Research Policy 45 (2016) 125–136

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Where and how to search? Search paths in open innovation

Henry Lopez-Vega[a,*], Fredrik Tell[b,c], Wim Vanhaverbeke[d,e,f]

[a] Department of Management and Engineering, Business Administration, Linköping University, 58183 Linköping, Sweden
[b] Department of Business Studies, Uppsala University, P.O. Box 513, 75120 Uppsala, Sweden
[c] KITE Research Group, Department of Management and Engineering, Business Administration, Linköping University, 58183 Linköping, Sweden
[d] Faculty of Business Economics, Hasselt University, B-3590 Diepenbeek, Belgium
[e] ESADE Business School, E-08172 Sant Cugat, Spain
[f] National University of Singapore, Faculty of Engineering, Singapore 117575, Singapore

ARTICLE INFO

Article history:
Received 3 September 2012
Received in revised form 22 August 2015
Accepted 23 August 2015
Available online 22 October 2015

Keywords:
Search space
Search heuristics
Organizational search
Innovation intermediaries
Problem framing
Boundary spanning

ABSTRACT

Search for external knowledge is vital for firms' innovative activities. To understand search, we propose two knowledge search dimensions: search space (local or distant) and search heuristics (experiential or cognitive). Combining these two dimensions, we distinguish four search paths – situated paths, analogical paths, sophisticated paths, and scientific paths – which respond to recent calls to move beyond "where to search" and to investigate the connection with "how to search." Also, we highlight how the mechanisms of problem framing and boundary spanning operate within each search path to identify solutions to technology problems. We report on a study of 18 open innovation projects that used an innovation intermediary, and outline the characteristics of each search path. Exploration of these search paths enriches previous studies of search in open innovation by providing a comprehensive, but structured, framework that explains search, its underlying mechanisms, and potential outcomes.

1. Introduction

Organizational search is central to classic and contemporary innovation theories (Laursen, 2012; Nelson and Winter, 1982). However, while firms in search of "new combinations" (Schumpeter, 1934) build on accumulated experience, they are also cognitively constrained by previous choices and resource commitments, potentially resulting in myopia (Levinthal and March, 1993) and high R&D expenses. Segments of the rapidly expanding discussion on open innovation have revisited and revitalized the role of search in innovation (c.f. Afuah and Tucci, 2012; Felin and Zenger, 2014; Laursen and Salter, 2006). A key idea in open innovation is that firms should exploit search outside the confines of their organization (c.f. West et al., 2014), making the search for external knowledge an important managerial task (Laursen and Salter, 2006, p. 147). Search for external knowledge is arguably quite complex and difficult, involving uncertainties and characteristics such as the tacitness, complexity, rivalry, and indivisibility of knowledge which may not be conducive to its detection and transfer (c.f. Zollo and Winter, 2002). Despite this complexity, search has been analyzed primarily by using one-dimensional constructs such as local vs. distant (Knudsen and Srikanth, 2014), which seldom recognize how different heuristics interact with the solution location (Nickerson and Zenger, 2004).

This paper explores the dynamics and direction of search. We suggest that organizational search involves two dimensions (Gavetti and Levinthal, 2000). The first refers to *where* to search, i.e., the location of solutions – local or distant – in relation to currently available solutions (Katila and Ahuja, 2002; Levinthal and March, 1981). The second concerns *how* to search, and which search heuristics to apply, i.e., experiential or cognitive search (Gavetti and Rivkin, 2007; Nickerson and Zenger, 2004). So far, research on open innovation focuses mostly on where to search in a given search space (Garriga et al., 2013; Laursen and Salter, 2006; Piezunka and Dahlander, 2015), and several scholars lament the relatively small attention given to how search takes place, and what alternative search heuristics are applied in open innovation (Felin and Zenger, 2014; Jeppesen and Lakhani, 2010).

