Knowledge acquisition throughout the lifecycle

Vendrell-Herrero, Ferran; Gomes, Emanuel; Opazo, Marco; Bustinza, Oscar

DOI:
10.1108/JKM-05-2021-0387

This is the author's copy of a Manuscript published by **Emerald** in *Journal of Knowledge Management*, accepted 9th August 2021.

Knowledge acquisition throughout the lifecycle: product and industry learning frameworks

Ferran Vendrell-Herrero[a], Emanuel Gomes[b*], Marco Opazo-Basaez[c], and Oscar F. Bustinza[d*]

[a] *Birmingham Business School, University of Birmingham, Birmingham B15 2TT, United Kingdom, Phone +44 (0) 121 414 8563, email: f.vendrell-herrero@bham.ac.uk*

[b] *Nova School of Business and* Economics, Universidade Nova de Lisboa, Carcavelos Campus, Rua da Holanda, no. 1, 2775-405 Carcavelos, Portugal, Phone: +351213 801 600, *email: emanuel.gomes@novasbe.pt*

[c] *Deusto Business School, Deusto University, Faculty of Economics, University of Granada, 48007 Bilbao, Spain, Phone: +34944139000 (Ext. 2732), email: marco.opazo@deusto.es*

[d] *Department of Management, Faculty of Economics, University of Granada, 18071 Granada, Spain, Phone: +34958241000 (Ext. 20177), email: oscarfb@ugr.es*,* Corresponding author

Purpose – *The aim of this paper is to distinguish clearly between industry and product lifecycle models and to elucidate their different ramifications for organizational learning and knowledge.*

Design/methodology/approach – *We examine existing knowledge on industry and product lifecycles to highlight the differences and similarities and develop a framework with implications for learning and innovation in digital manufacturing industries.*

Findings – *We identify and associate one dominant type of learning with each phase of the industry lifecycle: Learning-by-Participating in the introduction phase, Learning-by-Feedback in the growth phase, Vicarious Learning in the maturity phase, and Learning-by-Memory in the decline phase. The study also provides insight into how different types of learning influence product lifecycle in digital innovation. From this perspective, Learning-by-Feedback is crucial to co-creation, co-production and open innovation. Similarly, Learning-by-Doing and Learning-by-Memory are essential to production and usage stages, respectively.*

Research implications/limitations – *The conceptual development in this paper follows a somewhat critical but ultimately elucidative analysis that highlights important research avenues in the interplay of product/industry lifecycle, organizational learning, and digital innovation.*

Originality/value – *This article clarifies a perennial theoretical problem by differentiating two concepts often conflated in the literature. More importantly, it*

Acknowledgements. *We thank three anonymous reviewers for their valuable suggestions. Ferran Vendrell-Herrero, Marco Opazo-Basaez, and Oscar F. Bustinza acknowledge support from FEDER/Ministerio de Ciencia, Innovacion y Universidades–Agencia Estatal de Investigacion, Spain, grant number PGC2018-101022-A-100. Emanuel Gomes would like to acknowledge financial support from Fundação para a Ciência e Tecnologia (UID/ECO/ 00124/2013) and Social Sciences Data Lab (LISBOA-01-0145- FEDER007722 and Project 22209).*

contributes to the knowledge management literature by shedding light on the connection of industry and product lifecycle theories to different types of organizational learning.

Keywords *Product lifecycle, Industry lifecycle, Organizational learning, Digital innovation*

Paper type *Real impact viewpoint.*

1. Introduction

Organizational learning is deemed an essential element of knowledge management (McElroy, 2000). Indeed, organizational learning research in the knowledge management literature is conclusive that accessing and absorbing new knowledge is essential to gaining and sustaining a competitive advantage (Castaneda *et al.*, 2018; Chaudhuri *et al.*, 2020; Pereira *et al.*, 2021). Moreover, knowledge management has a strong orientation to innovation. Scholars broadly believe that greater development of internal knowledge (e.g., Learning-by-Doing, Learning-by-Participating and/or Learning-by-Memory) and greater access to external knowledge (e.g., Learning-by-Feedback and/or Vicarious Learning) allow for higher levels of innovation (Crupi *et al.*, 2020). At the same time, attributions of knowledge and learning outcomes are widely viewed as quite context-sensitive (Cohen, 1986). Though previous research has investigated such dynamics across a variety of organizational (e.g., Allanson and Montagna, 2005), sector (Andriankaja *et al.*, 2015), and national (Liu and Yuan, 2016) contexts, no research to date has focused on understanding the learning and knowledge management processes in the context of the different stages of industry and product lifecycles. This study addresses this gap.

Despite the fact that scholars from various disciplines—such as strategy (Anderson and Zeithaml, 1984), engineering (Hepperle et *al.*, 2009), innovation (Klepper, 1996), marketing (Brax and Visintin, 2017), and international trade (Wells, 1968)—frequently use the concept of lifecycle, there is widespread confusion about the term's meaning and nature (Routley *et al.*, 2013). As a result, the concepts of product lifecycle (PLC) and industry lifecycle (ILC) are often used interchangeably. However, although these concepts are interrelated, they focus on different units of analysis and possess different implications for learning and knowledge management Whilst ILC comprises a high degree of collective learning and knowledge aggregation (e.g., Woolley *et al.*, 2010, Bernstein *et al.*, 2018), PLC requires information processing and individual/team knowledge acquisition (e.g., Mack and Szulanski 2017; Joseph and Gaba 2020). Interestingly, confusion between these two constructs emerges from recent technological advances in the field of digitization that have enabled manufacturing firms to generate value through smart systems that improve both consumer experience and operation of the product (Del Giudice *et al.*, 2020). The growing debate in this area suggests that manufacturing companies can provide digital services to enhance value creation throughout the PLC, which includes the planning, design, preparation, production, use, and disposal phases of the product (e.g., Brax and Visintin, 2017; Bustinza *et al.*, 2021). This is not, however, the first concept to be termed PLC. Another literature stream emerged under the same name during the 70s to explain changes in industry structure and technological development over time (e.g., Day, 1981; Mullor-Sebastian, 1983). Instead, this earlier stream considers industry as its primary unit of analysis. It focuses on understanding an industry's aggregate sales evolution through various phases, namely introduction, growth, maturity, and decline (Peltoniemi, 2011). In this article, we refer to this literature as ILC.

To illustrate the differences between these two theories, we take the example of the automotive industry. An ILC analysis can examine the evolution of car industry sales from their emergence in the early 20th century to the present (Routley *et al.*, 2013). It essentially functions as a lens to illustrate and further explain the periods of the market's cycle, from the market's initial slow growth (around the year 1900) to the exponential growth period of the 1930s and the innovative maturity that has allowed the industry to combine phases of growth with phases of stagnation (from the 1970s onwards). A PLC analysis, in contrast, seeks to understand how and when a specific company within the industry plans and designs a new automobile model, when each car produced is utilized and maintained, and/or when and how the vehicle is disposed of at the end of its lifespan. This confusion in terminology (and often, inaccurate use) has prevented a deeper understanding of the ramifications of these theories for both organizational learning and the development/implementation of innovation.

