Knowledge communities, a key element in six-sigma implementation strategies and deployment

Silvia **PONCE** and Sid-Ali **ZAHAF**

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Résumé

Les résultats d'une étude exploratoire des programmes six sigma de cinq entreprises canadiennes, montrent que le développement des communautés des connaissances et apprentissage serait un élément important à considérer dans les initiatives six sigma. Les études de cas soulèvent des aspects particuliers dans les efforts d'implantation et du déploiement. On soutien que la configuration des activités, et notamment la structure des communautés de connaissances des organisations, constituent des éléments critiques au succès de l'implantation du six sigma et de son déploiement.

Mots-clés : Structure de connaissances six sigma; Communautés de connaissances; Hiérarchies cognitives; Modularités des équipes; Études de cas.

Abstract

The results of an exploratory study of six-sigma programs, in five Canadian enterprises, suggest that the development of knowledge and learning communities is instrumental to sustaining six-sigma initiatives. Case studies highlight particular aspects of implementation and deployment efforts. It is argued that the configuration of activities and especially the structure of knowledge communities in organizations are critical elements of successful six-sigma implementation and deployment.

Keywords: Six-sigma knowledge structures; Knowledge communities; Cognitive hierarchies; Team modularity; Case studies.

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Introduction

Six-sigma is probably one of the most attractive and typical "best practice" in the new knowledge-based economy. Within many corporations, the pursuit of ambitious financial goals and gains—mostly inspired by the success stories of Motorola and General Electric (GE)—is sustained by knowledge workers that develop databases, adopt project management styles and implement knowledge-based organizational structures. At the same time, the practice has spawned a host of new businesses, leading to the development of a dynamic market comprising a variety of knowledge-based services, notably training, consulting, distribution of software applications and information technology support.

Since its introduction in the mid-eighties, many large corporations have been investing substantial resources in six-sigma efforts, as a means of accelerating their learning and taking the prescribed path to spectacular financial achievements. Although some firms have succeeded, some of the biggest have not been enticed by the approach, others have abandoned their six-sigma initiatives and many are struggling for survival.

Business experts and analysts attribute six-sigma effectiveness and success to the package that facilitates its implementation. Accordingly, managers are not expected to work out the "how to" because the blueprint of the implementation, i.e. the road map, has been tested and proved successful (Hammer & Goding, 2001). Clearly, this line of thought implicitly assumes that knowledge transfer is straightforward.

It has also been claimed that six-sigma is "the most important breakthrough management tool ever devised" (Harris & Schroeder, 2000). In contrast, it has also been argued that the six-sigma trend is harmful to the quality profession, destabilizing previous quality efforts and organizations (Dalgleish, 2003).

To better understand contradictory perceptions and public debates on six-sigma and its benefits, and to lay the foundations for subsequent systematic research, an exploratory study on six-sigma implementation strategies and deployment was conducted. Five case studies in Canadian enterprises shed light on knowledge aspects of the implementation of six-sigma initiatives. The objective of this article is to present the results of this study. Findings suggest that six-sigma programs should be reviewed from a knowledge perspective. The development of knowledge and learning communities emerges as a key issue in sustaining six-sigma implementation and deployment. The configuration of six-sigma related activities and the structure of these knowledge communities within organizations apparently play a critical role.

The article is structured as follows. First, building on a literature review, implementation strategy and deployment of six-sigma programs are discussed. Second, case study methodology, descriptions and findings are presented. Third, six-sigma is reviewed from a knowledge perspective and hypotheses are formulated. A discussion of managerial and academic implications concludes the paper.

Literature review

The practice of six-sigma has mainly been discussed in specialized publications by practitioners and consultants through descriptive cases and prescriptions based on their personal experiences (Tatham & Mackertich, 2003; Bailey, 2001; Zinkgraf, 1998). Impressive figures on investments, returns and program scope are conventionally included, which is a deterrent to small organizations (McClenahen, 2004; Godfrey, 2004; Anonymous, 2003b, Hammer, 2002; Harry, 1998). Moreover, much of these works build on the same success stories (Snee & Hoerl, 2003, Lucier & Seshadri, 2001, Henderson & Evans, 2000; Harry & Schroeder, 2000). Little evidence of systematic academic research has been referenced, although a set of key elements and major issues related to implementation and deployment, presented in this section, are recurrent.

