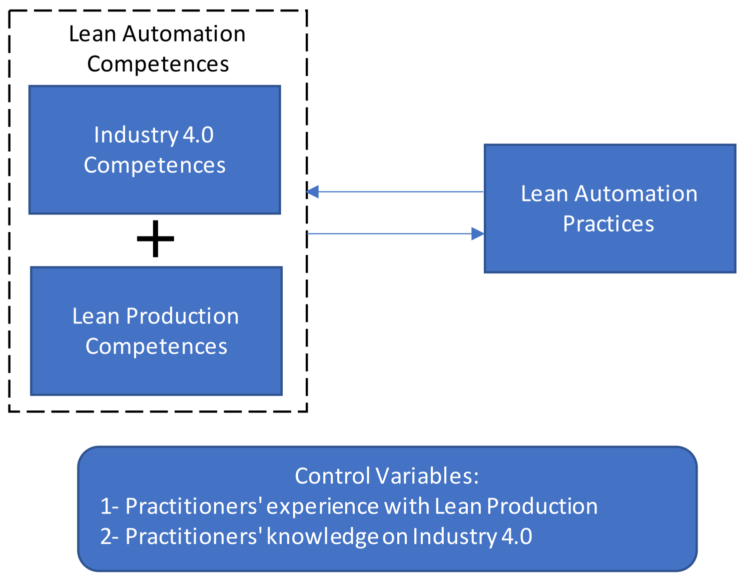

Figure 1 – Theoretical model investigated

3. Method

3.1 Research strategy

This research examines how the LA competences, which stem from LP and I4.0, relate to LA practices. As this is an exploratory research, we adopted an empirical approach as part of the methodological procedure, which allows obtaining knowledge through direct and indirect observation or experience (Goodwin, 2005). To collect data and quantify the empirical evidence, we adopted the survey method with non-random choice of respondents. The survey method presents many advantages, such as high level of representativeness, low cost, good statistical significance, and a standardized stimulus to all respondents (Montgomery, 2013). Hence, the proposed method was comprised of three main steps: (*i*) instrument development, (*ii*) sample selection and data collection, and (*iii*) data analysis. These steps are subsequently detailed.

3.1. Instrument development

The questionnaire had three parts. Initially, we collected data on respondents' profile (role, years of lean experience and I4.0 knowledge) and their organizations (tier level, size and sector). Guidelines were provided to respondents to help them define their own level of knowledge on I4.0, in order to reduce subjectivity. We asked respondents to rate themselves as basic (i.e. they were able of describing what the main I4.0 technologies are and their benefits, in general terms, without further deepening) or moderate/advanced (i.e. they could engage in a technical discussion about I4.0 adoption or lead its adoption in multiple contexts). Then, in the second part of the questionnaire, respondents were asked to indicate the adoption level of the 31 LA measures proposed by Tortorella et al. (2020a) in their organizations (see Table 1). For that, we used a five-point Likert scale, ranging from 1 (not used) to 5 (fully adopted). In the third part of the questionnaire, we consolidated the sixteen LP competencies proposed by Seidel et al. (2017) into twelve, since we interpreted that four of them were more properly related to LP principles instead LP competences. Then, we combined the LP competences with the I4.0 competences suggested by Hecklau et al. (2016), Grzybowska and Łupicka (2017), and Łupicka and Grzybowska (2018), displayed in Table 2. Respondents were asked to indicate in a 5-point scale (1 for 'not developed' and 5 for fully developed) the level of those competences considering middle managers in their companies. According to Holmemo and Ingvaldsen (2016), van Dun et al. (2017) and Tortorella et al. (2019), middle managers play a key role in executing the strategic guidelines and implementing the improvement initiatives.

Hence, their competences are relevant for the success of a lean implementation, justifying the focus on this role.

Two senior academicians (> 20 years working with LP) and one experienced practitioner (> 10 years) pre-tested the instrument to verify its face and content validity (Kothari, 2004). These experts recommended a few changes in taxonomy and wording of the questions. Additionally, some procedures were performed to curb potential common method variance (Huber and Power, 1985). Regarding the design of the questionnaire, dependent variables were displayed far from independent ones (Podsakoff and Organ, 1986). An initial statement informing about the anonymous and confidential nature of the study, and the fact that there were no right answers was inserted in the questionnaire (Podsakoff et al., 2003).

3.2. Sample selection and data collection

A non-random approach with predefined selection criteria was used for sampling (Smith, 1983). The utilization of non-random respondents that meet certain criteria to collect data and quantify empirical evidence is a common approach in similar studies (e.g. Tortorella et al., 2020a; 2021), and can help answering research questions whose topic is still at its early stages. Respondents should be experienced in LP and aware of I4.0 technologies. Due to the limited amount of companies adopting both LP and initiated at I4.0 (Tortorella and Fettermann, 2018), we included companies from different industrial sectors in the sample. Additionally, even though LP implementation is more common in high-volume and discrete-parts manufacturers, Marodin et al. (2015) highlighted that the pervasiveness of its practices across different industries is not known, justifying the cross-industry sample.

Because the researchers have already developed a large network with organizations through previous collaboration activities (e.g. consultancy, research and education), the identification of potential respondents was facilitated. A pre-selection was carried out by identifying potential respondents among people with both theoretical and practical experience in LP and at least the theoretical basis on automation. The questionnaire was initially sent to 658 practitioners from companies located in Brazil during October and November 2020. From those, 110 responses were received, resulting in a response rate of 16.7%. As shown in Table 3, 56.4% of the sample was from companies with less than 500 employees and from tiers 1 or 2 in their respective supply chain. Participants were predominantly from the chemical and automotive sectors. The majority of respondents were engineers or analyst in their companies (38.2%), and claimed to have a moderate or advanced knowledge on I4.0 (51.8%). In terms of LP experience, the sample was perfectly balanced between those who had more than 5 years of experience and the ones with less than 5 years.