The aim of this article is, therefore, first, to clarify the significant differences between PLC and ILC, and, second and most importantly, to identify their implications for organizational learning within the context of digital innovation in manufacturing industries. The article contributes to the knowledge management literature in two ways. First, based on previously developed definitions of PLC in the fields of engineering and marketing, it develops a taxonomy of PLC from a knowledge management perspective. Second, it reveals the types of learning that companies should focus on in each phase of the ILC and PLC. By establishing this knowledge-based relational taxonomy, the article aims to illustrate these types of learning in the increasingly important context of digital innovation. The article also contributes to lifecycle theory by going beyond traditionally considered factors (such as competition, price, costs, innovation, new entrants, industry consolidation, and innovation) to shed light on the learning and knowledge management dynamics across the different stages of product and industry lifecycles.

The paper is structured as follows. We first provide an overview and differentiate theories of ILC and PLC by developing a taxonomy that identifies the different stages of the lifecycle from a knowledge management perspective. We then develop our theoretical framework by associating different types of learning with the various stages of industry and product lifecycles. We conclude by discussing the main implications of our paper for theoretical and practical knowledge management.

2. Background literature

This section provides definitions for ILC and PLC as a way of defining the boundaries between these two constructs. The section ends with a discussion that enables integration of both constructs from their applicability in a generic context and within the organizational learning literature.

2.1 Industry Lifecycle (ILC)

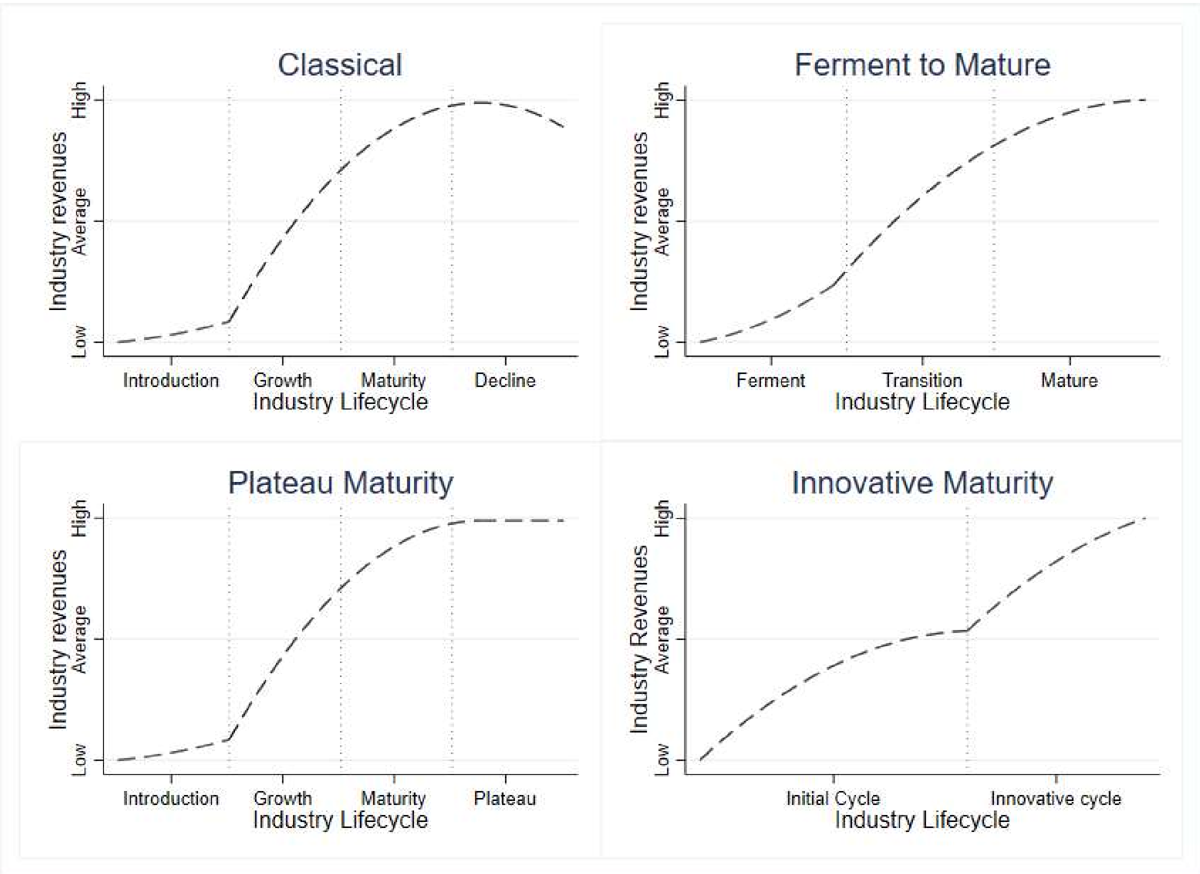
The ILC literature is extensive and helps us understand various industry-level sales' developmental dynamics (Peltoniemi, 2011). Although the extant literature provides a variety of lifecycle models applicable to a variety of sectors, two versions are widely acknowledged within the context of manufacturing industries, "classical" and "ferment to mature," as well as two significant variations of these models, "plateau maturity" and "innovative maturity" (see Figure 1).

The two central models (classical and ferment to mature) differ in the number of stages and inclusion/omission of a decline phase. The classical model comprises four phases, a gradual introduction, exponential sales growth, maturity or stagnation period, and finally, a decline in product sales (Day, 1981). The ferment to mature model, in contrast, presents two gradual growth phases, ‘ferment’ and ‘transition,’ and a sustained ‘mature’ stage that does not lead to a decline in sales (Gomes *et al.*, 2021).

Of the two important variations of the dominant models, plateau maturity is similar to the classical model except that industry sales volume does not change (stagnant sales growth). The only way to gain competitiveness in such an industrial environment is thus to increase domestic market share, open up to new markets, or diversify into other industries. Due to these options and the wide-scale adoption of digital technologies, the diversification option is becoming more and more common (Li *et al.*, 2021).

The remaining variation, innovative maturity, stems from the notion that an industry systematically reinvents itself to reinitiate a growth phase (Routley *et al.*, 2013). In this context, it is common for firms to engage persistently in process innovations to find new ways to produce at lower costs and increase sales volume by decreasing the prices (e.g., textile industry). It is also common to engage in product innovations to expand demand and increase product price (and in many cases also quantity). The mobile phone industry perfectly exemplifies this phenomenon. As the first generation of mobile phones reached maturity, the second generation of smartphones emerged, increasing the sector's sales volume exponentially.