Combining the "where" and "how" dimensions of search, we propose a framework for firms' search for external knowledge that encompasses situated search paths, analogical search paths, sophisticated search paths, and scientific search paths. In pursuing these search paths, firms can exploit two mechanisms to identify solutions in idea and technology markets: first, a problem framing

* Corresponding author.
E-mail addresses: henry.lopez.vega@liu.se (H. Lopez-Vega), fredrik.tell@fek.uu.se (F. Tell), wim.vanhaverbeke@uhasselt.be (W. Vanhaverbeke).

http://dx.doi.org/10.1016/j.respol.2015.08.003

mechanism (Baer et al., 2013; Kaplan, 2008; Von Hippel and Von Krogh, 2015) that involves focusing on and articulating the problem as a technology need before its dissemination, and second, a boundary spanning mechanism (Fleming and Waguespack, 2007; Rosenkopf and Nerkar, 2001) that involves recognizing and connecting the technology need to a specific crowd of technical or scientific solvers. We address the following research questions: (1) What are the characteristics and objectives of each search path? (2) How do problem framing and boundary spanning mechanisms facilitate the identification of solutions?

Our findings draw on 18 open innovation projects to study how innovation intermediaries (c.f. Chesbrough, 2006; Roijakkers et al., 2014) help clients find potential solutions to their technology problems,[1] by selecting a search path and exploiting search mechanisms. Our research involves an embedded case study conducted at a leading innovation intermediary-NineSigma. A new breed of innovation intermediaries (e.g., NineSigma, InnoCentive, Yet2.com) is offering services to assist firms in their search for external knowledge and intellectual property (IP) management. We focus on intermediaries that facilitate connections between firms (knowledge-seekers) pursuing search for solutions and ideas in technology markets, and a global network of solution-providers such as R&D laboratories, university faculty, and specialist companies (Boudreau et al., 2011; Jeppesen and Lakhani, 2010; Sieg et al., 2010).

Our findings make several contributions to the literature. Theoretically, we propose a search path framework to clarify and explain complex search patterns and choices, and to extend theories in the innovation literature that build on the search framework suggested by March and Simon (1958). We also propose two new types of search – analogical and sophisticated – as important search options. Finally, we connect the problem framing (Baer et al., 2013; Kaplan, 2008; Von Hippel and Von Krogh, 2015) and boundary spanning (Fleming and Waguespack, 2007) literatures to propose mechanisms related to the solution of problems within these search paths.

The paper is structured as follows: Section 2 presents the two search dimensions, discusses the search mechanisms, and describes the four proposed search paths. Section 3 discusses the research design and data collected. Section 4 describes how the search for solutions to problems is associated with our four search paths, and examines the use of problem framing and boundary spanning mechanisms in 18 open innovation projects. Section 5 discusses how the selection of a specific search path influences the identification of solutions to problems. Section 6 presents our main conclusions.

2. Literature review and framework

2.1. The search for solutions to problems

Organizations search for alternative solutions to problems when current routines fail to produce results that match the organization's aspirations (March and Simon, 1958). The screening of alternative solutions and task decomposition are major components of the problem-solving process (March and Simon, 1958, p. 178).[2] For cognitive reasons, "problemistic search" (Cyert and March, 1963, p. 120–122) tends to be both simple-minded and biased, causing organizations to search locally, in the vicinity of already identified solutions. Levinthal and March (1981, p. 309) describe this as "refinement search", which "emphasizes relatively immediate refinements in the existing technology, greater efficiency, and discoveries in the near neighborhood of the present activities."

However, when a problem cannot be solved using current routines, the firm is forced to innovate by developing new knowledge. "Innovative search" (Levinthal and March, 1981) includes distant search for new technologies, based on new combinations of knowledge (Carnabuci and Operti, 2013; Schumpeter, 1934). The subsequent literature on search and innovation investigates the properties and outcomes of refinement-oriented local search (exploitation) vs. innovation-oriented distant search (exploration) in more depth (Laursen, 2012; March, 1991). Also, these analyses focus on the location of alternatives relative to current behavior and "the elements that are to be searched" (Gavetti and Levinthal, 2000, p. 114). Below, we show that this search problem centers on the question of *where to search.*

2.1.1. Search space: where to search?

Firms looking for solutions to problems search among combinations of knowledge in a search space (Knudsen and Srikanth, 2014). How does the firm know where to start? By envisaging the search space as the relative distance from the firm's current knowledge base, search may be *local*, i.e., in the vicinity of the firm's current knowledge, or *distant*, i.e., farther away from the firm's current knowledge. In practice, knowledge categories and knowledge combinations need to be determined in advance. Knowledge categories can be represented by technological domains (e.g., internal combustion, electronics, bioenergy, etc.), industry classifications (e.g., automobiles, consumer retailing, telecommunications), or scientific fields (e.g., electromagnetic waves, particle physics, optimization). However, it is crucial that the focal firm understands where the appropriate knowledge is "stored" (e.g., in individuals, organizations, theories, patents, products, etc.) in order to effectively search for it.