As an additional verification for common method bias, we conducted a statistical analysis using Harman's single-factor test (Malhotra et al., 2006) including all study measures. Results pointed to a first factor explaining 29.6% of the total variance, which indicated that no single factor accounted for most of the variance in responses. Thus, we disregarded issues related to common method bias.

Table 3 – Sample characteristics

3.3. Data analysis

Due to our study's purpose, a set of partial correlation analyses for each pairwise relationship between competences and LA practices was conducted. Partial correlations allow to control the effect of the remaining items on the pairwise analysis of a given pairwise relationship (Baba et al., 2004). Partial correlations assess the intensity of the linear relationship between two items, also considering their association with the other variables. This approach is specifically proper for cases in which the relationship between two items may be affected by their relationships with the remaining ones (Legendre and Legendre, 2012). This method enabled the investigation of the relationship between all possible pairwise combinations between competences and LA practices. It is important to mention that the effect of multicollinearity on the estimated coefficients was verified through the variance inflation factors (VIF) for all variables, whose results were all below 5, indicating that multicollinearity was not an issue (Belsley et al., 2005).

This approach was applied to both respondents' LP experience and I4.0 knowledge. For LP experience, respondents were divided into low-experienced (< 5 years) and high-experienced (> 5 years). For I4.0 knowledge, we divided the sample into respondents who claimed having a basic knowledge and the ones who indicated a moderate or advanced knowledge on I4.0. Thus, four partial correlation analyses for the 14 competences and 31 LA practices were undertaken, totaling 1,736 pairwise analyses investigated. The sample's mean values and standard deviation for the competences and LA practices according to each level are presented in Appendix.

4. Results

Table 4 shows the results for partial correlations between LA competences and LA practices for less experienced (< 5 years) respondents on LP implementation. From 434 possible correlations, 385 significant and positive partial correlations (p-value < 0.05) were found. From the 31 LA practices, 15 were significantly correlated with all the 14 competences. In opposition, practice la_{21} (*extensive use of statistical techniques to reduce process variance through digital sensors and remote control of production integrated with collaborative engineering systems, which identify abnormal product/operating conditions*) was the one with the lowest number of significant partial correlation coefficients with the competences (5 in total). This may be due to the narrow applicability of this LA practice, which implies a narrow set of corresponding competences.

In terms of competences, 4 out of 14 (c_2, c_{12}, c_{13} and c_{14}) were partially correlated with all LA practices, while c_8 (*identify and manage barriers during improvement initiatives implementation journey*) was the least correlated competence (16 in total). This can result from the wide scope of this competence, which is useful for the LA implementation project as a whole, while having a diffuse and weak relationship with specific LA practices.

It is also worth mentioning that we found only four strong pairwise partial correlations, whose coefficients were greater than 0.7 (Baba et al., 2004). Two of them involved c_{13} (*develop data processing and analytics*) and the other two encompassed c_{14} (*put in practice statistical tools*), which are competences derived from I4.0.

Table 5 displays the partial correlation coefficients when utilizing data from respondents more experienced in LP (> 5 years). The number of significant partial correlations increased from 385 to 395, and twelve strong correlations were found between six LA practices and seven LA competences. Regarding LA practices, 12 out of 31 had significant coefficients with all the 14 competences, while la_{20} (*large number of equipment/processes on shop floor are currently under statistical process control and monitored through digital sensors integrated into collaborative engineering systems*) was correlated with only 7 competences. Interestingly, practices la_5, la_6 and la_9 presented three strong partial correlations each. With respect to competences, four of them (c_1, c_5, c_{11} and c_{13}) were significantly correlated with all LA practices, and c_9 (*practice continuous improvement as an interrelated system of principles and practices*) was the least pervasive one being significantly correlated with 19 practices. Competence c_5 (*provide value-added information clearly and objectively*) was involved in three strong partial correlations with LA practices.

Table 4 – Partial correlation between LA practices and competences using perceptions of practitioners with less than 5 years of LP experience (n = 55)

Table 5 – Partial correlation between LA practices and competences using perceptions of practitioners with more than 5 years of LP experience (n = 55)

When considering I4.0 knowledge as the control variable, results were slightly different. Table 6 reports the partial correlation coefficients for the analysis using respondents with basic knowledge on I4.0. 399 significant coefficients were found (91.9% of total pairwise relationships), which was the highest total number of significant partial correlations among the four analyses performed. However, only one strong partial correlation was obtained.

Fourteen LA practices were significantly correlated with all LA competences. Similarly to what was found in the analysis with respondents less experienced with LP, la_{21} was the practice with the lowest number of significant correlations with competences (8 in total). As for competences, half of them were correlated (p-value < 0.05) with all LA practices. The one with the lowest number of significant correlations was c_9, which was also observed in the results obtained for practitioners with more than 5 years of LP experience.

Finally, Table 7 shows the outcomes for the partial correlation analysis using responses from practitioners that had moderate or advanced knowledge on I4.0, according to their self-assessment. In total, 339 significant partial correlations were obtained (78.1% of possible pairwise correlations), which was the lowest number among all four analyses. Five LA practices were correlated with all competences, while la_{20} was seems to be correlated with only three which is similar to what was found in the analysis with more LP experienced respondents. In terms of competences, only c_{14} was correlated with all LA practices, while c_{10} (*develop* *actions that, based on ethical principles, respect the community, the environment and the workers' safety*) had a significant correlation with fourteen practices. Two strong partial correlation coefficients were found.

