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The hidden side of innovation: why tinkerers matter

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Abstract

Moving from research on embodied knowledge and learning in cognitive sciences and from the scholarly debate on science-driven and experience-based modes of learning and innovation, we advance an analytical and theoretical framework to think about the role of "making" things in innovation processes. We define tinkering in the context of innovation and we claim that it has three fundamental functions. First it is a form of epistemic action that generates abstract knowledge in and for itself, thus functioning as a mechanism that fuels scientific endeavors and the advancement of formal science. Second we claim that tinkering orients and directs search activities by a number of stakeholders, contributing to the momentum of emerging product concepts and categories. Finally we posit that that tinkering is a way of framing innovation, thus mobilizing resources, attention and legitimizing novelty in industries and markets. In order to ground our definition and conceptual framing of tinkering, we provide examples of the three functions in the development of the aircraft and of the personal computer. The paper closes with a systematization of the

different instantiations of tinkerers as they have been identified in a variety of streams of literature on innovation and with a set of research questions that could build on the definition we advance.

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1. Introduction

The scholarly debate has analyzed and modeled innovation according to two frames of reference, synthetically labeled as STI –science, technology and innovation– and DUI –doing, using and interacting– (cf. Jensen et al., 2007). The former places a particular emphasis on scientific research and on systematic, disciplined search as the triggers for innovation processes. The latter focuses on the *praxis* and the experience of economic actors, on their reciprocal interactions and on the learning processes that ensue from action and interaction. Empirical analyses of innovation documented how the two modes often coexist within technological trajectories, within industries and within organizations (Pavitt, 1984). The degree of dominance of one frame over the other depends on time –the more exploratory the stage of a technology trajectory, the more experience-based the development of innovative knowledge–, on contexts –either geographical or sectorial–, on firms' strategies –dominated by the imperative of innovation or by other strategic priorities– and on the vantage of the analyst. While in principle the academic and policy-making communities have recognized the co-existence of both the frames in innovation processes and economic growth, empirical analyses and policies have tilted eminently towards the STI frame of reference, especially in the last decade signed by the emphasis on the so-called knowledge economy (Foray & Lundvall, 1996; Foray, 2004; Mokyr, 2002).

Some analyses warned against the overemphasis on formal research, on science and on technology-push in innovation and economic growth. Such an emphasis is believed to orient and influence subtly but profoundly industrial policy-making and firms' strategies. The centrality of knowledge in fact went to the detriment of manufacturing *–doing*, performing activities on material resources– that has come to be perceived as commoditized and irrelevant in terms of innovation and economic growth. Nations and companies handed a remarkable part of their manufacturing operations to firms in emerging economies, shifting their focus on science and formal R&D (Pisano & Shih, 2009; Herrigel, 2010; Zirpoli & Becker, 2011) or other knowledge-intensive activities (Gereffi et al., 2005). Recent analyses by scholars (Herrigel, 2010) and practitioners (Manyika, 2013; Davidson, 2012), suggest that the disentanglement of formal research and manufacturing is detrimental to the innovative capabilities of firms and territories. As a response, emerging social movements are advocating manufacturing as a fundamental component in the innovation equation. The makers movement (Anderson, 2010; Crawford, 2006; Crawford, 2009) and the rediscovery of the tinkering and do-it-yourself cultures in the United States (Davis, 2012) call for a thorough reconsideration of the role of "making" artifacts and of materiality as means to produce novel knowledge. As it often happens, the mobilization of attention around emerging cultural and social practices is associated to often exaggerated claims about the end of previous paradigms – the end of the corporation, the end of organized and hierarchical processes of knowledge creation, the end of the service economy and the like. While our paper does not deal with the credibility of such claims, it espouses the vigorous turn of attention called by these movements towards the reconsideration of materiality and tinkering as crucial elements in effective and sustainable innovation ecosystems.

Moving from the investigation on embodied knowledge and learning in cognitive sciences and from the scholarly debate on the reciprocal influences between science-driven and experience-based modes of learning and innovation, the present article aims at providing an analytical and theoretical framework to think about the role of "making" things in innovation processes. In particular we claim that tinkering has three fundamental functions in innovation processes. First it is a form of epistemic action that generates abstract knowledge in and for itself, thus functioning as a mechanism that fuels scientific endeavors and the advancement of formal science. Second we claim that tinkering orients and directs search activities by a number of stakeholders, contributing to the momentum of emerging product concepts and categories. Finally we posit that tinkering is a way of framing innovation and of mobilizing resources, attention to obtain legitimation in industries and in markets. In order to ground our definition and conceptual framing of tinkering, we provide examples of the three functions of tinkering taken from accounts of the development of the aircraft and of the personal computer. The paper closes with a systematization of the different instantiations of tinkerers as they have been identified in a variety of streams of literature on innovation and with a set of research questions that could build on the definition we advance.

