Scale-up phase in deeptech start-ups: Replication or massive learnings?

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Abstract

Because of the possible response to main, current and global issues, a particular attention is paid to deeptech start-ups and their growth mechanisms. Nevertheless, first observations on technological start-ups point out a limited growth. As deeptech start-ups are developing by nature advanced technologies, they are intended to be deployed on different markets, revealing technological genericity. Scaling these technologies encounters unfortunately some hurdles and seems to be more complex. This article focuses on scale-up for deeptech start-ups and on means to achieve this development phase. Literature usually considers scale-up as a phase of business model replication, suggesting low learnings. On the contrary, our hypothesis is to regard scale-up as a more complex phase in deeptech start-ups development, through additional means and learnings that have to be determined. This research is based on 8 case studies from different fields: For each start-up, we study what should be learnt and what should be relevant design strategies to ensure scale-up. Main issue in scale-up phase appears to prove that most of activities will not change, that should refer to the concept of creation heritage, taking into account external interactions.

1. Context: empirical and academic backgrounds

1.1. Characterisation of deeptech start-ups

Recent term of deeptech appears to point out a category of technological innovations (Chaturvedi 2015). Since then, reports, events and specialised structures have been breeding. According to Bpifrance, the French public investment bank, deeptech start-ups are defined as young and innovative companies pursuing a social or environmental impact and for which technologies come from research results[1].

First observations underline longer development time and significant funding support (BCG x Hello Tomorrow 2017). Indeed, empirical data about development of technological start-ups show growth difficulties and simultaneously better survival rate. It is typically the case of French i-Lab prize-winner companies. This innovation contest was created by the French Ministry of Higher Education, Research and Innovation in 1999, in order to stimulate start-ups creation from research works[2]. In 2019, for the 21st edition, Bpifrance notes a good[3] survival rate at 65 % on all the former prize-winners (more than 3000 technological projects have been rewarded); but average workforce stays at 12 employees, when 97 % of compagnies employ less than 50 persons and 63 % less than 10[4].

This assessment is all the more interesting that it is also raised in academic literature. Rannikko *et al.* (2019) take the example of a cohort of *new technology-based firms* (NTBF) in Sweden. Considering the definition of Storey and Tether (1998), NTBF term could be shortened in high-tech SMEs. That is, i-Lab prize-winners match with this definition. Observations are similar: Rannikko *et al.* (2019) notice also a better survival rate with a more complex growth (high

[1] cf. https://www.lesdeeptech.fr/decouvrir-deeptech [accessed 2 June 2021]

[2] For example, in 2020, there were 73 winners, who shared 20 million euros.

[3] Average survival rate for companies created in France in 2010 is 72 % at 3 years and 60 % at 5 years, according to INSEE Première n°1639, March 2017).

[4] In comparison: 61 % of French companies have less than 10 employees, according to INSEE (2018) and DARES (2016) studies.

growth is unusual). This empirical observation justifies an interest in study of technological start-ups.

It should also be noticed that we are focusing on start-ups, considered as relatively new[5] companies with high potential in terms of growth. Although Ries (2011) highlights "conditions of extreme uncertainty" for describing start-ups activities, our approach linking entrepreneurship and design suggests the relevance of a reasoning in the unknown (Le Masson *et al.* 2019): Particularities of deeptech start-ups lead us to believe that they have greater unknowns on the technological side and on the customer side as well.

1.2. Defining scale-up

Mechanisms related to the development of deeptech start-ups are not yet fully understood, in particular about specific features of scale-up phase. Democratised due to a report of the World Economic Forum (2014), the term "scale-up" specifies ventures with a great impact on society through their new technologies and services and employment capacities. Indeed, this development phase reveals itself typically through an increase in employees, sales, customers or revenues. To characterise scale-up, we refer to entrepreneurship literature focusing on scalability. In particular, we observe that scalability is one of the recurrent topics in business model studies. They insist on different parameters' changes.

On an economic view, scalability is the capacity to get economies of scale: Revenues are increasing, while costs are increasing slower (Stampfl, Prügl, and Osterloh 2013; Lund and Nielsen 2018; Zhang, Lichtenstein, and Gander 2015). Otherwise, sales and employees increases are brought out in business model studies (Cavallo *et al.* 2019) and in entrepreneurship, especially for linking growth with employment (Picken 2017; Aernoudt 2017). Market penetration and customers database increase are mentioned in entrepreneurship literature too (Eisenmann, Ries, and Dillard 2013; Duruflé, Hellmann, and Wilson 2017). This is an indicator especially monitored in case of digital ventures (Huang *et al.* 2017; Stampfl, Prügl, and Osterloh 2013). Besides, funding aspects bring other factors to describe scale-up, which is linked with a certain level of investment. Aernoudt (2017) mentions a "scale-up equity gap", explaining the departure of growing start-ups from Europe to the US at the moment of an internationalisation of their activities. The role of venture capital in the growth of start-ups has been studied by Davila, Foster, and Gupta (2003), who point to the influence of valuation changes on employee growth.