Table 6 – Partial correlation between LA practices and competences using perceptions of practitioners with Basic knowledge on I4.0 (*n* = 53)

Table 7 – Partial correlation between LA practices and competences using perceptions of practitioners with Moderate or Advanced knowledge on I4.0 (*n* = 57)

5. Discussion

Results for the pairwise relationships between LA competences and practices appear to have contrary trends when considering respondents' background. On one hand, as respondents' LP experience increases, the intensity of such relationships seems to increase as well. Not only the number of significant correlations was larger, but also the number of strong correlations. Experienced practitioners tend to be more prepared to judge not only the tangible aspects of a lean implementation, such as the adoption level of LA practices (Plonka, 1997; Wickramasinghe and Wickramasinghe, 2020; Tortorella et al., 2020b), but also the presence of intangible and more subtle factors (Carleysmith et al., 2009; Jayaraman et al., 2012), such as the competences of their companies' middle managers. Our findings corroborate to that. Further, the perception of respondents who are more experienced in LP seems to be comprehensive and systems-oriented, since 30 out 31 LA practices were supported by at least 10 out of the 14 competences. This suggests that, according to these respondents' perception, the implementation of LA practices is positively associated with a diversity of competences either from LP or I4.0.

On the other hand, when respondents' I4.0 knowledge is higher, the relationship between competences and LA practices is less evident. This outcome may be due to an overly technical view of I4.0, which tends to be more reductionist than the systems-oriented LP perspective. Another possibility is that more knowledgeable I4.0 practitioners are more likely to have a more critical perspective of competences and practices associated with I4.0. This interpretation can be associated with May and Kruger's (1988) indications, which were later explored in the organizational context by Thompson and Martin (2010). These authors propose four stages of competence development: (*i*) unconsciously incompetent, (*ii*) consciously incompetent, (*iii*) consciously competent and (*iv*) unconsciously competent. Practitioners with moderate or advanced I4.0 knowledge might be more critical about their opinions, leading to more conservative results for the pairwise relationship between competences and LA practices. Regardless respondents' LP experience and I4.0 knowledge, several commonalities were found in the pairwise relationships between competences and practices. First, all significant partial correlations had positive coefficients, which indicates the positive correlation between the competences and practices. This converges to the indications from Raweewan and Kojima (2020), which highlight the need for developing additional skills for the proper digitalization of LP. Second, as shown in Table 8, 324 pairwise relationships were found significant in all four analyses, suggesting that they occur independently of the respondents' characteristics. There seems to be a consensus that practices la_3, la_5, la_6 and la_9 are correlated with all competences. All these LA practices are supply chain-oriented; i.e. they help improving the relationship with either suppliers or customers. In terms of competences, c_2, c_{12}, c_{13} and c_{14} were the ones with the highest number of similar significant correlations considering all four analyses. While c_2 derives from LP (Seidel et al., 2019), c_{12}, c_{13} and c_{14} originate from I4.0 (Hecklau et al., 2016; Grzybowska and Łupicka, 2017; Łupicka and Grzybowska, 2018). In common, they refer to individual's ability of identifying, analyzing and solving problems through robust methods. This emphasizes the relevance of developing such competences in middle managers of companies undergoing a LA implementation. Such finding is aligned with indications from Spear (2004; 2008), which stresses the need for training lean leaders to be good problem-solvers. Our results build on this by incorporating computer programming- and data analytics-related competences as a support for the digitization required by the LA implementation. Therefore, we can summarize the main findings of our research as follows:

a) All significant pairwise relationships between LA practices and LA competences were positive;
b) Supply chain-related LA practices are more likely to be extensively associated with all competences. This may stem from the complexity of supply chain management, which involves coordination between a number of diverse stakeholders, often under conditions of uncertainty; and
c) Competences related to the identification, analysis, and problem-solving through methods that incorporate computer programming and data analytics were the ones mostly associated with LA practices.

Table 8 – Consolidation of the pairwise partial correlation between LA practices and competences

6. Conclusions

This study aimed at investigating the pairwise relationships between LA competences and LA practices. Responses from 110 practitioners were classified according to two respondents' characteristics: LP experience (i.e. < 5 years and > 5 years) and I4.0 knowledge (i.e. basic and moderate/advanced). Four partial correlation analyses were performed, being one for each level of each characteristic.

From a theoretical perspective, our study provides initial evidence on the competences that support the LA implementation. Since the integration of I4.0 technologies into LP practices is a recent phenomenon, literature on this matter is still scarce. Our results indicate that LA is associated with the same competences of LP but requires the addition of specific I4.0 competences such as 'c_{13}-develop data processing and analytics' and 'c_{14}-put in practice statistical tools'. Although LP implementation already stressed the need for problem-solving competences, with the integration of I4.0 technologies the amount of data collected, stored, shared, processed and analyzed significantly increases, demanding the development of more sophisticated competences to manage it. Hence, certain competences that so far had only been mentioned in I4.0 studies were significantly correlated with LA practices, evidencing that the implementation of LA practices requires I4.0 competences. This finding suggests that, although LA derives from LP, its approach has some specificities that may represent the next production paradigm.

With regards to practical contributions, our research provides companies some guidance on the competences necessary to an effective LA implementation. The identification of the pairwise relationship between LA competences and LA practices allows companies to customize the development of their staff, especially middle managers, so that they present the competences that are more likely to support the desired LA practices. Since some competences may require a long time to be developed, our results allow companies to anticipate potential issues based on the focus of their LA implementation, thus providing managers guidelines that help them anticipate which individual competences are necessary to successfully adopt the LA practices of interest. Additionally, it was observed that when companies are seeking LA implementation at a supply chain level, the adoption of the corresponding practices may demand a diversified set of competences. This must draw the attention of management so that they can assess whether they have settled the proper competences before expending any effort.