2. Tinkering in linear and interactive models of innovation

Management and innovation literatures are constellated by a lively debate on the mechanisms and processes of innovation. Particular attention has been devoted to different frames of reference to analyze and understand learning processes entailed in innovation: science-based R&D *vis-à-vis* experience-based learning (Hendry & Harborne, 2011). In their reprise of previous analyses of different "national" paths in the development of wind turbine technology (cf. in particular Garud & Karnøe, 2003), Hendry and Harborne (2011) note that the risk in framing the unfolding of innovation is that of anchoring to two extremes: either to downplay the contribution of formal R&D and science to innovation in favor of an overemphasis on experimentation and learning by doing or *vice versa*. Similarly, the opposition between attributions of linearity –science and technology push– and those of emergence and iteration –user and/or manufacturer pull– could result in an oversimplification of the variety of processes, mechanisms and actors that populate innovation trajectories in time and space.

Innovation is the outcome of intricate dynamics and ongoing relations among a multitude of actors (Bijker, 1987): oppositional framings of the process often rely on oversimplified interpretations of models proposed in literature –as it happened for the linear model of innovation (Balconi et al., 2010)– whose renditions by critics are often unfair and stylized. We especially agree with Balconi *et al*. (2010) and their caveat for proponents of non-linear and emergent frameworks: models where everything depends on everything else and where everything happens instantaneously –or a-chronologically– do not come in handy neither for empirical investigations nor for policy elaboration. Mechanisms and time need to be taken into serious consideration for these models to explain complex phenomena. While we remain neutral as to the debate among proponents of different models of innovation, we aim at uncovering and defining one of such mechanisms, tinkering. We posit that it could equally address the lack of clear causal processes in non-linear models of innovation and at the same time it could contribute to provide the linear model with a more nuanced grasp of actual innovation dynamics. We aim at shedding light on tinkering as a mechanism and tinkerers as agents that situate at the interface between the different constituencies –and logics– that populate the innovation landscape: firms, R&D laboratories, research institutions, demand.

We define tinkering as the *creation of workable material artifacts* resulting from the experimental and serendipitous combination of *resources* that can be *material* –components, raw materials, extant products– and *intangible* –e.g. ideas, theories, and science. Such an activity is performed by actors that *enact a resource pool* in the contexts in which they are located and *apply their mental and manual work upon them* in order to create material artifacts.

Our definition of tinkering draws from Knorr (1979) and Jacob (1977) and is enriched by the somehow similar definition of *bricolage* (Lévi Strauss, 1962; cf. also Baker & Nelson, 2005; Stinchfield et al., 2012). Tinkering consists in using what is at one's disposal to realize artifacts «even though [one] does not know exactly what he is going to produce» (Jacob, 1977, p. 1173). Making do with what is at hand –leveraging on available and idiosyncratic constellations of resources– is the distinguishing characteristic of bricolage as a way to both construct problems and solve them (Knorr, 1979; Lévi Strauss, 1962). This specific way of developing artifacts and solutions stands in sharp contrasts with engineering (Jacob, 1977; Lévi Strauss, 1962): the latter in fact refers to the existence of a preconceived and clear plan –the engineer can envision in advance the results of his or her efforts– and presumes the availability to the agent of raw materials and specialized equipment designed for the task the engineer is called to perform. Finally, the *oeuvre* of the engineer approximates the level of perfection made possible by the technologies and knowledge of the time –she optimizes– while the tinkerer's artifacts are far from perfect as a result of both a sense of purpose emerging in the process of doing as well as of the re-use of means that were originally conceived for other uses and ends (Baker & Nelson, 2005).

In addition, we stress the *making* dimension associated with tinkering, which consists in the realization of artifacts (objects, prototypes) out of available resources and the commitment to experimentation. Through this we aim at differentiating tinkering as a mechanism from others consolidated in the literature such as learning by doing and learning by using. While those mechanisms can be entangled in reality, we do not point to the gains in efficiency that come from repeated action, nor to the codification of tacit knowledge through abstractly doing or using. We refer to actions aimed at the construction of material objects (Henderson, 1998; Cacciatori, 2008) or, in Jacob's parlance, «some type of workable object» (Jacob, 1977). Our definition of tinkering, thus, takes into consideration *materiality* as a constitutive dimension of the process –that is experimenting with physical resources– and the *artifact* –a material object with recognizable (even though not necessarily foreseeable or pre-determined) shape and functionality.