Key six-sigma elements

In general, previous publications have provided prescriptive guidelines for six-sigma implementation. Four key elements are identified: (1) Top management engagement and leadership, (2) six-sigma blueprints of the implementation road map, (3) six-sigma organizational structure, training and DMAIC (define, measure, analyze, improve and control) methodology and (4) financial gains and benefits (Snee & Hoerl, 2003, Eckes, 2001, Pyzdec, 2001, Neuscheler-Fritsch & Norris, 2001, Harry & Schroeder, 2000).

Six-sigma programs may differ in scope but all major works agree that six-sigma implementation is a top-down, strategic and robust process (Snee & Hoerl, 2003, Lucas, 2002, Smith & Blakeslee, 2002, Pzydec, 2001, Harry & Schroeder, 2000, Yilmaz & Chatterjee, 2000, Breyfogle III, 1999). Top management commitment, leadership and customer focus are critical components of six-sigma philosophy (Byrne, 2003, Bañuelas & Antony, 2002, Anonymous, 2002a, Douglas & Erwin, 2000). The alignment of six-sigma initiatives to strategic intent, and objectives, is thus not an open question; despite the down-top technical roots of the approach (Lucier & Seshadri, 2001, Harry & Schroeder, 2000).

Strategically, it should be noted that some companies manage to navigate in the present business world without embracing it, as 3M's CEO James McNerney recently suggested. After explaining that process improvement and quality programs at 3M, including six-sigma, were a sort of "a menu approach", three years ago, McNerney recently said: "…I just felt very strongly that the entire company needed to adopt one methodology, [to develop] a common language. Quite frankly, it didn't have to be Six Sigma. But Six Sigma was something I was familiar with. I believed in it and a number of the people in the company also did, so that was sort of the one we all decided to go after." (McClenahen, 2004).

Accordingly, it is acknowledged that six-sigma provides focus, a framework for structuring management and improving processes. Defining the way business is done, six-sigma becomes the DNA of organizations (Tatham & Mackertich, 2003; Smith & Blakeslee, 2002; Bailey, 2001). Additionally, many firms are grappling with the question of how to integrate six-sigma into other practices and quality approaches. Marash (in Kohnen, 2004), has recently advocated for fusion instead of confrontation. Hammer (2002) in turn, has positioned six-sigma under the process-management umbrella, whereas Klefsjö *et al.* (2001) has placed six-sigma within total quality systems. A more conciliatory approach that emphasizes complementarity has been proposed by Kubiak (2003), who recommends systemic integration through the development of links among different approaches. Nonetheless, promoters of the Malcolm Baldrige, the National Institute of Standards and Technology (NIST), have indirectly positioned six-sigma at the bottom of a hierarchy, at a process level, under ISO 9001: 2000 and the Baldrige (Anonymous, 2002c).

The six-sigma road map is widely discussed in the literature, particularly as a success factor (Byrne, 2003). Broadly, it consists of three overlapping stages: (1) preparation, (2) implementation and (3) deployment. In these stages, training at different levels and degrees is required. Training prepares knowledge workers (black belts, green belts and other roles), strengthens organizations and determines the continuity of six-sigma initiatives (Voelkel & Chapman, 2003). Training shapes six-sigma organizational structures and builds six-sigma strategies. Accordingly, Sanders and Hild (2000) have outlined three six-sigma implementation strategies based on the way six-sigma organizations are trained and structured: six-sigma organization, six-sigma engineering organization, and strategically selected projects and individuals.