This multiplicity of parameters does not help to define precisely scale-up phase in start-up development. Moreover, using the term scale-up, which originally appeared in the information and technology field, has long been the subject of controversy. Hill (1990) had already tried in vain to find a universal definition and had ended up advising to be vigilant and to systematically specify the chosen definition.

Despite a lack of academic literature about original scale-up sources (Zhang, Lichtenstein, and Gander 2015), shared acknowledgement is numerous difficulties after early stages, explaining many failures. At first sight, scale-up begins from product-market fit (Eisenmann, Ries, and Dillard 2013), supposing main design efforts were done before. At this stage, one might be tempted to consider the scale-up as a simple replication phase.

Nevertheless, some hurdles are underlined by Picken (2017), who creates a specific phase dedicated to complex subjects that founding teams have to deal with after business concept validation (named start-up phase).That shows efforts still to be made after a theoretical market fit: in particular, "setting a direction and maintaining focus" and "positioning products/services

[5] created in the last 10 years

in an expanded market" are brought to the light. That being said, market exploration does not seem to be complete at the time of scale-up: It will still be a time of learnings. In case of deeptech start-ups, technological aspects have to be taken into account too, which is a first limit of this literature.

In a nutshell, entrepreneurship and particularly business model scalability literatures seem to consider scale-up as a phase of development in terms of customers database or market share acquisition. Consequently, market and customers are supposed to be known or at least require only limited adaptations. Considering that known and unknown could be different in case of deeptech start-ups, this may be a limitation for applying these business model theories. We seek to highlight these differences through a review of design literature.

1.3. A design approach

To determine unknowns faced by deeptech start-ups, a design approach should be relevant. Although business model scalability has been studying mainly digital ventures (Stampfl, Prügl, and Osterloh 2013), their issues are quite different from those of deeptech start-ups, more likely to be faced with industrialisation, hardware development, B2B strategies, etc. Thanks to entrepreneurship as design works, new research ways have been opened to link these two fields (Berglund, Dimov, and Wennberg 2018; Romme and Reymen 2018), clarifying for instance notions such as "opportunity" or strengthening approaches like "effectuation" (Sarasvathy 2001).

This first opening in entrepreneurship as design underlines that design and innovation management are a significant help to define growth conditions, for instance for generic technologies (Le Masson *et al.* 2016) or for exploring the unknown (Cogez *et al.* 2013). As introduced earlier, exploring the unknown should help to understand complex reality of deeptech start-ups development. It is all the more relevant that deeptech is by nature a typical case of double unknown (Kokshagina *et al.* 2016), that is a "situation in which the level of uncertainty is high and both technology and markets are as yet unknown". This double unknown situation justifies also the capacity to develop generic technologies, characterized by appearance of several applications derived from a same technology.

Although this kind of technology has long been known (for example, the notion of General Purpose Technology introduced by Bresnahan and Trajtenberg (1995) refers to technologies with influence on technical progress and economic growth), their development logic seemed to come under hazard or uncontrolled evolutionist processes. Recent works prove that genericity design can be managed and that may have unexpected rentability forms (Hooge *et al.* 2016). Maintaining wide and structured exploration logics might improve the probability to penetrate a market. Deeptech start-ups, through market and technology unknowns, should be well advised to develop generic technologies. In addition, double unknown echoes the two tyrannies for NTBF investments: Projects risks and costs related to VC funds size (Murray and Marriott 1998). That underlines the more complex design and decision spaces met during deeptech start-ups development.

In that case, scaling a deeptech start-up has to consider the necessary double exploration, on technology and on markets, which has to be conducted during the development. Consequently, design literature leads us to make the following assumption: Massive learnings have to be realised during scale-up phase to achieve success, transforming the start-up into a "gazelle" as named by Duruflé, Hellmann, and Wilson (2017). That is why the hypothesis of the replication of a technical solution between two customers can be ruled out.