We provide a framework to analyze and conceptualize tinkering as a mechanism responsible for the delimitation of the innovation search space, for the coordination of the actors involved in innovation processes and as a framing device allowing for the mobilization of resources and for the creation of novel markets. To articulate the framework we will rely on historical accounts of the inception and further development of innovations that have been largely and extensively accounted in literatures as diverse as management, economics, history and sociology. After the identification of the functions of tinkering, we provide also a preliminary assessment of the characteristics of tinkerers, drawing from extant literature as well as from accounts of recent events.

3. A framework to think about and analyze tinkering

3.1 Tinkering as a form of epistemic action: building to think

Academic research has highlighted the complexity of human knowledge distinguishing between abstract, embodied and distributed knowledge. In the field of cognitive sciences and artificial intelligence the well-established concept of human cogitation as a fully rational process based on codified knowledge (symbols) and a formal set-of rules (models, heuristics, routines) is under question. Michael Anderson (2003), analyzing a large body of literature specialized on a different approach to human cognition, pointed out how cognition is strictly related to the physical experience and the structure of human senses and perceptions. This is especially true in the field of artificial intelligence, where several experiments conducted with robots (characterized by an abstract and rational cognition) demonstrated their impossibility to deal with a dynamic and complex context. Those failures led to elaboration of a different idea of cognition, the so called embodied cognition that: «focuses attention on the fact that most real-world thinking occurs in very particular (and often very complex) environments, is employed for very practical ends, and exploits the possibility of interaction with and manipulation of external props» (Anderson, 2003). This approach is based on the consideration that the separation between the rational mind (based on abstract representations and formal set of rules) and the irrational body (based on senses and experiences) that characterizes the cognitivist theory is fading away. Lakoff and Johnson effectively pointed this consideration: «This is not just the innocuous and obvious claim that we need a body to reason: rather, it is the striking claim that the very structure of reason itself comes form the details of our embodiment […]. Thus, to understand reason we must understand the detail of our visual system, our motor system and the general mechanism of neural binding».

The concept of embodied cognition is close to the concept of situated cognition elaborated in social sciences. In fact, situated cognition points out the substantial inseparability between the act of knowing and doing. In particular, the work of Jean Lave (i.e. the book "Understanding Practice" co-authored with Seth Chaiklin) highlighted how knowledge is contextualized within physical, social and cultural activity. From this perspective, the focus shifts from individual subjectivity to dynamic interactions among people within the complexity of social and cultural relations. Cognition is not an abstract process: it is a practical one in the sense that it happens in the interaction with the real world and with other people and is based in given social and cultural context. Therefore, learning is not an isolated and individual process but is social and based on practice. Lave and Wenger (1991) pointed out the relevance of community of practice in sustaining the production and diffusion of knowledge. They defined Legitimate Peripheral Participation as the process that characterizes the level of involvement of the members in the community. The position of the member (from periphery to the core) signals the recognition of the community in terms of practice and knowledge. What, in fact, activates the learning process is the need to belong to the community.

In our view, tinkering represents a form of action which is contingent –it is situated in specific contexts characterized by certain resources, both material and intellectual– instrumental to the production of theories of the world. In this sense making is the fundamental trigger for thinking and for the speculation related to causal relations between phenomena. Tinkering is thus a form of reflective agency which aims at using what is at hand –a form of bricolage– not in only in an exploitative sense –that is to reach clear physical goals like solving a pressing and pragmatic problem– but in an exploratory sense, that is to experiment with the environment and its resources in order to construct a map of the possible and generate novel problems as well as the premises for their solutions. Lévi-Strauss (1962) has summarized this peculiar ability to interact with the world, identifying the figure of the «*bricoleur*» as «someone who works with his hands and uses devious means compared to those of craftsman». In Lévi-Strauss (1962) view, the bricoleur embodies the relevance of magical thought as a form of reasoning and knowledge acquisition that is different (although complementary) from scientific thought. The bricoleur uses pre-existing tools and materials that has at hands in ways and for purposes that were not necessarily designed for, adapting to the limitations of the context. The engineer is the expression of the objectivity of science, the bricoleur is the expression of subjectivity: «the 'bricoleur' also, and indeed principally, derives his poetry from the fact that he does not confine himself to accomplishment and execution: he 'speaks' not only with things, as we have already seen, but also through the medium of things: giving an account of his personality and life by the choices he makes between the limited possibilities. The 'bricoleur' may not ever complete his purpose but he always puts something of himself into it. » (Lévi-Strauss, 1962)

The do-it-yourself culture that was rediscovered recently represents a clear example of this posture by agents: while it can be oriented towards the attainment of a pragmatic goal –for instance to provide a house with a cabinet– the main motivation behind the involvement of thousands of individuals in the creation of furniture is that of exploring the subtleties of materials and tools, and to develop an awareness of the possibilities associated with the available technologies, materials and procedural knowledge. As highlighted in much literature on situated learning it is a form of learning that is triggered by practice and replenished of contents through practice. It is not though a routinely repetition of an action – or a set of actions– aimed at improving one's ability in doing something, like a form of exercise. It is, on the contrary, a set of actions aimed at creating workable objects in order to provide agents with knowledge related to causal relations among environmental resources and to explore the limits of what is possible and therefore thinkable.