Training systems are hierarchical (Kubiak, 2003, Hoerl, 2001, Ingle & Roe, 2001, Sander and Hild, 2000). Yet beyond technical aspects (DMAIC methodology, techniques and tools) and certification programs, training modifies people's roles and transforms organizations. Snee (2003) has identified up to 11 interacting six-sigma team member roles, while Milivojevich (in Voelkel, 2002) report two parallel structures. In any case, training develops cognitive hierarchies that co-exist and interact with

traditional authority-based hierarchies. Incidentally, Harvey (2003) illustrated this particular interplay when he had said that at Bombardier, "a master black belt instructs the boss of his own boss".
The maturing of six-sigma programs has ushered in discussions of new issues regarding implementation, deployment and applicability in the literature. Nascent topics include continuity, human resources involvement, e-commerce, six-sigma technology support and integration of technologies (Godfrey, 2004, Fister Gale, 2003, Little, 2003, Kendall & Fulenwider, 2002, Eckes, 2002; Smith & Blakeslee, 2002). Nonetheless, the adoption of six-sigma in services and small organizations has received little attention.

Derivatives such as DFSS, Design for Six Sigma or I-DFSS, Innovative design for Six Sigma (Antony, 2002), DeFeo & Bar-El, 2002) are another area of concern. Making designs more robust increases customer satisfaction (Douglas & Erwin, 2000), significantly enhancing the potential of six-sigma principles in their applications to areas other than predictable processes. For close to two years, the application of six-sigma to R&D has also been discussed in panels sponsored by the Industrial Research Institute (IRI), in the United States. The panels notably agree that six-sigma and DFSS are distinct philosophies, not tools, addressing core organizational competencies (Johnson & Swisher, 2003; Johnson, 2002).

Nonetheless, Bañuelas & Antony (2003) have argued that switching from six-sigma to DFSS, is not a straightforward decision. The DMAIC methodology must be converted to a DMADV methodology (define-measure-analyze-design-verify), a non-reactive, non-incremental methodology able to "discard existing processes and substitute them with radical ones" (Bañuelas & Antony, 2003). Design teams of major corporations practicing DFSS have introduced dramatic improvements, but, as Treichler et al. (2002) argue, deployment is neither an easy task nor a rapid transition.

A major issue on deployment

Bertels & Patterson (2003) explain that most of the time, six sigma deployment follows a three-stage process: (1) demonstration of potential for success, (2) strategic process improvement and (3) transformation. Two mechanisms sustain deployment to drive improvements: the project (usually short term, four to six months), and the workshop (very short, usually one week) aimed at instantaneous transformations (Harvey, 2003).

Selection of business processes and projects is a major endeavor. It has been described as the six sigma's "Achilles' heel", "the most difficult element of six sigma deployment" and one of the "many paths of resistance" (Voelkel & Chapman, 2003, Snee & Rodebaugh, 2003, Kelly, 2002).

The selection of six-sigma projects appears to be critical for two main reasons. On one hand, it has a tremendous impact on the continuity and performance of six-sigma initiatives (Bertels & Patterson, 2003). On the other hand, it is extremely demanding in experience, time and resources. Experience cannot be overestimated (Lynch *et al*., 2003). Tracking and scoping projects shape and determine six-sigma programs, although discussions on the "how to" and supporting tools have only recently surfaced in the literature (Conklin, 2003).
Snee & Rodenbaugh (2002) have identified four key phases of project selection and process maturation: (1) Identification of BB projects, (2) creation of a project hopper, (3) examination of the project portfolio and (4) creation of an integrated improvement system. Bertels & Patterson (2003) contend that project selection at organizations comprises three phases: (1) Opportunistic project selection, (2) linking to strategic imperatives and (3) using a process management system. Kelly (2002) puts forth an alternate view, labeling the phases as (1) Identifying a project selection steering committee, (2) adopting a project selection matrix and (3) scheduling fixed customer and project evaluation meetings.

The major aspect driving the exploratory research, described in the next section, is the strong prescriptive tone of most of the reviewed publications.

Case studies

Five companies leading six-sigma programs agreed to participate in the research. Three are Canadian divisions of three different large American corporations. Of the remaining two firms, both are distinct divisions of the same large, diversified Canadian corporation.

Research Methodology

The research followed the design proposed by Yin (1994) for single exploratory case studies. Official six-sigma programs were the unit of analysis. Data collection techniques included document analysis and semi-structured interviews (Kvale, 1996). Content analysis involved transcription and coding.

Two interviews were conducted at each company, and at least one of the participants acted as a main data source, that is he or she allowed at least one hour for the interview (these interviews were recorded). All participants had been directly involved in an official six-sigma program for more than two years, and 80% had been working on such programs on a full-time basis. Table 1 summarizes the interviewers' profile.