Nevertheless, capitalisation of first development learnings must be thought out and organised. This could prove that reaching a new market (even in a pivot strategy) does not call into question either all the work carried out and therefore the accumulated expertise, nor all the external standards to which the value proposition must contend. While a deeptech start-up provides a disruptive technology, it is indeed a tension between conforming to institutional expectations and providing a real innovation, which has to be taken into consideration, all the more that it seems to be even greater in case of deeptech. This is made clear through the notion of legitimate distinctiveness, introduced by Navis and Glynn (2011).

The deeptech entrepreneurial activity in its development phase could be analysed through a principle that is both generative and preserving. On one hand, it is about designing a line of innovative products over the long term, by ensuring products regeneration. On the other hand, it is based on the capitalisation of past expertise. The simultaneous evolution of a creation and a tradition was introduced under the notion of creation heritage by Hatchuel *et al.* (2019). The additional contribution of this concept is that it allows us to move away from the "need-client-market" logic alone, but also to introduce a response to the promise of impact.

This design approach enables us to think that deeptech scale-up cannot be reduced to a simple replication process. The scale-up challenge could be to define what constitutes the creative heritage of the start-up. Thus, our hypothesis is that scale-up phase consists in learning what have to change or not.

1.4. Research questions

Between a simple replication process and massive learnings, these two visions of scaling indicate our unsatisfying understanding of deeptech start-ups development mechanisms. First step consists in defining essential learnings. Design research and distinctiveness pave the way to economy of learnings. With this in mind, we seek to answer the following questions:
RQ1 *What should be learnt during scale-up phase to guarantee specificities of ventures?*
RQ2 *To what extent is scale-up about learning what to leave unchanged?*
RQ3 *What should be an identification process of stable specific elements?*

2. Research methods

2.1. Sample constitution

This research is based on case studies in the context of a theory-building process (Eisenhardt and Graebner 2007). Table 1 provides main information concerning studied companies. Indeed, our start-ups sample includes 8 start-ups developing innovative products or services, which are based on different technical fields. 6 of them are classified as deeptech by Bpifrance, that is to say they respond to the following requirements (in addition to a positive social or environmental impact:

- technological development is linked with scientific research (through research collaborations, research skills within collaborators and particularly within the founding team, or support from a technology transfer organisation)
- market penetration is complex because of a proven technological lock
- to differentiate from competition, an intellectual property strategy is defined
- time-to-market is significantly longer than average regarding technological fields.

Case studies	**Business sector**	**Deeptech (Y/N)**	**Exchange modality**	**Interlocutor (function)**	**Date**	**Duration**	**Recording (Y/N/Incomplete)**
Case 1	Mobility / Energy	Y	long-term observation	CEO; President; all functions; members of supervisory board	01/02/2021; 19/02/2021; 12/03/2021; 08/04/2021; 16/04/2021; 28/04/2021; 05/05/2021; 25/05/2021; 28/05/2021; 10/06/2021	1h + 1h06 + 53 min + 1h14 + 1h04 + 1h24 + 55 min + 1h50	Incomplete
Case 2	Agri-food industry	N	long-term observation	CTO	from October 2020		N
Case 3	Consulting	N	interviews	CEO	09/02/2021; 03/03/2021	41 min + 48 min	Y
Case 4	Mobility / Energy	Y	interviews	CEO	25/02/2021	1h03	Y
Case 5	Information technology	Y	interviews	CEO	25/02/2021; 26/02/2021	18 min + 44 min	Y
Case 6	Information technology	Y	interviews	VP Marketing	02/03/2021		N
Case 7	Biotechnology	Y	interviews	CTO; CEO	10/03/2021; 25/03/2021	1h04	Incomplete
Case 8	Biotechnology	Y	company visit	CTO; chief of staff of the CEO	06/10/2020		N

Table 1: Summary of key information from start-ups case studies

We chose to add to these 6 deeptech start-ups 2 others, which are not considered as deeptech (cases 2 and 3). This helps us to determine deeptech specific features, emphasising potential differences.

2.2. Data collection and objectives

Interviews focus on understanding challenges faced during scale-up (how are there anticipated or experienced?). In particular, we look for design efforts and processes put in place to address challenges. This should shed light on skills that need to be acquired and role that the different actors in the start-up ecosystem can play. With a such qualitative methodology, we try to understand in detail necessary learnings to overcome hurdles and to define deeptech ventures' specific features.