3.2. Tinkering as delimiting the innovation search space: materializing the unknown and the intangible

Beyond being a form of exploratory practice aimed at producing theoretical knowledge for its own sake, tinkering represents also a mechanism through which extant knowledge is selected and enacted. Knowledge is unevenly distributed in society (Hayek, 1945) and generated by a number of actors through a variety of processes, either through the logics of the scientific inquiry or the practices of a number of actors in heterogeneous contexts (learning by using for example, externalities and spillovers). The development of novel products –and of novel technologies at large– is said evolve along trajectories characterized by high degrees of initial uncertainty and the subsequent emergence of dominant designs that gradually gain momentum (Dosi, 1982). We posit that tinkering plays an important role in technological trajectories since it selects and enacts extant knowledge and technologies produced or possessed by a variety of actors and orients their subsequent efforts in innovation search. Uncertainty at the initial stage of a technological trajectory is due to the existence of equifinality –any given thinkable outcome could be reached equally by all of the existing potential means– and equipotentiality –different outcomes could be reached by the same set of means. The realization of a workable object represents the instantiation of one of the several potential configurations that extant knowledge and technologies could assume. In particular it addresses extant dispersed knowledge and available resources towards specific types of functions and towards specific types of demands. We thus claim that the act of tinkering embodies extant knowledge and resources in an artifact that displays particular functions that satisfy specific demands. In doing this, the artifact *creates* both an industry – intended as an arena composed by actors contributing to the satisfaction of a specific (set of) needs and demands, and a market, intended as a specific type of user.

The creation of a workable material artifact –with its shape, architecture and structure and a distinguishing set of features and functions– represents a way to give a visible and concrete form to one possible future and to coalesce the efforts and search processes of a variety of actors whose knowledge is dispersed and autonomous. Such an artifact orients search processes by stakeholders and actors whose knowledge and resources have been enacted by the tinkerer and at the same time it suggests the potential organization of the innovative labor among all of the participants in an innovation system and a value chain. The artifact, thanks to its making components and their reciprocal relations visible and tangible, provides a template also for the coordination of efforts within the value chain of the innovative product or service in question.

3.3 Tinkering as framing and social mobilization

A number of accounts on the infancy of many of the technologies and innovations we became familiar with emphasize the role of activists and social movements in framing novel technologies to be understood and appreciated by prospective users and society at large (Davis et al., 2008; Rao & Giorgi, 2006; Rao, 2009). To interpret novelty, actors –consumers, citizens, and society at large– typically draw from their existing set of understandings and taken for granted frames (Goffman, 1959; Barley and Tolbert, 1997). Innovation is, as Hargadon and Douglas (2001) put it, a collision between «two social forces, one accounting for the stability of social systems and the other for change» (p.476). Proponents of innovation usually strategically bridge and mediate between the realm of technical possibilities and the institutional arrangements in which they are embedded. In order for a trajectory to gain momentum they need to legitimize novelty and mobilize stakeholders to command increasing commitment and resources. Such a mobilization, in addition, scales up by creating attention and tension among peripheral participants and the general public, creating awareness and familiarity with new categories and also the premises for a demand of new products or solutions. Literature on social movements and organizations has provided with accounts of how such a mobilization occurs, either through mechanisms of mindful deviation (Garud & Karnøe, 2001) or through more forceful acts of mobilization such as the construction of new sets of meanings and shared identities around *hot* causes (Rao, 2007).

Central in much of the analyses appealing to social mobilization of resources, stakeholders and commitment is the concept of frame and of framing practices. Frames are «schemata of interpretation that enable individuals to locate, perceive, identify and label occurrences within their life space and world at large. By rendering events or occurrences meaningful, frames function to organize experience and guide action, whether individual or collective» (Snow et al., 1986, p. 464). As Kaplan puts it «frames shape how individual actors see the world and perceive their own interests» (Kaplan, 2008): they are devices that create meaning, and enable either the conservation of social order in front of perceived threats, or the affirmation of novelty and the initiation of change. Their function is that of enacting selected portions of the set of ambiguous and varied signals characterizing a situation and combining them into an intelligible schema. While research on frames and framing processes has devoted a great deal of attention to symbolic action and interaction, we believe that artifacts should be considered as crucial instantiations of frames and framing processes and that their function is that of making the possible and the future intelligible, testable and verifiable. The shape, function, structure of the artifact, in fact, embody ideas and conceptions related to the potential uses, values and social situations in which the prospective product will have a utility. In our view tinkerers, in their quest for understanding the world and experimenting potential uses of knowledge and technologies, act as crucial actors in the mobilization of a variety of stakeholders by embodying identities and values in workable objects.