Table 1
Interviewers' profile

Case	*Main data source*	*Second data source*
A	Certified Black Belt	Six-sigma vice-president
B	Six-sigma vice-president	Black Belt
C	Quality leader	Black Belt (non certified; part-time basis)
D	Master Black Belt	Green Belt (part-time basis)
E	Master Black Belt	Black Belt

Three main questions were addressed in this exploratory research:

(1) What is the role of top management in the six-sigma program implementation?
(2) Which are the most important elements in the six-sigma implementation road map?
(3) What real gains can you attribute to the six-sigma program?

Results were validated by e-mailing a report to each company and soliciting the feedback of participants whose role was main data source.

Description

Companies A and B are principal divisions of a large, diversified multinational Canadian corporation that employs thousands of people in North America and Europe. They design, manufacture and distribute innovative products and services worldwide. Their six-sigma initiatives took shape in the late 90s, after the CEO realized the important gains and benefits of AlliedSignal and General Electric's six-sigma programs. The program was in fact a logical follow-up to previous TQM and continuous improvement efforts.

Smaller than company B, company A was the chosen division for the six-sigma implementation pilot project in the corporation. B had officially launched its six-sigma program by the end of the nineties, nearly two years later than A, as illustrated in Figure 1, which summarizes the milestones that reflect the dynamics of six-sigma programs.

Figure 1
The dynamics of six-sigma programs

Case	*The companies' road map*
	1995 *2000* *2005*
A	● Top management decision; executives (champions) training. ● First six-sigma implementation effort: Formation of the first pilot implementation team (12 to 15 people); training at all hierarchical levels. ● Dissolution of the first pilot team: Six-sigma potential demonstrated; major problems encountered at the organizational and project selection levels. ● Formation of a second pilot team; hiring of an experienced consultant; middle management resistance to six-sigma initiative. ● Second six-sigma implementation effort officially launched; CEO message to middle management (more than 100 people): "if you do not commit yourself to our six-sigma program, you quit the company". ● Six-sigma deployment.
B	● Six-sigma implementation officially launched. ● Six-sigma leadership and top management commitment is demonstrated. ● Six-sigma deployment.
C	● Top management decision and commitment; training at all hierarchical levels. ● Six-sigma implementation driven by shareholders' value creation. ● Six-sigma deployment; shift to customer satisfaction orientation.
D	● Six-sigma mandate (from the headquarters) received by top management. ● Six-sigma implementation oriented to fulfil the mandate. ● Six-sigma deployment.
E	● First six-sigma program launched; top management mandated to commit to the program by the American headquarters. ● Second six-sigma program launched, lean six-sigma and DFSS approaches. ● Six-sigma deployment.

Company C is an important Canadian service division of an American corporation highly committed to six sigma initiatives. It employs nearly 300 people in Montreal. The six-sigma experience of the American headquarters has been extremely beneficial to its six-sigma implementation and deployment.

Company D is a division of one of the leading Canadian manufacturers, distributors and exporters in its field. More than 50% of its stock is held by an American corporation highly committed to six-sigma, but its own initiative has not derived any benefits from its shareholders experience.

Comparable in size to A, C and D, company E is a large Canadian division of a mature American corporation. Since the late 1990s, after an impressive performance in the early 90s, the division had been struggling for survival. As illustrated in Figure 1, the company is working on its second effort to implement and deploy a six-sigma program. Companies A and E belong to the same industry.

Chronologically, six-sigma programs were launched at approximately the same time at A, C and D; the remaining programs started nearly two years later.

Main findings and discussion

The findings are presented in two steps. First, critical facts are summarized according to the key elements coded throughout the case data collection and analysis (Yin, 1994). The ensuing discussion compares the dynamics of six-sigma programs.

Effective role of top management

As Figure 1 illustrates, building companies' commitment to six-sigma programs has not been an easy task. Some companies had to conduct a second launch effort, and top management commitment to six-sigma was not necessarily achieved before official programs were launched. Some cases showed an authoritarian leadership. Over time, only companies A, B and C demonstrated strong commitment.