Organizations primarily search in the proximity of existing routines and previous solutions (Levinthal and March, 1993; Stuart and Podolny, 1996). Therefore, when conducting *local search*, organizations look for solutions that build on knowledge already in use. Although local search decreases the probability of finding novel solutions, it increases the chances of finding and acquiring workable solutions. In contrast, *distant search* entails knowledge recombination (Fleming and Sorenson, 2004; Rosenkopf and Nerkar, 2001), which may provide opportunities to identify disruptive innovations and achieve competitive advantage. Building on Schumpeter's (1934) seminal argument, knowledge recombination and integration is a quintessential element of innovative capability (Carnabuci and Operti, 2013). Distant search essentially involves the search for solutions that are unrelated to the firm's current knowledge base. However, organizations often filter out solutions based on distant knowledge, preferring to evaluate solutions from local knowledge sources (Piezunka and Dahlander, 2015).

A mechanism that helps to balance the local–distant search space is *boundary spanning*. Although exploring within the boundaries of the firm's technological domain may satisfy a specific technology need, boundary spanning involving a distant technological domain helps identify new ways to solve problems (Rosenkopf and Nerkar, 2001). Most firms employ mechanisms that facilitate the identification of short-term solutions, i.e., local search, or potential longer-term breakthroughs, i.e., distant search (Hargadon and Sutton, 1997). Understanding the underlying search space is at the heart of the boundary spanning mechanism (Fleming and Sorenson, 2004), which enables information processing, interpretation and translation of knowledge, and negotiation of common meanings

[1] Hereafter referred to as "problems."

[2] March and Simon (1958, pp. 178–179) also discuss randomness and the hierarchical structure of problem-solving in search. We acknowledge that innovation involves much more than just search for solutions since it requires knowledge integration, implementation, and diffusion, market acceptance, etc. but in this study we focus on the search problem.

among heterogeneous parties and across cohesive technological boundaries (Fleming and Waguespack, 2007).

Innovation intermediaries such as Innocentive and NineSigma are actors that have developed specialized processes to conduct local and distant search by organizing innovation contests across distinct knowledge fields (Roijakkers et al., 2014; Spradlin, 2012). These problem-solving contests forge links between (knowledge-seeking) firms searching for external technological solutions, and potential technological solution-providers (Afuah and Tucci, 2012; Chesbrough, 2006). However, several authors are critical of the relatively scant attention paid to how innovative search takes place and the alternative search heuristics applied in open innovation (Felin and Zenger, 2014; Jeppesen and Lakhani, 2010). Below, we discuss this dimension of search for external knowledge as a question of *how to search.*

2.1.2. Search heuristics: how to search

The focus in the cognitive dimension of search is on the heuristics used by firms to evaluate alternatives when making decisions (Gavetti and Levinthal, 2000, p. 114), and the processes involved (Gavetti and Rivkin, 2007). Existing analyses emphasize the separation between action and cognition: "one part [of decision making] occurs in the world of cognition and comprises ways of conceptualizing the firm and its environment. The other unfolds in the world of action and consists of mechanisms that shape what a company actually does" (Gavetti and Rivkin, 2007, p. 420).

Experiential search is guided by a desire for direct feedback from trials (Nickerson and Zenger, 2004). An important element of experiential search is the "on-line" evaluation of alternatives, and the subsequent action on immediate feedback from current actions without reflecting on their causes (Gavetti and Levinthal, 2000; Zollo and Winter, 2002). Boundedly rational organizations can activate accumulated routines or programs (Cyert and March, 1963). Nelson and Winter (1982) consider "routine development" as exemplifying experiential search processes, often described as "learning by doing" (Pisano, 1994).