4. Pre-histories of industries and innovation: enter the tinkerers

An adage by Mark Twain (cit. in Ceruzzi, 2003, p. 207) resonates with our line of reasoning on the nature and role of tinkering and tinkerers: «very few things happen at the right time, and the rest do not happen at all. The conscientious historian will correct these defects». Economic accounts of innovation, indeed, often make sense of apparently chaotic and erratic events, sometimes alluding to a sort of economic inevitability (Sarasvathy, 2001). Often such inevitability takes the form of linear accounts of innovation that move from familiar entities – universities, research centers, firms and their R&D Departments– and familiar frames about the "normal" trajectory of innovation. Fortunately, actual historical accounts of the development of innovations and industries do preserve depth and breadth in the recognition of the congeries of events underlying the development of artifacts, markets and industries and we will draw on a selection of them to root our proposal into extant empirical evidence.

3.1 The birth of the airplane: a history of tinkerers

The inception of the airplane represents a fruitful area to delve into the complexities of invention and innovation and to trace the processes and mechanisms that brought to the constitution of the industry (this section draws on Gibbs-Smith, 1962). While everybody would agree on placing the starting date of the industry –and of the airplane itself– with the first flight by the Wright brothers in 1903, the very pre-history of the airplane and of the industry goes back at least one century. Almost all of the technical and functional features of the Wrights' airplane –elevators, rudders, devices to change the angle of attack, undercarriage and many others– were proposed, tested and built between 1799 and 1850 by an inventor and engineer from Yorkshire, Sir George Cayley who spent a large part of his life designing and building kites and gliders and tinkering around the idea of "flying machines". His interest was fueled by the success of helicopter models and of balloons, even though he was fascinated by the idea of a type of aerial navigation that was controlled and not natural (as in balloons). Not only he is seen as the father of the modern aircraft industry, but also the initiator of modern aerodynamics science applied to aircraft thanks to his speculations and publications that followed his experimentations.

It was Cayley that brought the airplane to his current functional form thanks to the idea of relying on fixed wings to provide lift and on an external source of propulsion for speed. Such a concept stood in stark contrast with the then dominating designs and concepts that mimicked birds' flapping wings (ornithopters). The understanding of aerodynamics applied to flight in Cayley's history is solidly attached to the observation and systematization of the outcomes of his experimentations with gliders and kites that he fixed on poles in the hills in the surroundings and that he flew with different angles of attack and different combinations of angles between fixed wings and tail wings. Simple devices –small models– as well as more complicated ones –such as a full-size glider of 300 square feet– represented the artifacts that constellate his path towards the refinement of a flying machine whose structure and design resembles that of modern airplanes. While he practically solved issues related to aerodynamics and lift, propulsion remained his unsolved challenge, although he attempted to provide it with different types of flappers, gunpowder propelled engines, airscrews.

Epistemic action

Our definition of tinkering posits that tinkering and the creation of workable artifacts is an exploratory activity through which theoretical –abstract– knowledge about the world is produced. The case of Cayley is exemplar from this point of view. Fascinated by the flight of birds, by balloons and attracted by the idea of controlled flight, he started experimenting with materials and different propulsion systems. Testing his creations –kites and gliders– he gathered observations and evidence related to the forces governing aerial navigation. His reflections on the outcomes of the experiments and his elaborations on the behavior of objects in the air were published in a series of memoranda. The memoranda Cayley jotted down to document his experiences were collected in three papers that were published by the Journal of Natural Philosophy, Chemistry and the Arts in 1809, 1810, entitled "On Aerial Navigation". Within these writings Cayley identified and scientifically defined the four aerodynamic forces of flight (weight, lift, drag, and thrust) and *de facto* stimulated further scientific advancements and research endeavors in aerodynamics.