Characteristics of six-sigma implementation road maps

Prescriptive models described in the literature appear to be too simplistic and not suitable in describing the intensity of different elements and the configuration of activities comprised in road maps. Moreover, a variety of training efforts and six-sigma organizational structures were observed: silo (company A), process (company B) and matrix (company C). By comparison, the organization structures of companies D and E were far less developed and structured than A, B, or C.

Selection of business processes and six-sigma projects

Little data was provided by the companies under study, but companies A and B demonstrated that learning was taking place. C had adopted headquarters' tools and mechanisms. D had introduced isolated elements and E was seeking to develop a system. In all cases, the behavior showed opportunistic characteristics.

Gains and performance measurements

When interviews took place, four of the five companies were working on the reengineering of their performance measurement systems; only D was not prepared to invest in the system. Awareness of small improvements rather than breakthroughs had led these companies to define strategic indicators and mechanisms to track and sustain initiatives. C demonstrated continuity and progress in gains. Gains at A and B were significant, although not impressive. D's gains seemed comparable to E, who was striving for results.

Discussion

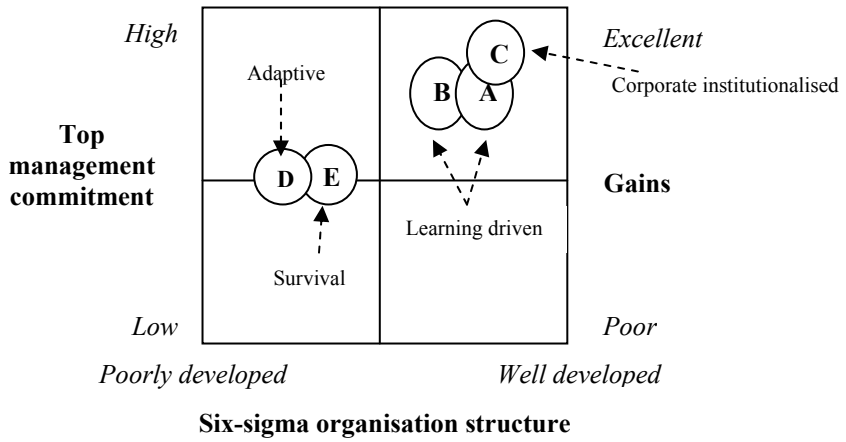
Using replication (Yin, 1994), cases were positioned along three of the four elements presented above. Two groups appeared, as seen in Figure 2. Six-sigma implementation and deployment programs at A, B and C were advanced, whereas they lagged at D and E. Building on codified evidence, six-sigma strategies were classified as learning driven at A and B, corporate institutionalized at C, adaptive at D and survival at E, as illustrated on the same figure.

To summarize additional supporting evidence: A, B, and C showed a comparable proportion of employees participating in six-sigma initiatives on a full-time basis and high top management commitment. C's better performance was attributed to customer-driven initiatives and program maturity. D and E were definitely weaker in: six-sigma organization structure, number of participants, time and integration. In addition, their training programs were far less structured than the remaining companies. E was slightly better structured and committed than D.

The small sample size did not allow for establishing cause-effect relations or correlations among the three elements illustrated in Figure 2. Chronological differences aside, insights were gained from

coding, which brought to light differences attributed to the dynamics of knowledge taking place in six-sigma experiences, suggesting a possible avenue for explaining the two categories described in Figure 2.

Figure 2
Six-sigma strategies and deployment: A comparative classification



Companies A, B and C provided evidence of the way their six-sigma knowledge had been developed. Following their initial training and learning, people at different levels were committed to applying new acquired knowledge. Many mechanisms that facilitate exchanges, interactions and sharing, as part of their six-sigma routines, had been devised. At A and B, cognitive hierarchies, as suggested by Sanders & Hild (2000), were built by "segmenting" people on the basis of their intellectual capabilities and their potential to learn. Interactions, as pointed out by Snee (2003), had been developed formally and informally, creating cohesiveness and a favorable environment for learning activities. It thus appeared that Piaget's (1972) theory of learning has been reproduced.