This work has some limitations that are worth mentioning. The competences encompassed here derived from previous studies on both LP and I4.0. However, as the understanding on LA implementation advances, there might be need for additional competences. To investigate that, it is recommended the development of longitudinal studies in which researchers could verify the need for further competences as the LA is implemented. Moreover, companies may not be able to concomitantly develop all competences to support LA implementation. Because our study did not provide any evidence on the interrelationship among the competences, future studies should check whether there is a precedence of competences; i.e. a development sequence of the competences that would favor a smoother LA implementation. Another opportunity refers to a potential moderating effect of the control variables (LP experience and knowledge on I4.0) on the relationship between LA practices and competences. Future studies could analyze such moderation to check whether there is any significant differences between the categories of each control variable, which was not addressed here. Finally, although we carefully managed the data to avoid common method bias, larger sample sizes with diversified contextual characteristics would allow the utilization of more sophisticated data analysis techniques (e.g. structural equations modelling). This could lead to additional findings that were not able to be raised with our approach.

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Table 1 – LA practices (adapted from Tortorella et al., 2020a)

	LA practices
la_1	Suppliers are directly involved in the new product development process through integrated and collaborative engineering systems, such as Manufacturing Execution System (MES), Supervisory Control and Data Acquisition (SCADA) and digital sensors.
la_2	Our key suppliers deliver to plant on Just-In-Time (JIT) aided by remote control of production, digital interfaces and Internet-of-Things (IoT).
la_3	We have a formal supplier certification program supported by digital automation without sensors.
la_4	Our suppliers are contractually committed to annual cost reductions by identifying abnormal product/operating conditions through sensors and IoT.
la_5	We have corporate level communication on important issues with key suppliers aided by integrated digital interfaces and engineering systems through IoT.
la_6	We take active steps to reduce the number of suppliers in each category using collaborative engineering systems.
la_7	We evaluate suppliers on the basis of total cost and not per unit price, identifying their product/operating conditions by means of digital sensors.
la_8	Our customers are actively involved, through digital interfaces and remote control of production, in current and future product offerings.
la_9	Our customers are directly involved in current and future product offerings through utilization of process-oriented technologies, such as digital automation, remote control sensors and integrated engineering systems.
la_{10}	Our customers frequently share current and future demand information with marketing department utilizing integrated digital interfaces and engineering systems with sensors.
la_{11}	Production is pulled by the shipment of finished goods through integrated and collaborative systems.
la_{12}	Production at stations is pulled by the current demand of the next station through integrated and collaborative systems.
la_{13}	Products are classified into groups with similar processing requirements through integrated and collaborative engineering systems.
la_{14}	Products are classified into groups with similar routing requirements through integrated and collaborative engineering systems.
la_{15}	Equipment is grouped to produce a continuous flow of families of products through integrated and collaborative engineering systems.
la_{16}	Families of products determine our factory layout through integrated and collaborative engineering systems.
la_{17}	Our employees practice setups to reduce the time required supported by collaborative engineering systems.
la_{18}	We are working to lower setup times in our plant utilizing integrated engineering systems.
la_{19}	We have low set up times of equipment in our plant, which are monitored by digital sensors integrated into collaborative engineering systems, obtained through utilization of additive manufacturing and augmented reality.
la_{20}	Large number of equipment/processes on shop floor are currently under statistical process control and monitored through digital sensors integrated into collaborative engineering systems.
la_{21}	Extensive use of statistical techniques to reduce process variance through digital sensors and remote control of production integrated with collaborative engineering systems, which identify abnormal product/operating conditions.
la_{22}	Charts showing defect rates are used as tools on the shop floor aided by digital interfaces integrated into collaborative engineering systems.
la_{23}	We use fishbone type diagrams aided by collaborative engineering systems to identify causes of quality problems.
la_{24}	We conduct process capability studies aided by collaborative engineering systems before product launch.
la_{25}	Shop floor employees drive suggestion programs utilizing machine digital interfaces integrated into collaborative engineering systems by means of IoT.
la_{26}	Shop floor employees lead product/process improvement efforts based upon digital sensors, remote control of production and collaborative engineering systems.
la_{27}	Shop floor employees undergo cross functional training utilizing digital interfaces, remote control of production, collaborative engineering systems to identify abnormal conditions, and IoT.
la_{28}	We dedicate a portion of everyday to planned equipment maintenance related activities based upon data from digital sensors integrated into engineering systems, MES or SCADA.
la_{29}	We maintain all our equipment regularly using data collected from machine digital automation sensors.
la_{30}	We maintain excellent records of all equipment maintenance related activities using data collected from machine digital automation sensors.
la_{31}	We post equipment maintenance records on shop floor for active sharing with employees through machine digital interfaces integrated into collaborative engineering systems, MES or SCADA.

Table 2 – LP and I4.0 competences

	Consolidated Competences	Seidel et al. (2017)	Camuffo and Gerli (2018)	Hecklau et al. (2016)	Grzybowska and Łupicka (2017)	Łupicka and Grzybowska (2018)
c_1	Identify what adds value to internal and external clients	√	√			√
c_2	Identify and solve problems with their teams using the PDCA (Plan, Do, Check and Act)	√	√	√	√	√
c_3	Use continuous improvement practices and principles	√	√			
c_4	Manage with emphasis on value flow rather than on isolated operations	√	√			√
c_5	Provide value-added information clearly and objectively	√	√	√	√	√
c_6	Put the group's interests above the individual ones	√	√		√	√
c_7	Practice self-development as well as professional and personal continuous evolution	√		√	√	√
c_8	Identify and manage barriers during improvement initiatives implementation journey	√	√	√		√
c_9	Practice continuous improvement as an interrelated system of principles and practices	√	√			
c_{10}	Develop actions that, based on ethical principles, respect the community, the environment and the workers' safety	√		√	√	√
c_{11}	Develop innovative and challenging actions	√		√	√	√
c_{12}	Develop computer programming/coding			√	√	√
c_{13}	Develop data processing and analytics			√	√	√
c_{14}	Put in practice statistical tools			√	√	√