Delimiting search

A number of enthusiasts of flying machines and aerial navigations were experimenting with a variety of potential solutions and artifacts all around the world. With Cayley as an initiator, the pre-history of the airplane is characterized by a number of other tinkerers working autonomously on the idea of flying machines. Alphonse Penaud during the 1870s was responsible for the improvement of propelling systems in unmanned models of flying machines through the introduction of twisted rubber engines and of design innovations that remained in the sector, such as the wings curved upwards at the tips and the rear stabilizer (Chanute, 1894). Lawrence Hargrave in Australia built box-kites whose form resembled that of modern biplanes. Samuel Langley in the United States at the turn of the century built together with his collaborators a model of airplane large enough to carry a person. Langley, backed from the War department, was among the first tinkerers in the pre-history of airplane production to enjoy the availability of capital and institutional attention. The Wright brothers, then, acquainted with many of the publications either written by these or early inventors or by journalists working for aeronautic magazines, triggered the modern history of aviation and airplanes (Meyer, 2012).

The circulation of publications such as Cayley's papers and publications edited by aeroclubs in different nations sustained the diffusion of these designs thus delimiting the space of search for solutions. Crucial design solutions such as fixed-wings –as opposed to flapping wings–and the separation of the sub-systems providing speed from those providing lift characterized many of the pioneering artifacts and prototypes realized around the world by these tinkerers and were the result of the consolidation of a "dominant design" originated by Cayley and refined by other tinkerers in many other places.

Framing and mobilizing

While balloons were a familiar category during the 1800s, airplanes represented an entirely new concept. The mobilization of resources and actors around the emergent concept was strictly connected to the activism of tinkerers –that were continuously demonstrating the potential of their creations– and to the gradual involvement in their experimentations of flight and balloon enthusiasts. Publications depicting and describing the artifacts and their features started circulating in aeroclubs around the world; tinkerers and engineers such as Octave Chanute compiled anthologies of prototypes of flying machines he encountered in his wanderings (1894). Wright's brothers demonstrative flights in Le Mans (France) at the very beginning of the century provided yet another occasion to envision the product and to make sense of its uses and future perspectives, generating attention and momentum on the novel category. The interest and curiosity for the airplane attracted also a number of firms operating in other industries that relied on the prototypes and on their observation and framing in publications and shows in order to start thinking about their industrial production. Short Brothers, a Northern Ireland firm building aerial balloons, devised that this new type of flying machines would have substituted balloons and turned their production facility into a plant devoted to the design and development of airplanes based on Wright brothers' designs. In 1908 they received two orders from amateur aviators: Charles Rolls –founder of Rolls-Royce, a client who had the chance to appreciate their work as balloon manufacturers– and another member of the Aero Club of Great Britain. Later Short Brothers built 6 airplanes for Wright Brothers and started to produce airplanes on an increasing scale in the 20s and 30s.

3.2 Tinkering and the inception of the personal computer

The inception of the personal computing as we know it has been narrated a number of times in scholarly outlets and in the popular press. Ceruzzi's (2003) exhaustive compilation of the major events constellating the history of modern computing provides a detailed chronology and account of the creation of the personal computer. As he puts it, at the beginning of the 70s the two main "souls" of the product –the microprocessor and time-sharing systems– were two forces proceeding independently and reciprocally oblivious. Engineers like Moore, Faggin (those that made the history of Intel and developed microchips) were perfecting silicon microchips and memory chips that were ever more powerful and increasingly cheap. On the other hand there were experimenters and users of time-sharing systems that were seen as the early means to access public computing.

Producers of chips proceeded along the path of single-purpose machines: the business idea behind Intel operations was that of selling the product to industrial customers who would have written «specialized software for it, which was then burned into a read-only-memory to give a system with the desired functions» (Ceruzzi, 2003, p. 222). The final product was no longer programmable and was going to be used for specific purposes. Thanks to the experimentations and tinkering of its engineers, though, Intel already developed more sophisticated systems, which aimed at the general purpose computer concept. They were named "Development systems" and were thought of as platforms for customers to actually test the software they were writing –in FORTRAN or other specialized languages. Even though these systems represented the progenitors of the personal computer, the idea never made into the plans and perspectives of Intel and its internal tinkerers/engineers.

The encounter between the two forces and the potentiality they had in store for the computing industry was triggered by the activities of hobbyists and minicomputer enthusiasts that during the seventies bought kits for amateurs that allowed them to upgrade their experimentations from the construction of radio or audio equipment to the construction of electronic artifacts. For instance, as reported in Ceruzzi the current configuration of a personal computer –a processing unit, an input unit and a video output unit– was the result of the experimentation of a tinkerer, Don Lancaster, whose project of the TV-typewriter, published by the magazine Radio-Electronics in 1973, that actually shaped the idea of the personal computer.