Data collection is adapted to 3 different exchange modalities:

- **long-term observation:** A precise study is conducted with start-ups involved. This can take the form of a research collaboration (case 1) or a diploma work (including a 4-months internship) undertaken by a student supervised by us (case 2). For these cases, all the discussions cannot be recorded, and informal exchanges are a rich data source. The approach is one of an intervention research in management through the contribution of design theories (David and Armand 2008).
- **interviews:** It is a classical modality, for which most of discussions were recorded and notes were taken. Questions were not the same between the cases, because of an interest in technological understanding (in order to measure design efforts to be made and specific hurdles to overpass).
- **company visit:** In case 8, empirical material was collected during a company visit (presentation and laboratory visit) and from a detailed history of their early entrepreneurial activity, recently published by a researcher after a long-term follow-up.

Because of our interest about scale-up phase, we only chose start-ups with a body of indicators pointing to a potential or proven scalability. Indeed, double unknown situation makes it difficult to determine a precise time for the beginning of scale-up phase. In addition, to avoid the use of traditional scalability indicators (as defined in section 1.2.), which are more characteristic of digital ventures, we looked for other indicators of change in innovation scale. In particular, this may include external acknowledgment, such as awards in various recognised competitions, partnerships and their nature (development of proofs of concept or research partnerships on upstream projects), evolution of patents portfolio, consideration of industrial issues (development of demonstrators), or even first product development realised. Some events could be another illustration of a scale-up: round table recomposing, teams' reorientation, or customer model change. A combination of some of these parameters or events makes it possible to consider the question of scaling for the given venture. Anyway, these elements are related to more traditional economic indicators (like fundraising, or number of employees).

2.3. Research instruments

3 main tools are used to form our vision of these start-ups:

- a detailed **timeline** is reconstructed from discussions and as much public content as possible
- registered **patents** (among other available data) are studied to extract information on technical development and competitive positioning

- **CK-theory** (Hatchuel and Weil 2003) is applied to illustrate technological and market explorations; in case 2, KCP workshops were also conducted with a group of collaborators

Not all of these research instruments were applied to every case, depending on available data. They particularly help us to determine what has to be learnt, which unknows should be treated as a priority and what is becoming known and has to be preserved.

3. Results

3.1. Learning areas

The study of these 8 start-ups highlights several dimensions of development. Table 2 presents these dimensions and offers a thematic merging, named learning areas, which may overlap.

DIMENSIONS OF DEVELOPMENT	LEARNING AREAS
Market and competitive positioning	**Customer model**
Product or service (value proposition)	
Customers	
Work coordination	**Corporate structuration and identity**
Collective cohesion	
Corporate purpose	
Existing value chain	**Mechanisms of value chain integration**
Suppliers	
Distributors	
Research partnerships	
Different institutional actors for support	**Stakeholders**
Investors and advisors	
Other stakeholders / networks	
Technological maturation	**Technical design**
Patent portfolio (or at least IP strategy)	
Proofs of concepts / demonstrators	
Law and its evolution	**Regulation**
Regulatory actors	
Lobbying	

Table 2: Learning areas in scale-up phase

All these dimensions are observed for each studied deeptech start-ups (all cases excepted 2 and 3). In particular, technical design appears to be a huge barrier for deeptech start-ups, which need to pursue research efforts over the long term. Development of patent portfolio brings it out clearly, and even more so for biotech start-ups (in cases 7 and 8, this can be counted in several dozen patents after only a few years of existence).

On the contrary, case 3 underlines that technological maturation is not a subject in exploring the unknown: Creating a new offer is completely different, depending on employees' own skills. This is also observed in case 2: Where first technological maturation needed a few years, new technological learning to develop a new commercial product is achieve in 6 months.

Learning related to each of the dimensions depends on the level of progress in the scale-up. For example, in case 8, which is one of the most advanced scale-up studied, some unknowns related to suppliers about their capacity to provide hardware and software have emerged and then have been overcome: This venture finally had to increase its internal competence to carry out the software part itself; such a choice necessarily influences the areas of corporate structuration and identity and technical design. This example also underlines possible overlapping of learning areas, making the analysis more complex.

Learning depends also on business sector. That is why we thought it was relevant to study deeptech start-ups in information technology (cases 5 and 6). Indeed, they highlight major differences with non-deeptech digital start-ups, particularly about customer model. Because of longer technological developments, we observe especially the difficulties to launch successive minimum viable products, characterising the Lean Start-up Approach and already underlines by Eisenmann, Ries, and Dillard (2013) in the limits of Hypothesis-driven entrepreneurship method. That prove the necessity to realise learning about customer model.