Table 3 – Sample characteristics

Respondents' Lean experience			Company size		
< 5 years	55	50.0%	< 500 employees	62	56.4%
> 5 years	55	50.0%	> 500 employees	48	43.6%
Respondents' I4.0 Knowledge			**Industry sector**		
Basic	53	48.2%	Chemical	13	11.8%
Moderate/Advanced	57	51.8%	Automotive	13	11.8%
Respondents' role			Metal-mechanics	12	10.9%
Analyst/Engineer	42	38.2%	Machine and equipment	5	4.6%
Supervisor/Coordinator	35	31.8%	Textile	5	4.6%
Manager/Director	33	30.0%	Food	4	3.6%
Tier level			Others	58	52.7%
1 or 2	72	65.5%			
3 or 4	38	34.5%			

Table 4 – Partial correlation between LA practices and competences using perceptions of practitioners with less than 5 years of LP experience (n = 55)

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	Nº of significant correlations
la_1		0.308	0.319	0.274	0.354	0.280			0.279	0.308	0.385	0.524	0.454	0.591	11
la_2	0.329	0.381	0.287		0.353	0.301					0.292	0.453	0.460	0.464	9
la_3	0.291	0.476	0.418	0.446	0.552	0.584	0.482	0.376	0.480	0.333	0.499	0.551	0.575	0.624	14
la_4	0.548	0.367	0.271	0.398	0.488	0.606	0.505	0.381	0.352	0.271	0.469	0.447	0.448	0.478	14
la_5	0.527	0.467	0.351	0.501	0.624	0.646	0.632	0.532	0.515	0.445	0.598	0.652	0.587	0.544	14
la_6	0.450	0.478	0.324	0.550	0.637	0.628	0.459	0.613	0.588	0.330	0.485	0.546	0.636	0.494	14
la_7	0.394	0.428		0.498	0.527	0.492	0.325	0.406	0.417			0.364	0.536	0.370	11
la_8	0.387	0.417	0.278	0.420	0.432	0.418	0.405	0.382	0.495	0.316	0.338	0.542	0.635	0.533	14
la_9	0.441	0.496	0.397	0.579	0.606	0.515	0.439	0.446	0.581	0.473	0.458	0.503	0.636	0.577	14
la_{10}	0.517	0.461	0.271	0.552	0.654	0.605	0.443	0.511	0.473	0.368	0.400	0.355	0.551	0.397	14
la_{11}	0.402	0.502	0.333	0.303	0.354	0.381	0.344		0.270	0.278		0.473	0.488	0.547	12
la_{12}	0.414	0.621	0.496	0.418	0.488	0.472	0.382		0.359	0.424	0.415	0.652	0.655	0.718	13
la_{13}	0.345	0.582	0.440	0.396	0.547	0.468	0.355	0.390	0.418	0.348	0.371	0.496	0.704	0.587	14
la_{14}	0.305	0.601	0.369	0.419	0.583	0.498	0.365	0.391	0.341	0.288	0.373	0.492	0.709	0.531	14
la_{15}	0.374	0.439	0.462	0.497	0.400	0.358			0.428	0.377		0.440	0.589	0.571	11
la_{16}	0.462	0.649	0.564	0.492	0.528	0.442	0.373		0.411	0.548	0.480	0.661	0.667	0.719	13
la_{17}	0.500	0.585	0.452	0.407	0.529	0.432	0.468		0.333	0.494	0.282	0.451	0.430	0.435	13
la_{18}	0.336	0.517	0.478	0.381	0.421	0.297			0.351	0.434	0.309	0.530	0.608	0.570	12
la_{19}	0.329	0.358	0.272	0.221								0.296	0.381	0.419	7
la_{20}		0.310			0.310				0.271	0.284	0.292	0.490	0.657	0.524	8
la_{21}		0.352			0.277							0.470	0.639	0.446	5
la_{22}	0.432	0.475	0.386	0.340	0.413	0.422	0.445		0.289	0.369	0.270	0.471	0.523	0.538	13
la_{23}	0.286	0.464	0.445	0.437	0.423	0.323	0.467	0.279	0.483	0.550	0.332	0.603	0.541	0.560	14
la_{24}	0.429	0.472	0.483	0.402	0.399	0.399	0.375		0.330	0.496	0.340	0.386	0.460	0.565	13
la_{25}	0.354	0.347	0.288	0.335	0.373	0.327	0.284			0.394	0.325	0.446	0.528	0.489	12
la_{26}	0.440	0.393	0.353	0.455	0.464	0.427	0.274	0.285	0.362	0.360	0.388	0.519	0.570	0.599	14
la_{27}	0.404	0.474	0.453	0.441	0.418	0.448	0.446	0.279	0.406	0.380	0.335	0.631	0.593	0.641	14
la_{28}	0.478	0.562	0.500	0.361	0.422	0.374	0.513		0.281	0.467		0.603	0.407	0.577	12
la_{29}	0.275	0.435	0.413	0.382	0.458	0.433	0.520	0.352	0.505	0.507	0.452	0.667	0.597	0.637	14
la_{30}	0.427	0.490	0.441	0.430	0.546	0.508	0.529	0.417	0.530	0.479	0.420	0.651	0.568	0.586	14
la_{31}	0.575	0.486	0.428	0.417	0.414	0.498	0.591	0.329	0.347	0.345	0.345	0.632	0.367	0.567	14
Nº of significant correlations	28	31	28	28	30	28	24	16	27	27	25	31	31	31	385

Note: Only significant partial correlation coefficients were reported (p-value < 0.05). Gray cells indicate strong partial correlation (i.e. coefficients > 0.7).