Cognitive search involves the use of representations and abstractions in the search for solutions (Gavetti, 2012). Cognitive search employs "off-line" evaluation (Gavetti and Levinthal, 2000), and learning-before-doing (Pisano, 1994). Such representations contribute to the development of heuristics of variable sophistication (Grandori, 2013; Nickerson and Zenger, 2004). Rather than allowing environmental stimuli to feedback directly into action, cognitive search allows for the feed-forward of information into existing or nascent representations. These off-line representations can be studied and then later enacted. Models can be developed using representations and systems of symbols which allow causal inferences which may be applicable more generally (Zollo and Winter, 2002).

A search mechanism facilitating search heuristics is problem framing, or problem formulation (Baer et al., 2013; Von Hippel and Von Krogh, 2015). Problem framing facilitates the interpretation of assumptions and expectations related to a specific problem, and provides guidance for the identification of potential solutions (Kaplan, 2008). It can take the form of knowledge articulation and codification to produce written documentation in the form of tools, manuals, etc. to describe new proposals and performance implications (Zollo and Winter, 2002), take place on-line or off-line (Gavetti and Levinthal, 2000), and involve heuristics such as case-based or deductive reasoning (Gavetti and Rivkin, 2007).

The open innovation literature suggests that innovation intermediaries can create value for knowledge-seekers by explicitly stating a "tacit" technological need in a document that can be used to solicit solutions in innovation contests (Sieg et al., 2010; Spradlin, 2012). This requires the use of search heuristics to identify whether a specific problem requires experiential or cognitive search (Boudreau et al., 2011). It has been argued that innovation intermediaries are more similar to consultants than brokers, since they engage more directly with firms by designing and supporting the innovation search process (c.f. Howells, 2006).

2.2. A framework of search paths

Previous research considers search in relation to either the search space or search heuristics. We propose that these two dimensions should be studied simultaneously: the "where and how" should provide an integrated view of the firm's search for external knowledge. We extend the research on search that uses one-dimensional constructs (e.g. Tippmann et al., 2013, p. 1870). We combine these two dimensions in relation to four different search paths: (1) situated paths, (2) analogical paths, (3) sophisticated paths, and (4) scientific paths. Fig. 1 depicts a typology of the main characteristics of each search path.

2.2.1. Situated search paths

Situated search is the default model in many evolutionary theories of organizations and innovation which emphasize the development of routines through local trial-and-error refinements (e.g. Cyert and March, 1963; Nelson and Winter, 1982). A situated search path operates on the basis of experimentation in the vicinity of previous solutions that lead to feedback on current actions, and verification of generalized beliefs based on repeated experiences and observations. Empirically, situated search is a component of the firm's innovative activity, as demonstrated in Martin and Mitchell's (1998) study of the US product market for magnetic resonance imaging devices in 1980–86. The authors show that incumbent firms searched in the vicinity of the dominant technologies, and subsequently introduced product designs similar to existing designs. Comparably, Stuart and Podolny (1996), using a network approach, analyze strategic partnering and the evolution of the technological positions of Japanese semiconductor producers patenting between 1982 and 1992. Their findings show that the majority of these manufacturers occupied distinct technology niches over the time period considered.

2.2.2. Analogical search paths

Analogical search can be described as drawing upon experiential knowledge from distant domains to inform current actions. Such search is enabled through the use of analogical reasoning (Gentner, 2002). Analogical reasoning involves structural comparison between a base and a target domain (often with unrelated content). Applying the characteristics of a solution that spans domains can provide new insights to solve current problems.

Analogical reasoning has been discussed in the context of strategic decision-making and innovation analysis (Gary et al., 2012). For example, Hargadon and Sutton (1997) discuss IDEO's experience of innovation through technology brokering. Analogical search paths that make use of technology brokering involve the blending by engineers of existing but previously unconnected ideas (see also Carnabuci and Operti, 2013; Hargadon and Sutton, 1997).