3.2. Learning, unknowns and knowns: Example of case 1

To illustrate this massive learning experience in deeptech start-ups, we represent these learning areas from *unknowns* (learning to do), *specific unknowns* (where design efforts are being made) and *knowns to be preserved* (issued from previous learning). For each learning area previously defined, we seek to know what our case 1 start-up needs to learn about the unknown elements it faces. For that, we list all elements appeared during interviews, meetings and work sessions in Table 3. Due to a rich empirical material for case 1, we have chosen to represent it only. Other cases could support some points or underline some differences (because of a proximity of issues dealt with case 1, case 4 is particularly relevant to help to determine unknowns).

At this development stage (early scale-up), the *knowns to be preserved* column is yet being filled. The *unknowns* column grows significantly (as case 1 shows it). Then specific unknowns could be determined. This is what will constitute what we can call its distinctiveness (*specific unknowns*). We see after that the start-up seeks to find the most relevant experiences with regard to its distinctiveness and to capitalise on them to extract knowledge to be reused (*knows to be preserved*). This dynamic continues insofar as the development of new products is continuous.

Learning areas	**Unknowns (learning to do)**	**Specific unknowns (where design efforts are being made)**	**Knowns to be preserved (issued from previous learning)**
Customer model	Lack of direct customers in case of equipment supply Creation of an artificial customer (equipment sales) Change in main customer (sales of co-product)	Test in artificial customer creation	*to be determined*
Corporate structuration and identity	Constitution of a logistic team (software development) Creation of other linked structures (special corporations) Expression of corporate purpose (form, terms, implications, opportunities)	Structuration for developing a complete solution	Research skills and knowledge about developed technology
Mechanisms of value chain integration	Global solution on the whole value chain Focus of a part of suppliers or target more suppliers as possible (boarder perspective of the mission) Equipments or services supplier? Business model of a design office (studies and technical specifications without operational part)?	Positioning on a part of supplier (specific quantity) and realisation of the whole value chain	Learning during realised studies and contact Development potentiality and reasons for choice (in order to capitalise on this reasoning for next products)

Learning areas	Unknowns (learning to do)	Specific unknowns (where design efforts are being made)	Knowns to be preserved (issued from previous learning)
Stakeholders	Reactions of citizens Interest of suppliers depending on their origin (cultural differences) Impact of competition between large groups positioned in this segment	*to be determined*	*to be determined*
Technical design	Scale 1 behaviour (real quantity, inputs and chemical mixture) Carrying out the chemical process with non-laboratory equipment (real equipment: what adaptations?) Impact of co-products Logistical optimisation	Reuse of co-products	Technological choices, some internal developed skills, and patent portfolio
Regulation	Regulatory constraints on transport (size of carriers, quantities) Future laws and political orientations (national and European) and direct influences on direct or indirect subsidies Construction of the lobbying landscape on a recent issue (what are the relative positions of the actors?)	Integration of lobbying networks to have an impact on regulation evolution	Knowledge on regulatory actors' landscape and subsidy schemes

Table 3: Learning, unknows and knows for case 1

3.3. Answers to research questions

RQ1 – *What should be learnt during scale-up phase to guarantee specificities of ventures?*
Scale-up has to be understood as a phase of design setting, where learning is a main activity on several dimensions. An exploration process in the unknown should be put in place, to optimise learning efforts. In particular, we observe with our different cases that technological design and customer model are huge unknowns in case of deeptech start-ups. Table 3 underlines that many unknowns appear during scale-up, challenging the idea of a simple replication.

RQ2 – *To what extent is scale-up about learning what to leave unchanged?*
Faced with a growing set of unknowns and because of limited resourced, it becomes necessary to make a choice about which unknowns to address. A specific process should be put in place to identify the unknowns to be addressed, which are becoming own constraints. These addressed unknowns might also define the distinctiveness or the identity of the start-up. Work sessions with case 1 enables to use the C-K Theory in order to define alternative concepts that take into account different sets of unknowns. By choosing some unknowns, start-ups also decide which known elements they can rely on. This discrimination is key to learning how to position oneself regarding the competition and build one's identity.

RQ3 – *What should be an identification process of stable specific elements?*
Thus, the challenge lies in choosing the right elements to preserve during development. It is also these elements that will enable the construction of future learning, capitalising on the knowledge acquired. That's why the notion of building a creative heritage seems relevant. However, no clear process is consistently observed at this stage of the research.

4. Discussions

This study is being completed with a more quantitative approach, through new interviews realised with a formal guide. This will also enable to improve the representativeness of our sample: Other cases will complete these elements. The purpose is to develop a model for customer acquisition and simultaneously technological development process, introducing the notion of creation heritage, due to an illustration of the previously descripted dynamics with more technical instruments (like Suh matrixes).

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