Contrarily, companies D and E provided explicit evidence of confusion in the understanding of six-sigma meaning, absence of institutionalized mechanisms of interaction and sharing, and little time available for informal exchanges, even if individual enthusiasm was evident.

What the study suggests is that six-sigma programs should be reviewed under a knowledge perspective to better understand the dynamics underlying initiatives. A preliminary effort in that direction is presented in the next section.

A knowledge-based analysis

Despite rapid developments in the knowledge management domain (Swartz, 2003), choosing a knowledge framework to analyze the dynamics of flows of six-sigma knowledge and its management is apparently not an easy task. Yilmaz & Chatterjee (2000) have somewhat adhered to Deming's system of profound knowledge (Deming, 1986), but an integral approach that combines knowledge transfer mechanisms and knowledge management interplays, in addition to knowledge content, should be suitable for analysis of six-sigma knowledge patterns.

"Contextual demands for knowledge application dictate which path to pursue", concluded Kakabadse *et al.* (2003) after compiling five knowledge models. Nevertheless, the authors contend that

knowledge absorption determines the focus on either knowledge transfer or knowledge management. Six-sigma knowledge dynamics, however, do not resemble a dichotomy. The application of Kakabadse *et al.*'s taxonomy demonstrates that the six-sigma knowledge model is extremely complex. Although closer to network and community models in characteristics, it takes from the elements of the five models these authors have identified – philosophy-based, cognitive, network, community, and quantum –. Accordingly, six-sigma knowledge model seems to be eclectic or composite.

Epistemologically, six-sigma follows the American pragmatism in three of its fundamental aspects: the definition of knowledge as an activity, its search for meaning and its utility (Collinson, 1987, Moore, 1972, Popper, 1972). Ontologically, six-sigma methodology is positivist in nature, it is data-driven, a practice based on facts. In contrast, the six-sigma knowledge model also combines interpretative elements (in character), individually and collectively. No fewer than 11 interactive roles have being identified (Snee, 2003). Such variety brings out the standardization of processes to reduce variability and transfer codified knowledge while sharing tacit knowledge to re-create and apply new knowledge acquired through training (Biedry, 2001).

Six-sigma related activities require people that can combine implicit and explicit knowledge locally. A good example has been provided by Biedry (2001), illustrating the use of human creativity in six-sigma analysis. In light of managerial concern and from a practical point of view, the point should be "the search" for effectiveness and efficiency of knowledge transfers and knowledge management occurring in six-sigma implementation and deployment. Consequently, particular six-sigma knowledge flows should be characterized. Insights into these dynamics can be gained by reviewing six-sigma at inter-organizational and intra-organizational levels, as follows.

Inter-organizational dynamics of six-sigma knowledge flows

For nearly two decades, the rapid expansion of six-sigma has powered the evolution of an important institutionalization process. As illustrated in Figure 3, which compiles some of the most relevant documented events as well as growth in publications (at the top of the figure), a diffusion process captures the dynamics and the impact six-sigma has had on business activities, at the inter-organizational level. Three stages of development are identified: birth and development of the approach, legitimacy and growth and institutionalization and propagation.

Along these three stages, new knowledge has been created by building on early adopters' learning and experiences, which could be explained as a social construction process around the practice. Nonetheless, it is important to determine how this diffusion process has been replicated in organizations.

Intra-organizational six-sigma knowledge analysis

Case studies show that the knowledge dynamics of the intra-firm six-sigma diffusion process does not necessarily follow the macro-linearity of the diffusion portrayed at the inter-organizational level. Codified evidence reveals a major contrast. The double efforts of cases A and E, in particular, suggest that regardless of the intensity of top management commitment, a "learning by doing" process is taking place, making six-sigma implementation a one step forward one step back process within organizations. These dynamics appear are consistent with Popper's theory that knowledge grows through criticism and inventiveness as well as based on previous knowledge (Popper, 1972).