2.2.3. Sophisticated search paths

We associate sophisticated search paths with deductive reasoning. Deductive reasoning generates predictions and hypotheses that evolve from general premises to specific applications of a more general set of scientific knowledge (Gavetti and Rivkin, 2007). This is a central characteristic of sophisticated search paths, in which explicit general theories feed forward into representations that make specific claims regarding (local) potential states of affairs

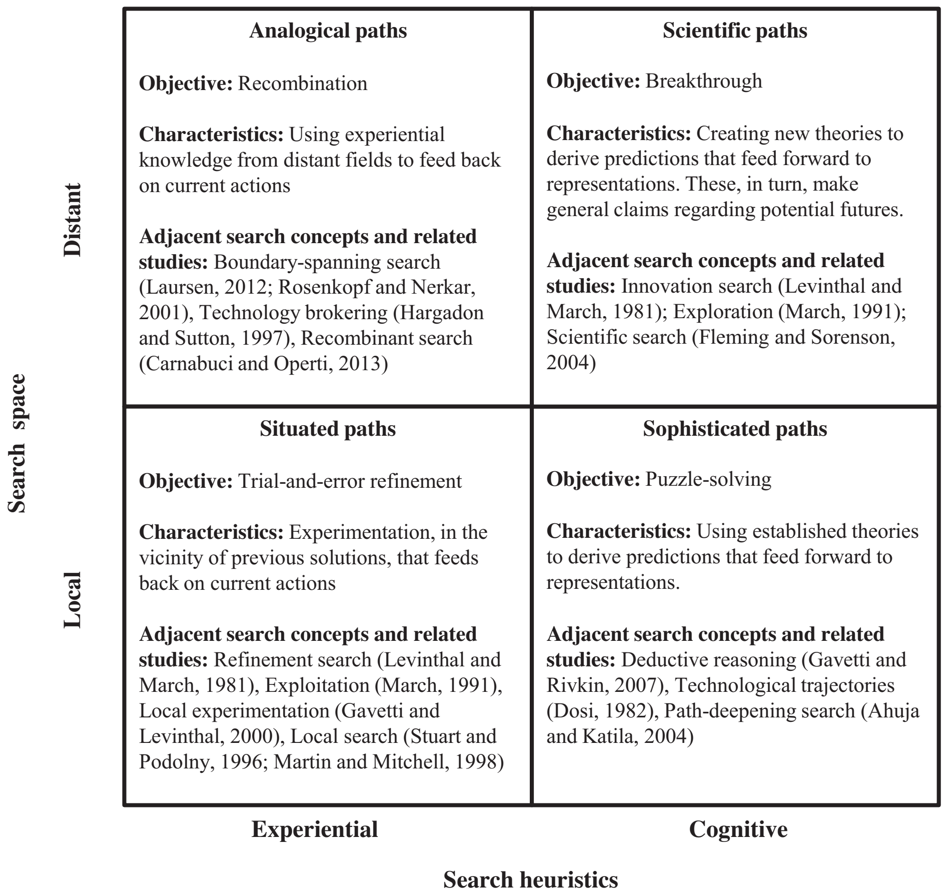

Fig. 1. Framework of search paths.

(Johnson-Laird, 2001). Dosi (1982) refers to sophisticated search paths within technological paradigms as "technological trajectories." A salient feature of sophisticated search paths is how they operate to achieve "path-deepening" search (Ahuja and Katila, 2004). Tripsas and Gavetti (2000) trace search deepening through increasing sophistication of representations in the evolution of Polaroid's search activities in digital imaging. Polaroid continuously invested large sums in R&D and developed radically new technologies within a clear search pattern, in which new products – camera systems for both consumer and commercial applications – built on these developments and applied this new knowledge to Polaroid's existing strengths in manufacturing.

2.2.4. Scientific search paths

Scientific search paths allow the discovery of theories and models which give rise to predictions that then feed forward into representations. These representations in turn make general claims regarding potential futures. Knowledge acquisition through exploratory (March, 1991) or innovative (Levinthal and March, 1981) search has been described as "searching" in science. Ahuja and Katila (2004, p. 891) study the acquisition of technological capability by US-based chemical firms from 1979 to 1992. They show that when the search space for recombination of existing technological solutions is exhausted, scientific search can extend the search space through the incorporation of new theoretical building blocks and hypotheses regarding cause-and-effect relationships. Similarly, Fleming and Sorenson (2004, p. 911), in their analysis of citations in US patents in 1990, suggest that scientific search paths "[provide] inventors with the equivalent of a map – a stylized representation of the area being searched."