Figure 1. Industry Lifecycle: Dominant models in the manufacturing industry



2.2 Product Lifecycle (PLC)

The concept of PLC focuses on the analysis of the different product development stages: planning, production, usage, and disposal (see Table 1). This field of research is closely linked to the digital innovation literature, especially in treating the provision of services by manufacturing companies or servitization (Rabetino *et al.*, 2015). In this context, studies suggest that one benefit manufacturing companies obtain from offering services is to generate value for the consumer during all phases of the PLC while also increasing consumer loyalty (e.g., Bustinza *et al.*, 2021).

Table 1 presents the two existing categorizations of PLC. Firstly, as in the second column of Table 1, Hepperle *et al.* (2009) follow an engineering design perspective to propose a model with nine superordinate phases. The model begins with (1) *product planning*, followed by (2) *product development and design*, which includes clarifying goals, structuring problems, proposing main solutions, and simulating and testing prototypes (among other activities). Subsequently, (3) *process preparation* plans materials and production and organizes logistics and control activities. Phase (4) *production* focuses on core production and assembly activities, whereas (5) *distribution* includes packaging and transportation activities. The rest of the phases aim primarily to support the consumer during the use of the product. They include (6) *utilization*, (7) *maintenance*, and (8) *modernization and upgrade*. The final phase is (9) *product disposal*.

Secondly, as shown in the third column of Table 1, Brax and Visintin (2017) adopt an industrial marketing perspective to posit eight phases of the PLC. These phases are widely accepted in the servitization literature as the dominant phases in which manufacturers must support consumers with services. This model starts with (1) *production*, followed by (2) *business analysis and consulting*. Phase (3) *solution design* involves analysing the technological environment, system requirement specification, maintenance plan, function design, and, when relevant, customer training content. It is followed by phase (4) *supply network design* and (5) *implementation*. Phases (6) *operation* and (7) *support* focus on supporting the consumer during product usage. As in the previous categorization of product lifespan, this categorization ends with (8) *disposal*, a phase that includes collection, transportation, brokering for re-sale, and recycling.

Table 1. Product Lifecycle phases

Authors' Taxonomy *Knowledge Management perspective*	**Hepperle *et al.*'s (2009) Product Lifecycle** *Engineering perspective*	**Brax and Visintin's (2017) Product Lifecycle** *Marketing perspective*
1. Production analytics Exploration process in which the company uses internal (R&D) and external (Co-creation and Co-production) knowledge acquisition to determine product design, product specifications, technological environment, and services attached to the product.	**1. Product planning** Process of envisioning, conceptualizing, developing, producing, testing, commercializing, sustaining, and disposing of organization's offer to satisfy consumer needs/wants and achieve organizational objectives.	**1 Production** Product design, hardware production, and software production
		2. Business analysis and consulting
	2. Product development and design Process that incorporates product's concept development, system design, and detail design; and testing and refinement stages.	**3. Solution design** Technical environment analysis, system requirement specification, maintenance plan, customer training requirement, functional design, and technical design.
		4. Supply network design
2. Core production Process in which firms need to work continuously on improving production processes to obtain a high-quality product at a competitive cost. During this phase, the company learns best practices of production and in industrial contexts might design implementation processes/services.	**3. Process preparation** Activity that involves product structure manufacturability evaluation, technological process design, tooling design, production process preparation, and production process organization.	**5. Implementation** Installation services, system engineering services, field engineering services, and training
	4. Production Phase that begins with pilot runs carried out in a production system intended for commercial use and ends when manufacturing start-up begins with low-to-high-volume production.	
3. Product lifespan Phase in which the company accompanies the consumer during product usage. This includes maintenance support and upgrading. During this phase, the company can capture the value generated in previous phases through services. This phase also provides feedback on first phase in designing new versions of the product and services associated with it.	**5. Distribution** This phase includes details of packaging, loading, transportation, unloading, and interim storage of the product.	**6. Operation** System operation and system-enabled process management.
	6. Utilisation This phase includes details of installation, use, maintenance, and repair of the product.	
	7. Maintenance This phase can be defined as the process of ensuring that a system continually performs its intended function at its designed-in level of reliability and safety.	**7. Support** Maintenance, on-field support, spare and consumables provision, and remote support.
	8. Modernization and upgrade This phase consists of adding or exchanging additional modules during product use phase.	
4. Product disposal Phase in which manufacturers consider how product can be reused or recycled. This phase has important implications for the environment and is closely related to the concept of circular economy.	**9. Product disposal** This phase is the end of product lifecycle, when three different scenarios are possible: reuse, waste, or recycle.	**8. Disposal** Collection and transportation, brokering for re-sale, and recycling.

Based on the categorizations above, we propose a new taxonomy that follows a knowledge management perspective in identifying relevant knowledge flows throughout the PLC. As shown in the first column of Table 1, this taxonomy is composed of four phases. It begins with (1) *production analytics*, which includes exploration activities and is fed by different forms of internal and external knowledge (Carayannis *et al.*, 2017). An example of internal knowledge in this stage is R&D. An example of external knowledge is co-creation practices, in which the customer is an active part of product development (Caputo *et al.*, 2019). Our taxonomy continues with (2) *core production*, which involves continuous improvement to minimize production costs and improve product quality (i.e., learning curve). Phase (3) *product lifespan* seeks to accompany the customer during product usage. Throughout this phase, the company captures value through services (Vendrell-Herrero *et al.*, 2021) and collects important information to guide the development of new products and services. Finally, phase (4) *product disposal* focuses on obtaining value through the reuse and recycling of the product. This phase involves a wide range of waste management services and is closely linked to the circular economy, so crucial for sustainable development (Stahel, 2016).

It is important to note that all of these categorizations are independent of the concept of ILC. In fact, all products will pass through these phases, regardless of the industry's lifecycle phase.

2.3 Degree of confusion and construct applicability

The coexistence of two theories about lifecycle is at least puzzling (Routley *et al.*, 2013). The context of servitization serves as an excellent example to envision the confusing use of these constructs. As mentioned above, servitization can be seen as a value generation process in which services support products to use during the different phases of the PLC. Yet, previous literature has depicted this value-enhancing function of servitization as an ILC process with an industry (rather than a product) dimension (e.g., Bustinza *et al.*, 2017).

In order to assess the degree of confusion, we conducted a pilot study based on primarily collected responses from ninety-three academic experts (see Appendix A). Using the Osterlind (1989) index, we validated two definitions for PLC. The definitions validated were incompatible because they involved different units of analysis: product and industry. Moreover, cluster analysis of the findings indicated that 26% of experts did not determine the unit of analysis. The remaining 74% disagreed about PLC's dominant unit of analysis, 54% believing that PLC's unit of analysis is product and 20% that it is industry. The percentages are similar regardless of the respondent's level of seniority or discipline. Altogether, we detected a great confusion between these two literature streams.