Formal cognitive hierarchies were found in all of the five companies examined, but cohesiveness and interactivity, facilitating knowledge sharing, differed between the two categories illustrated in Figure 2. Owing to their characteristics, these two categories have been developing neither communities of practice (Wenger & Snyder, 2000) nor conventional project teams, but rather loose groups and effective teams (Sheard & Kakabadse, 2002), respectively. In other words, either a "number of individuals brought together to achieve a task, but with [little] further development undertaken", at companies D and E, or "one in which development of a supportive social structure has occurred, with

each individual adapting his behavior to optimize his personal contribution to the team", in cases A, B, and C (Sheard & Kakabadse, 2002).

Figure 3
Six-sigma diffusion process
Illustration of critical documented events

Six-sigma citations at ProQuest and Emerald Databases:
Before 1991: **9** Between 1991 – 2000: **216** Between 2001 – (June) 2004: **709**

1979 – 1990 First stage **Birth and development**	1991 – 2000 Second stage **Legitimacy and growth**	2001 → Third stage **Institutionalization and propagation**
● 1979. Motorola's executive Art Sundry states: "*The real problem at Motorola is that our quality stinks!*" (Harry & Schroeder, 2000). ● 1981. Motorola's Chairman Robert Galvin challenges his company to achieve a tenfold improvement in performance over a five-year period (Harry, 1998). ● 1984. Motorola's Mikel Harry creates a detailed road map for improving product design and reducing production time and cost (Harry & Schroeder, 2000). ● 1985. Florida Power &Light launch its Six Sigma Program (Dahlgaard *et al.* 2001). ● 1987. CEO Bob Galvin officially announces Motorola's Six Sigma initiative (Harry & Schroeder, 2000). ● 1988. Motorola University launches its training program on Six Sigma implementation (Harry, 1998). ● 1990 Motorola's Six Sigma Research Institute is founded (Harry & Schroeder, 2000).	● 1994. AlliedSignal. CEO Larry Bossidy launches Six Sigma program (Zinkgraf, 1998). ● 1994. Mikel Harry opens the doors to the Six Sigma Academy, Scottsdale, Arizona. First clients: General Electric and AlliedSignal (Harry & Schroeder, 2000). ● 1996, GE launches its Six Sigma Program (Hammer, 2002). ● 1996. Bombardier's leaders commit to six sigma practice (Hammer, 2002). ● Spring 1997. Citibank undertakes a six-sigma initiative (Douglas & Erwin, 2000). ● 1998. ASQ's first six-sigma class (asq.com) ● 1998. DuPont launches its Six Sigma implementation program within Specialty Chemicals business (Bailey, 2001). ● 1999. DuPont, global Six Sigma implementation (Bailey, 2001). ● 1999. GE Second year of spectacular gains are announced (Lucier & Seshadri, 2001). ● December 2000. GE Medical Systems reported 1,149 active six-sigma projects for customers (Lucier & Seshadri, 2001).	● 2001, Six Sigma Forum, in conjunction with the ASQ, publishes the first issue of the Six Sigma Forum Magazine (www.asq.org/pub/sixsigma/). ● 2002, 25% of the Fortune 200 claim to have six-sigma programs (Hammer, 2002). ● Summer 2002. The American National Institute of Standards and Technology, NIST, publishes a study (primarily for CEOs), stating the complementary nature of major quality systems: Baldrige, ISO 9000 and Six Sigma (Anonymous, 2002c). ● 2002 Six Sigma Academy Scottsdale, AZ, joins with consulting firm Accenture, NY to launch an eLearning Curriculum, a Web-based training resource (Anonymous, 2002b). ● Spring 2003. Six Sigma Forum tops 14,000 members (Anonymous, 2003a). ● 2003. CEO of the year, 3M Co.'s James McNerney, is committed to operating organic innovation, leadership development and … six-sigma (McClenahen, 2004). ● 2004. Rapid international growing interest in six-sigma (Godfrey, 2004).

Companies A, B, C and D showed documented evidence of the formation of their teams. At D, teams have been formed spontaneously around production problems leading to six-sigma projects. Despite the proven expertise of its members, results have not always been significant, showing inefficacy and inefficiency in its mechanisms; they demonstrated loose groups characteristics. Companies A, B, and

C have developed rigorous approaches to team formation, with accountability systems in place to measure gains and benefits, but which also promote interactions and tacit knowledge sharing; they demonstrated effective team characteristics.