3. Data and methods

3.1. Sample selection and research setting

The selection of NineSigma[3] was based on an initial study of the business models of 11 of the largest innovation intermediaries: InnoCentive, NineSigma, Yet2.com, TekScout, IdeaConnection, YourEncore, Innoget, BigIdea Group, InnovationXchange, Creax, and Ocean Tomo. We interviewed representatives from four of these intermediaries, and collected secondary data for the other seven. The NineSigma intermediation processes are similar to those of other innovation intermediaries. However, in contrast to InnoCentiveand Yet2.com, the business model used by NineSigma does not require solution-providers to sell their IP outright, and allows both parties to negotiate contractual agreements, e.g., licensing and co-development. Moreover, the NineSigma model involves knowledge-seekers receiving responses and contact documentation from all solution-providers, not just the winning solution-provider.

NineSigma's headquarters are in Cleveland, Ohio, with subsidiaries in Belgium, Japan, Korea, Australia, South Africa, and Brazil. Since its foundation in 2000, NineSigma has advised around 350 companies – primarily Fortune 500 firms and large multinational enterprises (MNEs) – engaged in research and new product launches, arranged over 2500 open innovation projects, and received over 35,000 unique proposals from solution-providers. NineSigma has an external innovation network of over 2 million

[3] http://www.ninesigma.com.

solution-providers distributed across 16 industry sectors in 115 countries. The technology suppliers include global multi-sector businesses (ca. 52%), university and government labs (ca. 34%), and inventors and consultants (ca. 14%).

3.2. Data collection

The data for this case study were collected via interviews with NineSigma program managers (PMs) and innovation and corporate managers from knowledge-seeking firms, and an ethnographic field study conducted at NineSigma's headquarters. We carried out 34 semi-structured interviews (see Appendix 1), each lasting over an hour. Of these, 12 were with NineSigma corporate managers and PMs to obtain a description of the intermediation process and search path characteristics and mechanisms. On average, PMs had worked at NineSigma for seven years, a scientific background (PhD degree), and practical familiarity with industrial product-development processes. The other 22 interviews with 18 knowledge-seeker representatives focused on open innovation projects and how NineSigma managed them. All interviews were recorded and transcribed. Interviewees shared archival information, e.g., diagrams and charts, to increase our overall understanding of the various interactions and decisions.

Moreover, we conducted an ethnographic study to highlight path-related nuances that interviewees might be unable or unwilling to share in interviews. For two months, the first author was a non-participant observer of innovation contest projects, was party to confidential conversations, and interacted with employees five days a week. This author took notes during all of these interactions, and later discussed them with NineSigma project managers.

3.3. Analytical approach

We entered the transcribed interview and observation field notes, videos, and archival information into Atlas.ti software for qualitative analysis. This procedure assisted in the data organization and coding, and facilitated analysis and interpretation of specific activities and mechanisms for each search path. We followed Strauss and Corbin (1998), interpreting and coding the intrinsic meaning of the four search paths and specific mechanisms. We applied two types of coding: open and axial.

The data analysis was conducted into two steps. First, we applied open coding to the information collected from observations of the interactions between knowledge-seekers and NineSigma, to distinguish the four search paths. In the second step, we open coded the interviews and observations of interactions between knowledge-seekers and NineSigma in order to empirically identify two generic mechanisms: problem framing and boundary spanning (see Section 4.1). Finally, we conducted axial coding to connect each search path to a specific mechanism (see Section 4.2). In line with previous research on mechanism-based explanations, we were interested in explicit and detailed empirical evidence to support our causal generalizations for each path and mechanism involved. Using the typology of social mechanisms proposed by Hedström and Swedberg (1998, p. 22), we analyzed the problem framing mechanism as an action-formation mechanism that remains at the knowledge-seeker level, since it shows a specific combination of characteristics for each technology problem. The boundary spanning mechanism is a transformational mechanism that disseminates an internally specified technology need to a network of solution-providers.

4. Search paths and search mechanisms

Section 4.1 describes the overarching properties and relationships of problem framing and boundary spanning. Section 4.2 explains the objective of each search path, and how problem framing and boundary spanning operate in each of the four search paths and help achieve the path objective.