Table 5 – Partial correlation between LA practices and competences using perceptions of practitioners with more than 5 years of LP experience (n = 55)

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	Nº of significant correlations
la_1	0.437	0.509	0.438	0.481	0.543	0.462	0.400	0.471	0.440	0.305	0.637	0.710	0.509	0.619	14
la_2	0.490	0.378	0.318	0.291	0.453	0.420	0.380	0.423	0.286		0.473	0.495	0.470	0.336	13
la_3	0.501	0.529	0.450	0.545	0.567	0.605	0.585	0.511	0.489	0.354	0.607	0.566	0.447	0.489	14
la_4	0.542	0.357	0.283	0.288	0.441	0.508	0.386	0.382			0.426	0.409	0.462	0.402	12
la_5	0.517	0.525	0.398	0.618	0.708	0.619	0.725	0.504	0.506	0.351	0.559	0.715	0.567	0.634	14
la_6	0.598	0.569	0.461	0.662	0.783	0.766	0.636	0.727	0.649	0.429	0.699	0.588	0.636	0.589	14
la_7	0.312	0.402		0.518	0.601	0.534	0.504	0.457	0.468		0.394	0.406	0.408		11
la_8	0.479	0.379	0.356	0.316	0.405	0.448	0.341	0.391	0.347		0.463	0.479	0.536	0.381	13
la_9	0.469	0.623	0.447	0.725	0.769	0.714	0.645	0.590	0.672	0.469	0.622	0.624	0.531	0.535	14
la_{10}	0.399	0.458		0.581	0.666	0.584	0.534	0.474	0.448	0.301	0.382	0.446	0.516	0.399	13
la_{11}	0.594	0.502	0.386	0.350	0.453	0.474	0.472	0.444	0.307		0.481	0.457	0.382	0.466	13
la_{12}	0.445	0.497	0.449	0.429	0.461	0.404	0.485	0.382	0.372	0.320	0.511	0.650	0.432	0.564	14
la_{13}	0.589	0.365	0.373		0.492	0.479	0.370	0.539		0.304	0.535	0.394	0.584	0.453	12
la_{14}	0.354	0.414		0.428	0.694	0.465	0.476	0.467	0.396		0.501	0.632	0.603	0.528	12
la_{15}	0.507	0.359	0.439	0.380	0.463	0.370		0.427	0.332	0.290	0.505	0.449	0.470	0.465	13
la_{16}	0.568	0.593	0.607	0.467	0.505	0.477	0.388	0.388	0.335	0.475	0.605	0.538	0.437	0.535	14
la_{17}	0.646	0.637	0.487	0.463	0.644	0.560	0.626	0.462	0.362	0.508	0.527	0.409	0.345	0.295	14
la_{18}	0.596	0.527	0.599	0.436	0.491	0.533	0.413	0.513	0.413	0.583	0.651	0.465	0.551	0.484	14
la_{19}	0.419	0.464	0.295	0.321	0.330	0.378	0.404				0.321	0.465	0.505	0.337	11
la_{20}	0.425				0.281			0.278			0.345	0.460	0.626	0.463	7
la_{21}	0.449	0.322			0.325	0.288	0.299	0.311			0.354	0.507	0.617	0.472	10
la_{22}	0.742	0.472	0.447	0.306	0.411	0.499	0.467	0.334		0.339	0.436	0.317	0.405	0.396	13
la_{23}	0.564	0.583	0.548	0.638	0.609	0.515	0.693	0.455	0.556	0.573	0.518	0.575	0.364	0.612	14
la_{24}	0.742	0.509	0.565	0.379	0.419	0.473	0.327	0.486		0.483	0.549		0.347	0.453	12
la_{25}	0.592	0.405	0.384	0.321	0.390	0.520	0.373			0.433	0.374	0.286	0.531	0.362	12
la_{26}	0.550	0.356	0.347	0.438	0.501	0.444	0.360	0.417	0.317	0.270	0.502	0.558	0.532	0.599	14
la_{27}	0.576	0.345	0.364	0.307	0.412	0.397	0.481	0.402			0.488	0.585	0.502	0.537	12
la_{28}	0.664	0.511	0.507	0.360	0.460	0.462	0.594	0.324		0.452	0.482	0.624	0.510	0.578	13
la_{29}	0.582	0.426	0.451	0.362	0.503	0.459	0.545	0.443	0.375	0.407	0.510	0.688	0.639	0.693	14
la_{30}	0.636	0.399	0.396		0.434	0.454	0.452	0.451		0.347	0.474	0.559	0.574	0.553	12
la_{31}	0.714	0.369	0.371	0.282	0.428	0.487	0.561	0.414		0.286	0.504	0.574	0.436	0.537	13
Nº of significant correlations	31	30	26	27	31	30	29	29	19	21	31	30	31	30	395

Note: Only significant partial correlation coefficients were reported (p-value < 0.05). Gray cells indicate strong partial correlation (i.e. coefficients > 0.7).