In companies A, B, and C, six-sigma organizations have permeated conventional structures transforming them into organic knowledge-based structures. D and E's structures appear to be strongly mechanistic. Parallel structures, as described by Voelkel (2002), were not identified.

The study suggests that six-sigma organic knowledge structures, developed by the most advanced six-sigma programs (A, B, and C), are modular in character (Koppl & Langlois, 2001). Formal six-sigma mechanisms such as project selection or performance measurement systems seem to act as standardized interfaces, providing focus but allowing flexible configurations of activities. Further research is needed, notably because the adopted research methodology does not allow generalization. As Yin (1994) previously demonstrated, case studies provide a sound basis for analytical generalization, that is, either to formulate a conceptual model and propositions or, derive hypotheses to be tested in subsequent research. Following these findings, eight hypotheses are formulated, to characterize six-sigma knowledge structures and dynamics.

Hypotheses

As summarized in Table 2, major strategic, tactical and operational issues have been addressed: drivers, focus, change management, knowledge structure and dynamics, performance measurement and project selection systems, modularity and team characteristics. A better understanding of six-sigma knowledge dynamics can be gained by confirming or refuting these hypotheses.

Table 2
Hypothesis to be tested in future research

Strategic character	Drivers of six-sigma programs	Hypothesis 1 Six-sigma programs are driven by an adaptive organizational behavior to respond to external demands and stakeholders' requirements
	Focus	Hypothesis 2 A successful six sigma program creates focus.
	Change management	Hypothesis 3 Adopters of six-sigma programs rely heavily on learning by doing (through trial and error) in dealing with change management.
	Knowledge structure of the organization	Hypothesis 4 Successful adopters of six-sigma programs develop a modular knowledge-community structure.
Tactical character	Performance measurement system	Hypothesis 5 Six-sigma program implementation requires an externally comparable customized performance measurement system.
	Project selection system	Hypothesis 6 Efficient project selection systems grow by building on previous knowledge while new knowledge is integrated.
Operational character	Effective modular teams	Hypothesis 7 Time needed to form effective modular teams depends on building supportive conditions that transform the old conditions.
	Day-to-day knowledge dynamics	Hypothesis 8 Effective six-sigma modular teams develop interactive and flexible patterns that facilitate exchanges, sharing and knowledge creation.

Conclusion

Is knowledge structure and dynamics the missing link in six-sigma practice? The study shows that six-sigma knowledge characteristics, and their impact on performance and gains, have not yet been addressed regardless of its knowledge content. This research has provided insights into six-sigma knowledge structures and dynamics. The findings suggest that the presence of modular teams may influence the development of advanced six-sigma programs.

Implications for practitioners and academia

Six-sigma has been hailed as revolutionary. On the subject of scientific revolutions, Kuhn (1972) has argued that intellectual revolutions replace one conceptual world view, a paradigm, with another…but the new one is not necessarily closer to the truth. He also elaborated on new theories, explaining that they are normally viewed as more complex than the previous ones. The six-sigma knowledge model is apparently not an exception to this rule.

Given its elements and characteristics, six-sigma is contextual. Similarly to Taylor's scientific management, the practice originated in the United States, at a particular historical time and conditions. As such, it is also specific. It embodies American management's specific values that, according to Calori & Dufour (1995) are: "oriented towards short-term and quick financial profit" and "individualistic". Yet it has also been suggested that the ultimate goal of six-sigma is to create focus that can enable firms to better navigate in the business world. Purposeful actions, creating oneness, coordinating efforts, development of sustainable long term goals are expected to help enterprises achieve continuous improvement and breakthroughs, while enriching people individually and collectively. It appears that the six-sigma organization knowledge structure, the configuration of intangible elements, i.e. the soft side, can potentially support this perspective. Prescriptions, on six-sigma, fall short in this area.

It is worth questioning what are we teaching about six-sigma, in relation to what are we practicing. Is it the hard, well codified and easily transferred facets? Management, owing to its object of inquiry, is a soft science, despite the growing interest practitioners and academicians are manifesting in the hard sciences. That being said, where is the soft side, the very source of competitive advantage, which supposedly helps differentiate organizations? Little research has been done in this field, and much remains to be explored.

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