4.1. Search mechanisms: problem framing and boundary spanning

In each search path the mechanisms of problem framing and boundary spanning are used to obtain solutions from idea and technology markets. By problem framing, the innovation intermediary can use its accumulated experience to (a) analyze the knowledge-seeker's problem, (b) frame problems in collaboration with the knowledge-seeker, and (c) define a specific technology need. By boundary-spanning the innovation intermediary can link the specific technology need to external solution-providers in previously unidentified technological and scientific areas. A NineSigma senior manager described these mechanisms as follows:

> We take problems. We take them apart into identifiable pieces, but not necessarily into the pieces as they would be applied. So, we take the application out of it and look at the pure science and then we go and identify. Another of our capabilities is that we can identify potential problem solvers. So, it is not passive, it is not posting on a chat, it is not having a website full of experts who accept every challenge; we look for specific capabilities related to every challenge... We can articulate the need, we can push it out to find where the solutions may exist and then we have a process for bringing those solutions – in the format of a proposal perhaps – and the two parties together.

In open innovation projects, problem-framing refers to articulating a knowledge-seeker's problem into a technology need before revealing it to external scientific and technological communities, i.e., solution-providers. The technology need is contained in a document, i.e., a request for proposal (RFP), which allows the innovation intermediary to assist the knowledge-seeker's team to separate the problem into decomposable parts. The objective is to highlight, e.g., business opportunities, technological specifications, possible approaches, IP specificities, limitations of the technology, project timing, and financial and evaluation criteria to obtain clear, concise, and compelling solutions to the problem. Knowledge-seekers use cross- or intra-unit meetings, committees, and task forces to craft the language that may balance the need for context specificity and the generality of the problem. These meetings were aimed at ensuring the requisite communication, collaboration, and delegation of responsibilities either to define problems concretely or to detach them from their current technological contexts and informational content.

In addition, innovation intermediaries use boundary spanning to identify and select previously unidentified solution-providers for the knowledge-seeker. Prior to broadcasting the already specified technology need, the innovation intermediary is responsible for matching knowledge-seekers and solution-providers in local or distant search spaces. This involves matching technological domains and potential areas of application with a specific crowd of solution-providers[4] not known to the knowledge-seeker. The innovation intermediary identifies a network of solution-providers that might be interested in, and capable of, responding to the specific technology need, but avoids too many and too wide-ranging responses.

Boundary spanning increases the number of solution-providers and their interest in the problem by clarifying the benefits to be

[4] NineSigma has built its contact database over 11 years; it is cross-referenced and used to categorize solution-providers according to expertise. Each technology need is broadcasted to approximately 15,000 potential solution-providers.

Search space	Experiential	Cognitive
Distant	**Analogical paths** **Objective:** Search for medium- to long-term solutions from technologically unrelated and previously unexplored domains **Expected type of innovation:** New processes or technologies to improve existing specifications **Characteristics:** Operational innovation **Path selection criteria:** Market creation, timescale of one year, implementation in multiple products, involvement of multiple business units **Examples:** Processes for delaying the drying of water-based emulsions (Sherwin Williams); innovative packaging to minimize the melting of chocolate bars in warm climates (Kraft Foods); redefinition of a bed mattress (Sealy); Alternative and more-efficient uses of copper, e.g., in healthcare (International Copper Association); packaging products from the military and oil industries (Ferrero Rocher); problems with optics and photonics (Carl Zeiss); innovative methodology (BP)	**Scientific paths** **Objective:** Search for long-term breakthrough solutions in unrelated scientific fields to problems that require either the recombination of knowledge or the discovery of a distant scientific network **Expected type of innovation:** Disruptive technologies, new business models **Characteristics:** Strategic insights, ideation results **Path selection criteria:** Application in new markets, timescale in years, implementation over multiple business units **Examples:** A washing machine that does not require water (Arçelik A.Ş.), alternative sources of sodium for potato chips (PepsiCo), substitutes for formaldehyde in hair products (L'Oreal)
Local	**Situated paths** **Objective:** Search for quickly implementable solutions to problems in familiar technological fields **Expected type of innovation:** Add-on technologies or information **Characteristics:** Defensive innovation, quick win, operational tactics **Path selection criteria:** Application in existing technology problems and markets, timescale of months, implementation in a single product **Examples:** a natural-based sunscreen and aluminum-free deodorants (Natura Cosmetics), new membrane technologies for a tire and rubber company (Goodyear), technology efficiency improvements to cope with government regulations (Rheem Manufacturing), newly proven technologies for a healthcare manufacturer (Kimberley-Clark)	**Sophisticated paths** **Objective:** Search for short-to-medium-term insights into visible market and industry trends **Expected type of innovation:** Additional added-value technologies for existing products **Characteristics:** Solutions for a market-entry opportunity, proof of concept, pre-launch, consumer involvement **Path selection criteria:** Application in existing markets; timescale one year; implementation in multiple products **Examples:** A foam component for electric shaving machines (Philips), alternative use of roofing granulates in asphalt shingles (3M); alternative chemistry methods to increase the sustainability and reduce the toxicity of paints (Akzo Nobel), new technology to augment physical greeting cards with digital experiences (Hallmark Cards)