A high degree of confusion means that the constructs might be applied erroneously. One particular context in which this has an effect is organizational learning. The type/process of knowledge acquisition largely depends on the level of aggregation within the organization or the business ecosystem (Piezunka *et al.*, 2021). In our context, industry evolution is characterized by a high degree of collective learning and knowledge aggregation (e.g., Woolley *et al.*, 2010; Bernstein *et al.*, 2018). In contrast, product development is more characterized by information processing and individual knowledge acquisition (e.g., Mack and Szulanski 2017; Joseph and Gaba 2020). Based on this, we argue that organizational learning will differ depending on the unit of analysis considered in the lifecycle approach; hence, we develop separate frameworks of organization learning for ILC and PLC.

3. Theoretical framework

3.1 Types of learning

This study considers five types of organizational learning. The first, *Learning-by-Doing*, is an internal mode of learning built by combining the scientific method with trial and error. Companies that adopt this mode continuously improve competitiveness by setting up new products or production processes and testing them in the real market. This mode of organizational learning is primarily exploratory and grounds its learning curves in production contexts (Epple *et al.*, 1991). The second, *Learning-by-Participating*, is another internal experiential mode of learning. It is similar to Leaning-by-Doing as it integrates scientific method and trial and error components but differs from Learning-by-Doing since individuals or teams do not make choices, which are ultimately taken by a higher-level entity that is normally an organization or a group of organizations. By definition, Learning-by-Participation produces knowledge aggregation rather than individual learning.

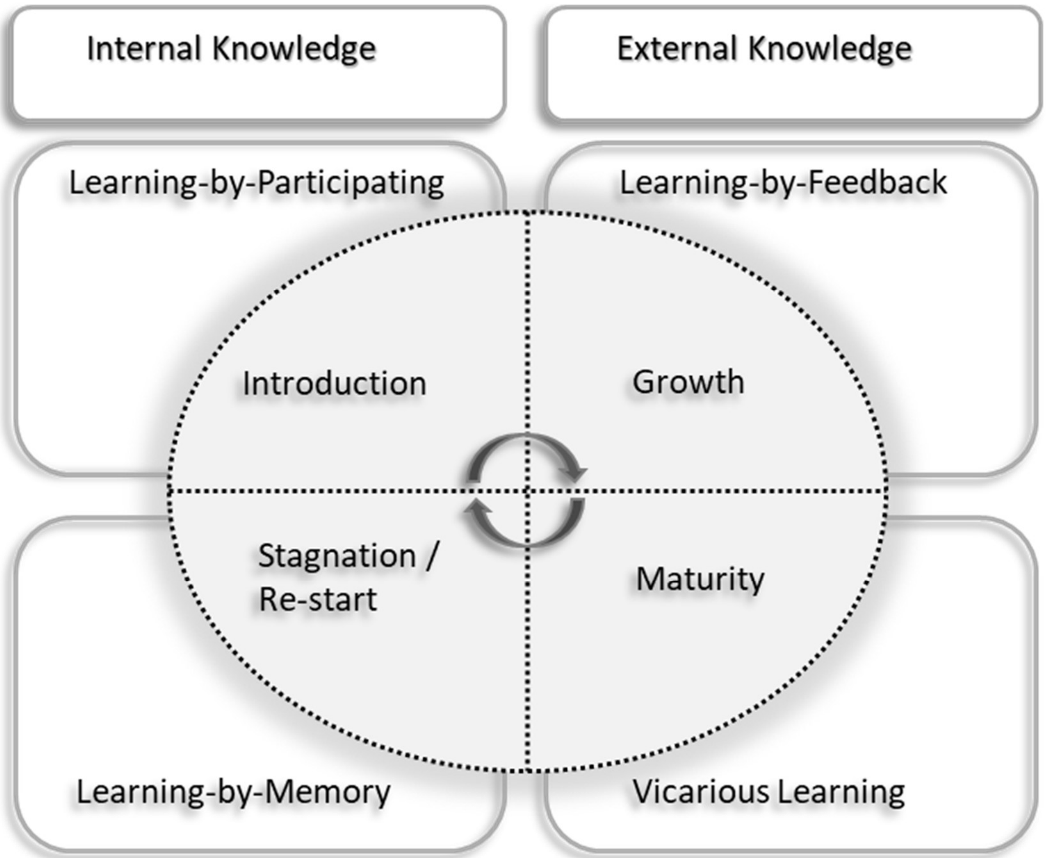
The third, *Learning-by-Feedback*, is an external form of learning that operates with feedback from experts and/or other organizations with more expertise on a specific topic (Del Junco *et al.*, 2010). In this context, external knowledge sources might include customers, partners, and suppliers (e.g., co-creation). The fourth, *Vicarious Learning*, is a distinctive organizational "learning that occurs through being exposed to and making meaning from another's experience," knowledge, or practice (Myers, 2018, p. 610). Therefore, in our framework, vicarious learning constitutes an external form of learning where best practices are identified and learned by observing the experiences, products, practices, and processes of similar other firms, resulting in a shared understanding of the product's performance criteria (Peltoniemi, 2011).

Finally, *Learning-by-Memory* is an internal form of learning that consists of reflectively revisiting the organization's past (Gomes *et al.*, 2021). This type of learning is also consistent with strategy restoration, "an organization's reinterpretation and re-enactment of discontinued aspects of its own history for present use and for the sake of enhanced future performance" (Miller *et al.*, 2019, pp. 2). In the next two sections, we aim to integrate these types of learning with the ILC and PLC models in the context of digital innovation.

3.2 Industry lifecycle and learning

As presented in Figure 1, a highly innovative environment allows for continued industry regeneration and reactivation of sales, leading to a rotating process, that is, an innovative maturity model. In the context of digital innovation, industries are thus expected to move from a stagnation phase to a phase of renewal and growth. We represent this process in the internal part of Figure 2. This rotating process enables us to establish a relationship between the phases of the ILC and the types of organizational learning presented.

Figure 2. The interplay between Industry Lifecycle and Learning



We argue that, because an introduction phase includes no reference models or experts to learn from, the only way to improve performance is through aggregated trial and error (Learning-by-Participating). Although internal development of knowledge may still be important in a subsequent growth phase, organizations can avoid making mistakes that others have already made. Throughout this phase, companies are more open to sharing knowledge and initiating co-creation and Learning-by-Feedback processes. During the earlier stages, the learning process tends to be more cooperative than competitive and takes place primarily through collective learning as a way to legitimate a new industry. In the maturity phase, companies compete for greater market share, and incumbent firms make efforts to solidify their status quo by establishing a dominant design (Anderson and Tushman, 1990). In such circumstances, organizations do not necessarily share their source of competitive advantage, although they can observe their rivals' success and learn from best practices (Vicarious Learning). Finally, organizations are expected to reflect on the whole lifecycle in the stagnation phase and attempt to restore organizational strengths (Learning-by-Memory). Organizations then prepare for a new growth phase that may emerge from the emergence of a new technology or business model.