Delimiting search

The progenitor of the personal computer, the Altair minicomputer based on the Intel 8080 processor and created by H. Edward Roberts, represents the first exemplar of minicomputer that had both a large commercial success and that aligned with the performances of the more expensive products realized by firms such as DEC. It was sold as a kit to be assembled and then expanded and programmed by the legions of enthusiasts around the United States and Canada. Its adoption by a number of tinkerers and computer enthusiasts was due to gaming eminently, which it made possible and relatively easy. The fact that the Altair did not store the data when it was shut off brought both autonomous tinkerers and those working for extant companies in the industry to design and develop external storage devices, such as audiocassette recorders or floppy disks, an example of delimitation of innovation search following from the shape and functions offered by a workable object realized by a tinkerer. Similarly, the need to program easily and flexibly these machines brought other tinkerers and experts – namely Bill Gates and Paul Allen– to start working on compilers and programming languages that enriched and deepened the scope of uses and functions of these mini-computers.

Epistemic action

Other figures and institutions occupy a central role in the history of the personal computer. The one that is often mentioned as the “cradle” of the personal computer is the Xerox PARC, located in Palo Alto. Staffing the center was a relatively easy task for the head of PARC, since in the 1970s a mounting opposition towards the financing of basic and applied research –in computing and in other fields– by the Department of Defense and for military purposes. While the institutional solution envisioned was that of shifting the financing and governance of US research to a non military authority, the National Science Foundation, the lack of resources it suffered at the beginning and the uncertainty that characterized the life and work of scientists at that time made PARC an interesting perspective for academics doing research in fields connected to computing. Psychologists doing research on the augmentation of human intellect, students of ergonomics, electronics and the like found in PARC a playground to tinker with novel technologies and machines around novel concepts of computing artifacts in order to produce scientific –that is abstract– knowledge relevant for theories and conceptual frameworks in their fields (Ceruzzi, 2003). The current WIMP interface (Windows, icons, mouse and pull-down menus) that we still use in our personal computing devices, as well as the very concept and design of the personal computers and of its peripherals, were developed in PARC. As the story goes and has been told a number of times (cf. also Isaacson, 2011)

Framing and mobilizing

While a variety of tinkerers were developing the constitutive modules and elements of the personal computer in a number of places in the United States –both autonomously and within established firms or research institutions– the very concept of the personal computer started “leaking” from circles of experts to become increasingly interesting for both prospective regular consumers and for firms working in a variety of technologies and fields. Clubs of hobbyists played a crucial role in framing the object and in mobilizing resource. They gathered some charismatic figures we have learned to identify as the "creators" of the personal computer. Steve Jobs and Steve Wozniak are two among the most celebrated figures from this standpoint. As Ceruzzi (2003) puts it «The Apple II came closest to Stewart Brand's prediction that computers would not only come to the people, they would be embraced by the people as a friendly, nonthreatening piece of technology that could enrich their personal lives. The engineering and design of the Apple II reflected those aims» (p. 264). The object and its peculiar and recognizable design –both functional and aesthetic– was the result of the tinkering activities of the two founders of Apple and a number of other actors in the Homebrew Computer Club. «The Apple II was a tour de force of circuit design. It used fewer chips than the comparable Altair machines, yet it outperformed most of them. It had excellent color graphics capabilities, better than most mainframes or minicomputers. That made it suitable for fast-action interactive games, one of the few things that all agreed personal computers were good for. It was attractively housed in a plastic case. It had a nonthreatening, nontechnical name. Even though users had to open the case to hook up a printer, it was less intimidating than the Altair line of computers.» (Ceruzzi, 2003, p. 264). Elegance, simplicity, performance and a clear indications of the potential uses of the new machine (personal productivity, multimedia, creative endeavors, gaming) gave the product a visible meaning and envisioned for consumers and companies operating in the industry a purpose and a direction, thus creating momentum around the emerging "personal computer" concept.

4. Tinkerer: who art thou? Suggested paths for future research

The definition of tinkering we advanced in the previous sections aims at providing an illustration of the mechanisms through which tinkerers contribute to innovation processes. As stated, we see tinkerers as actors enabling innovation processes both in a linear frame of reference –that is in R&D and science-driven innovation processes– and in an emergent one – based on doing, using and interacting. We see tinkering as an activity that sustains three mechanisms: the first is the creation of abstract knowledge and theories that can fuel scientific endeavors through practice and intimacy with materiality; the second is the delimitation of the scope of innovation search for actors participating in an innovation trajectory and in a technological *filiere*, by making the shape, function, structure and architecture visible and tangible; finally we see tinkerers as *agit-props* that, starting from the artifacts they create, provide prospective consumers and stakeholders with a framing that makes novelty intelligible, legitimate and, ultimately, desirable. Moreover, and as a consequence of the delimitation of the innovation search, tinkerers through their prototypes mobilize the resources of other tinkerers and firms in an extant or emergent industry, providing *de facto* a device that serves as a mobilization and coordination device.