Table 6 – Partial correlation between LA practices and competences using perceptions of practitioners with Basic knowledge on I4.0 (n = 53)

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	Nº of significant correlations
la_1	0.299	0.346	0.366	0.357	0.418	0.335		0.291	0.353	0.339	0.487	0.583	0.479	0.604	13
la_2	0.389	0.305	0.301		0.370	0.340		0.293			0.353	0.444	0.481	0.397	10
la_3	0.377	0.423	0.433	0.435	0.554	0.602	0.491	0.468	0.488	0.388	0.562	0.542	0.539	0.556	14
la_4	0.522	0.335	0.316	0.326	0.467	0.571	0.430	0.411	0.289	0.307	0.479	0.451	0.509	0.469	14
la_5	0.460	0.433	0.360	0.538	0.666	0.626	0.656	0.513	0.525	0.431	0.577	0.732	0.621	0.618	14
la_6	0.449	0.390	0.315	0.540	0.650	0.642	0.454	0.621	0.558	0.329	0.525	0.563	0.663	0.512	14
la_7	0.309	0.289		0.451	0.521	0.472	0.355	0.402	0.406		0.315	0.422	0.470	0.330	12
la_8	0.445	0.335	0.283	0.356	0.439	0.449	0.353	0.443	0.409	0.287	0.485	0.491	0.607	0.437	14
la_9	0.374	0.403	0.339	0.594	0.660	0.574	0.494	0.505	0.602	0.451	0.569	0.588	0.652	0.583	14
la_{10}	0.444	0.387		0.573	0.697	0.650	0.517	0.541	0.518	0.357	0.481	0.496	0.599	0.485	13
la_{11}	0.503	0.418	0.331	0.279	0.365	0.395	0.409	0.297		0.305	0.369	0.521	0.447	0.532	13
la_{12}	0.464	0.479	0.431	0.375	0.485	0.452	0.484	0.321	0.343	0.399	0.458	0.718	0.551	0.673	14
la_{13}	0.469	0.386	0.375		0.479	0.460	0.350	0.446	0.312	0.339	0.443	0.502	0.672	0.538	13
la_{14}	0.276	0.401		0.375	0.579	0.431	0.403	0.390	0.330		0.394	0.586	0.626	0.531	12
la_{15}	0.461	0.277	0.401	0.362	0.412	0.410		0.336	0.324	0.340	0.420	0.448	0.559	0.542	13
la_{16}	0.550	0.516	0.542	0.393	0.519	0.473	0.405	0.291	0.319	0.551	0.566	0.624	0.554	0.639	14
la_{17}	0.501	0.507	0.414	0.324	0.478	0.419	0.475			0.450	0.345	0.435	0.329	0.364	12
la_{18}	0.498	0.408	0.475	0.326	0.403	0.393		0.301	0.308	0.463	0.422	0.504	0.571	0.500	13
la_{19}	0.398	0.357	0.311		0.280	0.302	0.359			0.308	0.299	0.355	0.397	0.420	11
la_{20}	0.369				0.326	0.348	0.280	0.329		0.297	0.427	0.511	0.674	0.538	10
la_{21}	0.359	0.307			0.312	0.307					0.324	0.472	0.629	0.454	8
la_{22}	0.613	0.453	0.458	0.326	0.403	0.497	0.462	0.284		0.445	0.427	0.450	0.497	0.534	13
la_{23}	0.408	0.438	0.424	0.466	0.497	0.433	0.603	0.332	0.470	0.567	0.448	0.660	0.465	0.627	14
la_{24}	0.600	0.435	0.505	0.308	0.363	0.489	0.346	0.339	0.230	0.533	0.486	0.354	0.463	0.550	14
la_{25}	0.502	0.312	0.344	0.276	0.357	0.475	0.347			0.494	0.466	0.385	0.553	0.474	12
la_{26}	0.509	0.317	0.352	0.409	0.476	0.498	0.344	0.368	0.341	0.361	0.506	0.570	0.573	0.643	14
la_{27}	0.540	0.376	0.421	0.332	0.400	0.485	0.467	0.339	0.295	0.379	0.432	0.607	0.545	0.617	14
la_{28}	0.606	0.530	0.533	0.333	0.413	0.444	0.564			0.498	0.366	0.603	0.394	0.586	12
la_{29}	0.433	0.378	0.391	0.333	0.447	0.477	0.549	0.413	0.422	0.512	0.544	0.686	0.599	0.663	14
la_{30}	0.576	0.427	0.446	0.324	0.492	0.555	0.495	0.464	0.382	0.496	0.522	0.592	0.579	0.567	14
la_{31}	0.680	0.446	0.486	0.355	0.415	0.554	0.574	0.365		0.430	0.440	0.589	0.383	0.581	13
Nº of significant correlations	31	30	26	26	31	31	26	26	21	27	31	31	31	31	399

Note: Only significant partial correlation coefficients were reported (p-value < 0.05). Gray cells indicate strong partial correlation (i.e. coefficients > 0.7).

Table 7 – Partial correlation between LA practices and competences using perceptions of practitioners with Moderate or Advanced knowledge on I4.0 (n = 57)