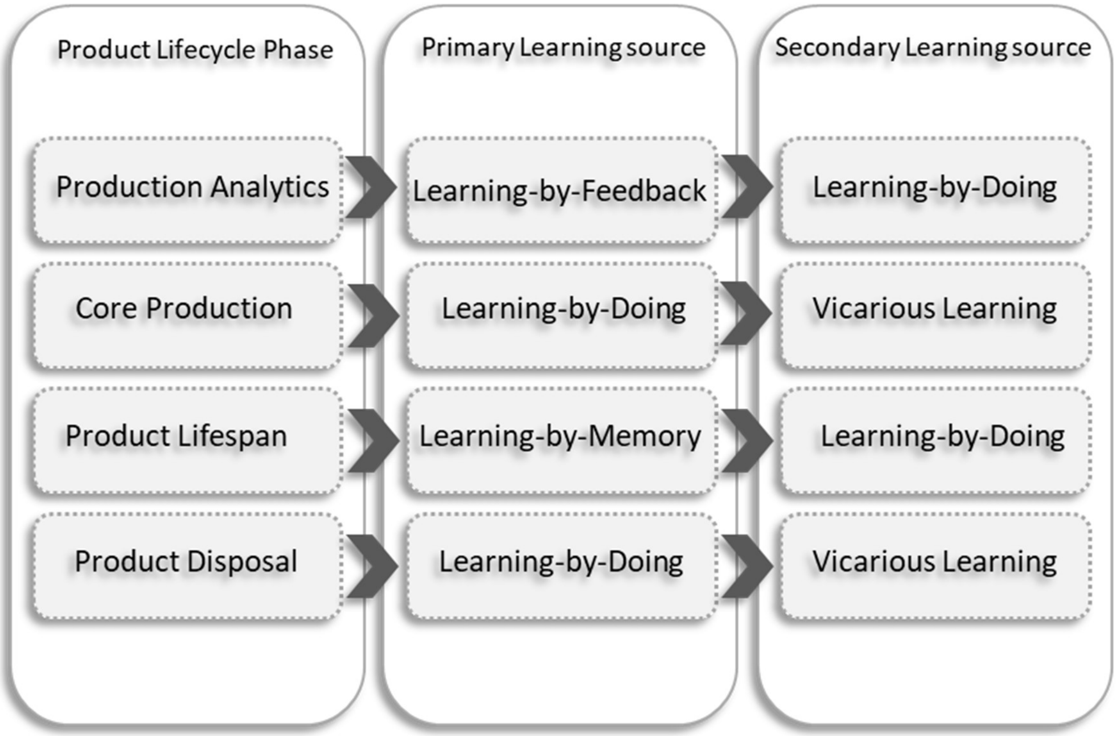
3.3 Product lifecycle and learning

As the PLC model cannot be structured as a rotating process, it is not possible to associate the different levels of organizational learning with the phases of the PLC, as was the case for the ILC model. By taking the digital innovation context as a reference, however, it is possible to identify the dominant types of organizational learning involved in the different phases of the PLC. Figure 3 presents what we consider to be primary and secondary sources of organizational learning during the four phases of the PLC.

During the *production analytics* phase, organizations conduct market research and gather information and opinions from consumers, suppliers, and other industry experts. As digital innovation is more seamless and customizable than product innovation, the constant dialogue with the customer to co-create and co-produce (i.e., Learning-by-Feedback) becomes fundamental to obtaining results in this phase of the PLC (Caputo *et al.*, 2019). The process of Learning-by-Feedback can be accentuated in this phase if the organization has open innovation systems in place (Martinez-Conesa *et al.*, 2017). Internal development may also be important during this phase, making Learning-by-Doing a secondary learning source.
As to the *core production* phase, much of the production literature emphasizes the importance of learning curves in improving production processes in manufacturing industries (Argote and Epple, 1990). The learning curve explains that Learning-by-Doing is the dominant form of individual/team/plant-based learning in most production contexts, including the context of digital innovation (Epple *et al.*, 1991). During this phase, it is also important to accurately

recognize and adopt other companies' production processes (Vicarious Learning) (Terlaak and Gong, 2008).

Figure 3. The interplay between Product Lifecycle and Learning



During the *production analytics* phase, organizations conduct market research and gather information and opinions from consumers, suppliers, and other industry experts. As digital innovation is more seamless and customizable than product innovation, the constant dialogue with the customer to co-create and co-produce (i.e., Learning-by-Feedback) becomes fundamental to obtaining results in this phase of the PLC (Caputo *et al.*, 2019). The process of Learning-by-Feedback can be accentuated in this phase if the organization has open innovation systems in place (Martinez-Conesa *et al.*, 2017). Internal development may also be important during this phase, making Learning-by-Doing a secondary learning source.
As to the *core production* phase, much of the production literature emphasizes the importance of learning curves in improving production processes in manufacturing industries (Argote and Epple, 1990). The learning curve explains that Learning-by-Doing is the dominant form of individual/team/plant-based learning in most production contexts, including the context of digital innovation (Epple *et al.*, 1991). During this phase, it is also important to accurately recognize and adopt other companies' production processes (Vicarious Learning) (Terlaak and Gong, 2008).

During the *product lifespan* phase, learning derives primarily from internal experience. Organizations thus collect product usage patterns and consumer feedback. This experiential information is stored in the organization's archives and will be essential at the time of crafting and launching new products and digital services, as it will feed production analytics. We argue that collecting retrievable information permits the organization to institute a process of memory building that will enable it to ponder its current activity effectively and influence future practices. In this phase, Learning-by-Memory is complemented by Learning-by-Doing, especially in relation to product maintenance and product upgrade. At this point, digital technologies facilitate interaction with customers and the implementation of continuously upgraded services to support the consumer experience (Rabetino *et al.*, 2015; Vendrell-Herrero *et al.*, 2021).

Finally, in the *product disposal* phase, waste management and recycling services are essential for the environment and operating within the circular economy (Stahel, 2016). These services are rather new but open a new industry market that manufacturers begin to enter, providing green as well as digital services (Opazo *et al.*, 2018). As a relatively emerging (service) industry, internal development dominates (i.e., Learning-by-Doing), but benchmarking best practices is also important (i.e., Vicarious Learning).