But who are the tinkerers? Are they the computers enthusiasts that populated the Silicon Valley in the 60s and 70s, or the legions of hobbyists tweaking their hardware to suit it to their needs? Are they ingenuous and extremely practical individuals such as Cayley? Where are they located? (see Table 1).

As it was made explicit in the previous sections we advance a functional definition of tinkerer, *vis-à-vis* a definition that relies on occupational status or on institutional affiliation (or lack thereof). In the literature, tinkerers have been called with different names in relation to different industries and geographical context they are involved in. They are the engineers working in Silicon Valley, as AnnaLee Saxenian described, that play a central role both in producing new ideas and in spreading them within different firms, contributing to the accumulation of local culture and knowledge. Those engineers play with technology, they constantly build prototypes and test them in a continuous *beta* approach (that eventually became part of the Google approach to innovation). Those engineers act as active nodes between the making of physical artifacts and the formalized pipelines of product development managed by firms. Tinkerers are, also, advanced consumers, as largely shown in the literature on user-driven innovation, on user entrepreneurship and in general on open innovation dynamics and processes (Shah & Tripsas, 2007; Von Hippel, 2003, 2005). These users mix and match products at hand (available in the market) in order to build something tailored to their needs. Those consumers are not alone but they organize themselves in communities where they share knowledge, experiences and advices.

Tinkerer	*Location*	*Industry*	*Literature*
Engineer	Silicon Valley	ICT	Saxenian (1996)
Consumers	Online (community) Temporary clusters (events/fairs/meetings)	e.g. Sports, software, gaming	Shah, Tripsas (2007) Von Hippel (2003) (2005)
Artisans	Italy, Industrial districts	Low -Tech, traditional industries	Bettiol, Micelli (2013), Micelli (2011)
Makers	Online (community, open source) and temporary clusters (events/fairs/meetings)	3D printing, hardware	Anderson (2012)
Tweaker	England (IX century)	Steam engine, looms	Meisenzahl, Mokyr (2012)

Table 1. Different instantiations of Tinkerers

They are also artisans and craftsmen that, with the knowledge developed with their hands and physically working with different materials, provide large-scale producers with prototyping competences, modeling capabilities, customization services thus functioning as active nodes in complex value chains. These once considered marginal figures played, as an example, a pivotal role in the success of Italian design movement (Bettiol, Micelli, 2013-forthcoming). The legion of makers and do-it-yourself enthusiasts celebrated in newspapers, magazines and recent essays such as the book *Makers* by Chris Anderson represent another promising area in order to understand how tinkerers can be appropriated entrepreneurially by the elaboration of peculiar business models.

Another interesting area where tinkerers play a crucial role is related to the benefits –or lack thereof– of the contiguity between R&D activities and manufacturing operations in nurturing and sustaining innovation systems (Pisano, Shih, 2009; Herrigel, 2010). The development of the conceptual underpinnings of our definition of tinkering, pointed explicitly to the availability of material resources as a condition of tinkering. Tinkerers in fact are *bricoleurs* making do with what is at hand. Our definition of tinkering, thus, see this activity as a combinatorial activity that is enacted and fueled by the contiguity with places in which materiality and material cultures are rooted and lively. Starting from our preliminary and exploratory proposal, future research efforts could frame the issue of materiality and material cultures and their role in innovation processes, thus bridging between literatures and theoretical frameworks addressing the issues of globalization and the international division of labor and innovation dynamics.

Finally, even though we provided a definition of tinkering and tinkerers that adds qualifications to the one of *tweaker* proffered by Meisenzahl and Mokyr (2012). Tweakers, in their definition, were those that improved and debugged existing inventions, while we are referring to individuals that do not fit with the other figure they isolate, that of the inventors that produced and developed breakthrough innovations to solve «major bottlenecks». In other words they refer to tweakers as to the tinkerers that adopted extant innovation and products and modified them marginally in order to increase their performances and utility. Our figure of tinkerers does position itself between the two they identified and our definition of tinkering defines precisely the activity of creating workable artifacts out of extant resources as the distinguishing feature of these individuals. While our definition fits with the pervasive nature of tinkering either within organizations and without, we recognize that a "hierarchy" and a more fine-grained distinction among tinkerers is required in order to weight the different contributions that these individuals provide to the development of innovations.

We are aware of the limitations of this paper that is both speculative and tentative. We need to enrich our research deepening our literature review, identified precise hypotheses and test them through a rigorous empirical work.

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