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	Nº of significant correlations
la_1		0.405	0.373	0.357	0.406	0.323			0.299		0.485	0.590	0.379	0.563	10
la_2	0.412	0.404	0.314		0.363	0.322	0.334				0.388	0.435	0.345	0.351	10
la_3	0.411	0.576	0.464	0.545	0.541	0.563	0.535	0.389	0.423	0.309	0.539	0.506	0.383	0.537	14
la_4	0.534	0.318	0.241	0.321	0.388	0.494	0.392				0.369	0.360	0.345	0.408	11
la_5	0.521	0.489	0.341	0.517	0.593	0.547	0.668	0.444	0.426	0.307	0.504	0.630	0.438	0.542	14
la_6	0.538	0.597	0.451	0.633	0.717	0.698	0.584	0.689	0.654	0.413	0.619	0.549	0.563	0.570	14
la_7	0.332	0.474	0.320	0.566	0.557	0.487	0.411	0.408	0.460		0.306	0.335	0.426	0.314	13
la_8	0.348	0.354	0.338	0.326			0.314		0.365			0.507	0.511	0.458	9
la_9	0.495	0.629	0.509	0.707	0.665	0.569	0.543	0.466	0.612	0.472	0.461	0.502	0.444	0.540	14
la_{10}	0.388	0.430		0.530	0.541	0.440	0.392	0.356	0.347			0.299	0.422	0.353	11
la_{11}	0.449	0.567	0.414	0.333	0.370	0.389	0.407	0.344	0.321			0.403	0.344	0.471	12
la_{12}	0.333	0.603	0.501	0.416	0.396	0.342	0.364		0.333	0.302	0.382	0.545	0.428	0.558	13
la_{13}	0.378	0.578	0.416	0.301	0.520	0.446	0.367	0.461	0.341		0.369	0.359	0.575	0.451	13
la_{14}		0.575	0.323	0.426	0.661	0.479	0.406	0.407	0.339		0.432	0.505	0.663	0.532	12
la_{15}	0.383	0.470	0.500	0.498	0.386			0.305	0.424	0.303		0.372	0.400	0.433	11
la_{16}	0.428	0.690	0.619	0.525	0.460	0.372	0.334		0.389	0.454	0.449	0.544	0.472	0.556	13
la_{17}	0.624	0.660	0.547	0.478	0.626	0.458	0.601	0.387	0.367	0.573	0.403	0.432	0.379	0.357	14
la_{18}	0.384	0.608	0.576	0.425	0.460	0.362		0.394	0.433	0.535	0.456	0.470	0.501	0.477	13
la_{19}		0.385										0.359	0.407	0.349	4
la_{20}												0.426	0.540	0.383	3
la_{21}		0.354										0.506	0.595	0.470	4
la_{22}	0.521	0.472	0.404		0.354	0.321	0.419					0.315	0.352	0.399	9
la_{23}	0.389	0.574	0.516	0.524	0.454		0.545	0.336	0.519	0.518		0.511	0.334	0.488	12
la_{24}	0.548	0.545	0.544	0.426	0.380	0.322	0.319	0.346	0.297	0.452	0.326			0.398	12
la_{25}	0.392	0.416	0.341	0.343	0.347	0.303				0.335		0.328	0.426	0.373	10
la_{26}	0.452	0.396	0.364	0.478	0.440	0.330		0.301	0.329		0.330	0.480	0.429	0.569	12
la_{27}	0.413	0.445	0.408	0.381	0.383	0.302	0.461	0.308	0.337		0.317	0.602	0.464	0.539	13
la_{28}	0.434	0.482	0.410		0.356		0.507			0.370		0.601	0.415	0.496	9
la_{29}	0.335	0.452	0.396	0.295	0.430	0.310	0.490		0.372	0.348		0.635	0.574	0.607	12
la_{30}	0.413	0.395	0.325		0.381		0.434	0.309				0.591	0.496	0.530	9
la_{31}	0.552	0.370	0.316		0.345	0.333	0.536					0.583	0.343	0.509	9
Nº of significant correlations	26	30	27	23	27	23	23	17	21	14	17	30	30	31	339

Note: Only significant partial correlation coefficients were reported (p-value < 0.05). Gray cells indicate strong partial correlation (i.e. coefficients > 0.7).

Table 8 – Consolidation of the pairwise partial correlation between LA practices and competences

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	Total
la_1		√	√	√	√	√			√		√	√	√	√	10
la_2	√	√	√		√	√					√	√	√	√	9
la_3	√	√	√	√	√	√	√	√	√	√	√	√	√	√	14
la_4	√	√	√	√	√	√	√				√	√	√	√	11
la_5	√	√	√	√	√	√	√	√	√	√	√	√	√	√	14
la_6	√	√	√	√	√	√	√	√	√	√	√	√	√	√	14
la_7	√	√		√	√	√	√	√	√			√	√		10
la_8	√	√	√	√			√		√			√	√	√	9
la_9	√	√	√	√	√	√	√	√	√	√	√	√	√	√	14
la_{10}	√	√		√	√	√	√	√	√			√	√	√	11
la_{11}	√	√	√	√	√	√	√					√	√	√	10
la_{12}	√	√	√	√	√	√	√		√	√	√	√	√	√	13
la_{13}	√	√	√		√	√	√	√			√	√	√	√	11
la_{14}		√		√	√	√	√	√	√		√	√	√	√	11
la_{15}	√	√	√	√	√				√	√		√	√	√	10
la_{16}	√	√	√	√	√	√	√		√	√	√	√	√	√	13
la_{17}	√	√	√	√	√	√	√			√	√	√	√	√	12
la_{18}	√	√	√	√	√	√			√	√	√	√	√	√	12
la_{19}		√										√	√	√	4
la_{20}												√	√	√	3
la_{21}		√										√	√	√	4
la_{22}	√	√	√		√	√	√					√	√	√	9
la_{23}	√	√	√	√	√		√	√	√	√		√	√	√	12
la_{24}	√	√	√	√	√	√	√			√	√			√	10
la_{25}	√	√	√	√	√	√				√		√	√	√	10
la_{26}	√	√	√	√	√	√		√	√		√	√	√	√	12
la_{27}	√	√	√	√	√	√	√	√			√	√	√	√	12
la_{28}	√	√	√		√		√			√		√	√	√	9
la_{29}	√	√	√	√	√	√	√		√	√		√	√	√	12
la_{30}	√	√	√		√		√	√				√	√	√	9
la_{31}	√	√	√		√	√	√					√	√	√	9
Total	26	30	25	22	27	23	22	12	16	14	16	30	30	30	323

Note: √ = significant partial correlation coefficient (p-value < 0.05) found in all four analyses.