4. Conclusions and implications for knowledge management

The present study contributes to broader business management and, more specifically, to the knowledge management literature by clearly differentiating two (related but different) concepts frequently and inaccurately used under the same term, PLC. Essentially, we argue that the main difference lies in the unit of analysis (industry vs. product) and that these theories should thus be differentiated as ILC and PLC, respectively. Another important contribution of the study is its development of a theoretical framework that connects the different phases of the lifecycle with the different types of internal and external organizational learning. To the best of our knowledge, this is the first conceptual effort to relate these literature streams.

This study has significant implications for advancing the discipline of knowledge management. First, the categories of ILC analysed are widely accepted, whereas the categories of PLC are nascent and vary depending on the literature stream. This study thus offers the first categorization for PLC consistent with mainstream knowledge management theory. As such, it provides a baseline classification for future research that examines knowledge stock and flows during the PLC. Second, the study differentiates the forms of organizational learning in the discipline of knowledge management into five processes. Three of these processes refer to the internal development of knowledge, whether experiential (Learning-by-Doing), aggregated (Learning-by-Participating), or reflective (Learning-by-Memory). The other two refer to the pattern firms adopt to access external knowledge, whether cooperatively (Learning-by-Feedback) or competitively (Vicarious Learning).

We believe that this initial classification enables the emergence of more integrative empirical research by connecting the organizational learning and knowledge management streams more effectively to the broader marketing and innovation literatures. Finally, the proposed frameworks for illustrating the interplay between learning and ILC/PLC open exciting new avenues of research for knowledge management scholars. For instance, future empirical research should validate the framework qualitatively by identifying the learning mechanisms underlying the different lifecycle stages. Similarly, quantitative research based on Structural Equation Modelling could test an integrative model that incorporates the relationships between ILC/PLC, organizational learning, and firm performance. Lastly, more conceptual work is needed to relate decision-making structures with the proposed learning frameworks throughout the industry and product lifecycles. In this way, future work should picture the tradeoff of information aggregation and individual knowledge in different phases of the ILC and PLC (Piezunka *et al.*, 2021).

Ultimately, the framework proposed is relevant for innovation managers. At the core of our model is the notion that firms learn and innovate differently, contingent on the stage of the industry (product) lifecycle in which they operate (on which they work). Our model thus helps practitioners to prioritize their forms of knowledge acquisition based on their contextual conditions. In expansive stages of the ILC, knowledge managers should focus on accessing aggregate knowledge through active participation, engagement and feedback with the development of the industry. In the recession stages of the ILC, knowledge managers should adopt best practices in the industry and use memory to restore business practices that were successful in the past within the organization. Regarding PLC, Learning-by-Doing will be the dominant form of knowledge acquisition, but not in all stages. It must be complemented with Learning-by-Feedback in the production analytics stage and becomes a secondary source of learning in the Product Lifespan stage. Learning-by-Memory is the primary source of knowledge acquisition. Within these managerial implications, our model predicts that digital technologies will provide opportunities for industries to regenerate and raise aggregate revenues in a rotating innovative maturity process, in which digital innovation is an enabler of Learning-by-Feedback through co-creation with customers and/or open innovation with suppliers/intermediaries/research agencies.

References

Allanson, P. and Montagna, C. (2005), "Multiproduct firms and market structure: an explorative application to the product life cycle", *International Journal of Industrial Organization*, Vol. 23 No. 7-8, pp. 587-597.

Anderson, C. R. and Zeithaml, C. P. (1984), "Stage of the product life cycle, business strategy, and business performance", *Academy of Management journal*, Vol. 27No, 1, pp. 5-24.

Andriankaja, H., Vallet, F., Le Duigou, J. and Eynard, B. (2015), "A method to ecodesign structural parts in the transport sector based on product life cycle management", *Journal of Cleaner Production*, Vol. 94, pp. 165-176.

Argote, L. and Epple, D. (1990), "Learning curves in manufacturing", *Science*, Vol. 247 No. 4945, pp. 920-924.

Bernstein, E., Shore, J. and Lazer, D. (2018), "How intermittent breaks in interaction improve collective intelligence", *Proceedings of the National Academy of Sciences USA,* Vol. 115 No. 35, pp. 8734-8739.

Brax, S. A. and Visintin, F. (2017), "Meta-model of servitization: the integrative profiling approach", *Industrial Marketing Management*, Vol. 60, pp. 17-32.

Bustinza, O. F., Vendrell-Herrero, F. and Baines, T. (2017), "Service implementation in manufacturing: an organisational transformation perspective", *International Journal of Production Economics*, Vol. 192, pp. 1-8.

Bustinza, O., Vendrell-Herrero, F., Sanchez-Montesinos, F. J. and Campos-Granados, J. A. (2021), "Should manufacturers support the entire product lifecycle with services?", *Sustainability*, Vol. 13 No. 5, pp. 2493.

Caputo, F., Garcia-Perez, A., Cillo, V. and Giacosa, E. (2019), "A knowledge-based view of people and technology: directions for a value co-creation-based learning organisation", *Journal of Knowledge Management*, Vol. 23 No. 7, pp. 35-56.

Carayannis, E. G., Grigoroudis, E., Del Giudice, M., Della Peruta, M. R. and Sindakis, S. (2017), "An exploration of contemporary organizational artifacts and routines in a sustainable excellence context", *Journal of Knowledge Management*, Vol. 21 No. 1, pp. 1314-1334.

Carmines, E. G. and Zeller, R. A. (1979), *Quantitative Applications in the Social Sciences: Reliability and Validity Assessment*, Sage Publications, Thousand Oaks, CA.

Castaneda, D. I., Manrique, L. F. and Cuellar, S. (2018), "Is organizational learning being absorbed by knowledge management? A systematic review"*, Journal of Knowledge Management*, Vol. 22 No. 2, pp. 299-325.

Chaudhuri, R., Chavan, G., Vadalkar, S., Vrontis, D. and Pereira, V. (2020), "Two-decade bibliometric overview of publications in the Journal of Knowledge Management", *Journal of Knowledge Management*, In Press.

Cohen, S. (1986), "Knowledge and context", *The Journal of Philosophy*, Vol. 83 No. 10, pp. 574-583.

Crupi, A., Del Sarto, N., Di Minin, A., Gregori, G. L., Lepore, D., Marinelli, L. and Spigarelli, F. (2020), "The digital transformation of SMEs: a new knowledge broker called the digital innovation hub", *Journal of Knowledge Management*, Vol. 24 No. 6, pp. 1263-1288.

Day, G. S. (1981), "The product life cycle: analysis and applications issues", *Journal of Marketing*, Vol. 45 No. 4, pp. 60-67.

Del Giudice, M., Scuotto, V., Papa, A., Tarba, S., Bresciani, S. and Warkentin, M. (2020), "A self-tuning model for smart manufacturing SMEs: effects on digital innovation", *Journal of Product Innovation Management*, Vol. 38 No. 1, pp. 68-89.

Del Junco, J. G., Zaballa, R. D. R. and de Perea, J. G. A. (2010), "Evidence-based administration for decision making in the framework of knowledge strategic management", *Learning Organization*, Vol. 17 No. 4, pp. 343-363.

Epple, D., Argote, L. and Devadas, R. (1991), "Organizational learning curves: a method for investigating intra-plant transfer of knowledge acquired through learning by doing", *Organization Science*, Vol. 2 No. 1, pp. 58-70.

Gomes, E., Lehman, D., Vendrell-Herrero, F. and Bustinza, O. (2021), "A history-based framework of servitization and deservitization", *International Journal of Operations and Production Management*, In Press.

Hepperle, C., Thanner, S., Mörtl, M. and Lindemann, U. (2009), "An integrated product lifecycle model and interrelations in-between the lifecycle phases", *International Conference on Product Lifecycle Management*, chapter 14, pp. 679-689.

Joseph, J. and Gaba, V. (2020), "Organizational structure, information processing, and decision-making: a retrospective and road map for research", *Academy of Management Annals,* Vol. 14 No. 1, pp. 267-302.

Klepper, S. (1996), "Entry, exit, growth, and innovation over the product life cycle", *The American Economic Review*, Vol. 86 No. 3, pp. 562-583.

Li, Z., Wei, J., Marinova, D. V. and Tian, J. (2021), "Benefits or costs? The effects of diversification with cross-industry knowledge on corporate value under crisis situation", *Journal of Knowledge Management*. Vol. 25 No. 1, pp. 175-226

Liu, X. and Yuan, Z. (2016), "Life cycle environmental performance of by-product coke production in China", *Journal of Cleaner Production*, Vol. 112, pp. 1292-1301.

Mack, D. Z. and Szulanski, G. (2017), "Opening up: how centralization affects participation and inclusion in strategy making", *Long Range Planning,* Vol. 50 No. 3, pp. 385-396.

Martinez-Conesa, I., Soto-Acosta, P. and Carayannis, E. G. (2017), "On the path towards open innovation: assessing the role of knowledge management capability and environmental dynamism in SMEs", *Journal of Knowledge Management.* Vol. 21 No. 3, pp. 553-570.

McElroy, M. W. (2000), "Integrating complexity theory, knowledge management and organizational learning", *Journal of Knowledge Management*, Vol. 4 No. 3, pp. 195-203.

Miller, K. D., Gomes, E. and Lehman, D. W. (2019), "Strategy restoration", *Long Range Planning*, Vol. 52 No. 5, pp. 101855.

Mullor-Sebastian, A. (1983), "The product life cycle theory: empirical evidence", *Journal of International Business Studies*, Vol. 14 No. 3, pp. 95-105.

Myers, C. G. (2018), "Coactive vicarious learning: toward a relational theory of vicarious learning in organizations", *Academy of Management Review*, Vol. 43 No. 4, pp. 610-634.

Opazo-Basáez, M., Vendrell-Herrero, F. and Bustinza, O. F. (2018), "Uncovering productivity gains of digital and green servitization: implications from the automotive industry", *Sustainability*, Vol. 10 No. 5, pp. 1524.

Ortega, F. (2008), "El Método Delphi, prospectiva en Ciencias Sociales", *Revista EAN*, Vol. 64, pp. 31-54.

Osterlind, S. J. (1989), *Constructing Tests Items*, Kluwer Academic Publishers, Boston.

Peltoniemi, M. (2011), "Reviewing industry life-cycle theory: avenues for future research", *International Journal of Management Reviews*, Vol. 13 No. 4, pp. 349-375.

Pereira, V., Patnaik, S., Temouri, Y., Tarba, S., Malik, A. and Bustinza, O. (2021), "A longitudinal micro-foundational investigation into ambidextrous practices in an international alliance context: a case of a biopharma EMNE", *International Business Review*, Vol. 30 No. 1, pp. 101770.

Piezunka, H., Aggarwal, V. A. and Posen, H. E. (2021), "The aggregation-learning tradeoff", *Organization Science*, In Press.

Rabetino, R., Kohtamäki, M., Lehtonen, H. and Kostama, H. (2015), "Developing the concept of life-cycle service offering", *Industrial Marketing Management*, Vol. 49, pp. 53-66.

Routley, M., Phaal, R. and Probert, D. (2013), "Exploring industry dynamics and interactions", *Technological Forecasting and Social Change*, Vol. 80 No. 6, pp. 1147-1161.

Shrotryia, V. K. and Dhanda, U. (2019), "Content validity of assessment instrument for employee engagement", *Sage Open*, Vol. 9 No. 1, pp. 1-7.

Stahel, W. R. (2016), "The circular economy", *Nature*, Vol. 531 No. 7595, pp. 435-438.

Terlaak, A. and Gong, Y. (2008), "Vicarious learning and inferential accuracy in adoption processes", *Academy of Management Review*, Vol. 33 No. 4, pp. 846-868.

Vendrell-Herrero, F., Vaillant, Y. Bustinza, O. F., and Lafuente, E. (2021), "Product lifespan: the missing link in servitization", *Production Planning & Control*, In Press.

Wells Jr, L. T. (1968), "A product life cycle for international trade?", *Journal of Marketing*, Vol. 32 No. 3, pp. 1-6.

Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N. and Malone, T. W. (2010), "Evidence for a collective intelligence factor in the performance of human groups", *Science,* Vol. 330 No. 6004, pp. 686-688.

Appendix A: An exploratory pilot study conducted to elucidate academic understanding of product lifecycle

PLC contains two units of analysis (product and industry). We argue that this distinction can lead to confusion and misunderstanding. To clarify this terminology empirically, we perform a pilot study in which we collect information from academic experts who study digital innovation from different disciplines: marketing/strategy, engineering/operations, and innovation/knowledge. The population studied here consists of active participants in the digital innovation academic community. We define active participants as academics who have attended the International Conference of Business Servitization[1] (ICBS) at least once or published an influential article in the field of digital innovation. The target population is composed of 263 academics with affiliations primarily in the EU and the UK. This population is relevant and convenient for assessing topic content validity, that is, the extent to which an empirical measurement reflects a specific content domain (Carmines and Zeller, 1979; Shrotryia and Dhanda, 2019). The population is relevant because participants are familiar with the concept of PLC and convenient because the authors are active members of the ICBS community and can benefit from a high response rate.

An e-mail with general instructions and a link to access an online questionnaire was sent to all targeted academics (February 15, 2021). The questionnaire was concise and had been structured around seven questions. Two control questions required participants to indicate their seniority and discipline, and five questions asked about the participant's understanding of the PLC, assessed using 5-point Likert scale items (see Table A1). The five items were associated with the different ways the PLC stages have been reported in the literature. As the industry unit of analysis markedly dominates the literature, we set up the first four items to constitute industry-level analysis (I_1 to I_4). In accordance with previously established procedures, we posed four questions in favour of a positive and one in favour of a negative answer to encourage disagreement (Ortega, 2008). The fifth item is dissonant and denotes a product unit of analysis (I_5). The survey was closed after 48 hours, with 93 responses, a 35.3% answer rate.

The analysis follows previously established statistical procedures (Osterlind, 1989) and consists of two parts. First, a congruence analysis validates each item independently. The

[1] ICBS is a community that aims to bring together academics, policy makers, and professionals interested in service and digital business models and their effect on organizations, industries, and regions. The conference has been organized on a yearly basis since 2012, in either Spain or Portugal. For more information, see www.servitization.org.

scholarly community can recognize one or more items as valid but cannot consider items that have different units of analysis as part of the same construct. Second, a cluster analysis of observations is performed using a decision criterion. Respondents are divided into those who attribute more value to the definitions associated with the industry unit of analysis (Ind), those who attribute more value to the definition associated with the product (Pr), and those who are undetermined (Und). Greater confusion is assumed when none of the Ind or Pr parameters is dominant (i.e., greater than 80%).

Table A1. List of statements concerning Product Lifecycle Theory

Please indicate the degree to which you agree or disagree with each statement below by clicking on the appropriate box: strongly disagree, mildly disagree, not sure (i.e., do not agree or disagree), mildly agree, or strongly agree.

	The following are commonly acknowledged phases of the product lifecycle:	**Strongly disagree (1)**	**Mildly disagree (2)**	**Not sure (3)**	**Mildly agree (4)**	**Strongly agree (5)**
I_1	Emergence, growth, maturity, decline	( )	( )	( )	( )	( )
I_2	Ferment, transition, maturity	( )	( )	( )	( )	( )
I_3	Infancy, childhood, adolescence, maturity, senescence	( )	( )	( )	( )	( )
I_4	Incubation, diversity, segmentation and growth, maturity, decline	( )	( )	( )	( )	( )
I_5	Planning, development and design, production, distribution, utilization, disposal	( )	( )	( )	( )	( )

Note: We gave respondents the option "I don't know," but choice of this option was negligible. "I don't know" responses were treated as missing data.

For the congruence analysis, we use the Osterlind index. The Likert scale must thus be transformed to values between -1 and 1 (i.e., -1 if 1; -0.5 if 2; 0 if 3; 0.5 if 4; 1 if 5). Equation (1) is then applied, where X_{ijk} = Assessment of indicator *i* in domain *k* by judge/respondent *j*; N = Number of domains included in the instrument; and n = Number of respondents who value the indicator. Note that this type of congruence index enables operationalization of the degree of consensus that the different stakeholders may manifest. Indicators will be considered as having consensus if $I_{ik} > 0.5$.

$$I_{ik} = \frac{(N-1)\sum_{j=1}^{n} X_{ijk} + N\sum_{j=1}^{n} X_{ijk} - \sum_{j=1}^{n} X_{ijk}}{2(N-1)n} \quad (1)$$

For the cluster analysis, we maintain the items in their original form and apply Equation (2) as a decision criterion. If $D_J > 0.5$, the respondent finds the definitions with an industry unit of analysis more appealing. If $D_J < -0.5$, the respondent finds the definitions with a product unit of analysis less appealing. If $D_J \in [-0.5, 0.5]$, we consider the respondent unable to determine whether the definition of PLC should have a product or an industry unit of analysis. Once respondents are clustered into groups, it is possible to calculate the percentage of respondents in each group (i.e., Ind, Pr, Und).

$$D_j = \frac{\sum_{i=1}^{4} I_{ij}}{4} - I_{5j} \qquad (2)$$

Results for the full sample and groups of interest are reported in Table A2. Only two items seem to be congruent, as the Osterlind index is above 0.5 (I_{1k} = 0.58 and I_{5k} =0.57). The fact that these two items have different units of analysis (I_{1k} has industry units of analysis, whereas I_{5k} has a product unit of analysis) reveals some confusion on the term PLC throughout academia. Multiple accepted definitions are possible if they are complementary (e.g., I_{1k} and I_{2k} would be complementary definitions of PLC) but not if they are antagonistic (e.g., I_{1k} and I_{5k} would be antagonistic definitions of PLC, as they have different units of analysis). Interestingly, neither respondent seniority nor respondent discipline seems to affect this result.

Table A2. Congruence and clustering results

	Sample		**Item congruence**					**Clustering experts**		
	Observations		*Industry*				*Product*	*Classification (%)*		
	N	%	I_{1k}	I_{2k}	I_{3k}	I_{4k}	I_{5k}	Ind	Pr	Und
Full sample	93	100%	0.58	-0.13	-0.12	0.03	0.57	20%	54%	26%
Respondent Seniority										
Full Professor	18	19.3%	0.50	-0.06	0.17	0.08	0.61	28%	39%	33%
Associate Professor	30	32.3%	0.55	-0.28	-0.28	-0.01	0.55	17%	66%	17%
Early career	45	48.4%	0.65	-0.06	-0.14	0.04	0.59	20%	51%	29%
Respondent Discipline										
Marketing/Strategy	28	30.1%	0.52	-0.34	-0.29	-0.05	0.64	14%	68%	18%
Engineering/Operations	30	32.3%	0.55	0.05	0.00	-0.15	0.48	23%	37%	40%
Innovation/Knowledge	35	37.6%	0.66	-0.11	-0.10	0.26	0.60	23%	54%	20%

Note: N refers to number of observations and % to the percentage of observations in each category relative to the full sample. I_{ik} is the Osterlind index calculated using formula (1). Last three columns refer to the percentage of respondents who see PLC as an industry-related construct (Ind), see PLC as a product-related construct (Pr), or cannot determine the unit of analysis (Und). Early career includes PhD students, postdocs, and assistant professors.

The findings for the cluster analysis also reflect controversy concerning the concept. Whereas most respondents seem inclined to associate PLC with a product unit of analysis (Pr = 54%), a large number of respondents remain in the other categories, especially in the undetermined group (Und = 26%). Interestingly, for full professors (most seniority in academic career), the three clusters are distributed almost evenly (Ind = 28%; Pr = 39%; Und = 33%). Another element worth mentioning is that the percentage of non-determination is highest for engineering scholars, reaching 40% of respondents in this category.

In sum, this pilot survey of 93 academic experts provides content validity to ensure that the instrument reflects the theoretical concept analysed (Carmines and Zeller, 1979). Our pilot study determines that the unit of analysis of the term PLC is not naturally understood. We recommend that future studies adopt terms oriented to each unit of analysis and refer clearly to industry lifecycle (ILC) when the research analyses industry evolution and to product lifecycle (PLC) when the research has a product unit of analysis.