Search heuristics

Fig. 2. Examples of search paths.

derived from working on the particular problem, and by soliciting for solutions that complement or substitute existing ones. Moreover, contact with specific solution-providers allows the knowledge-seeker to establish links with individuals, groups and associations representing particular scientific and technological domains or geographical areas, and enables the decision to continue or abandon a project.

4.2. Search paths

Based on the study of 18 different problems submitted by knowledge-seekers, Section 4.2 describes each of the four search paths. We discuss the specific objectives and contingencies related to each search path. We then describe how the mechanisms of problem framing and boundary spanning play out across each search path. Since each search path shares at least one search dimension with the other search paths, e.g., situated path projects will share a search space dimension with sophisticated paths, and search heuristics with analogical paths, the knowledge-seeker might select the wrong search path and the problem remain unsolved. We therefore describe the main differences between the described path and the two alternatives. Fig. 2 depicts the differences among the search paths and the studied company cases, and Table 1 presents the characteristics of the two search mechanisms.

4.2.1. Situated paths

The objective of situated paths is to search for quickly implementable solutions to problems in familiar technological fields, while applying knowledge-seekers' accumulated experience to the problem. Frequently, situated path problems involve incremental or minor adaptations, e.g., operational tactics, defensive innovation, or quick wins, which have specific project objectives such as methods or materials. Situated path problems are difficult to solve because of their strict specifications with regard to complexity, technological maturity, viability, and narrow set of possible solutions. Such problems require short-term solutions that can be implemented quickly, e.g., within 12 weeks. Situated path problems in our analysis involved collaboration between NineSigma and the knowledge-seeker in order to select and specify the problem, and evaluate the proposed solutions. Situated path projects are presented in Fig. 2.

An example of a knowledge-seeker's problem features Natura Cosmetics, which was looking for a naturally based ultraviolet (UV) absorber to replace petrochemical oils in a sunscreen. In the Natura example, the sunscreen problem was solved by a solution-provider operating in the laundry sector. A senior R&D manager from Natura explained:

> It was an available solution, but had not been applied in the cosmetic and personal care industry. Nobody had thought about that kind of technology. When we look for solutions, sometimes we miss solutions that we were not thinking about. Not exactly what we were searching, but a related technology, which could change the project.

The identification of solutions requires the use of problem framing and boundary spanning mechanisms. First, problem framing

Table 1
How search mechanisms influence search paths.

	Problem framing mechanism		Boundary spanning mechanism	
	Objective: Separate the problem into decomposable parts, and craft a statement of the problem in language that balances the need for generality with that for context specificity *Outcome*: Specifies the technological or scientific problem as a technology need, and states this need in writing, i.e., an RFP		*Objective*: Match the search scope and a specific crowd of solution-providers to a specific search path *Outcome*: Establishes links with scientific groups in new technological domains or geographical areas	
Search paths	**Effect on the interpretation of assumptions and expectations related to a specific technology problem**	**Boundary conditions**	**Effect on the balancing of the search space to identify short-term solutions or long-term breakthroughs**	**Boundary conditions**
Situated paths	The level of abstraction and codification is determined to attract solvers of related technological fields	Criteria and specifications are flexible to avoid disappointment with received solutions	The identification of solution-providers in other geographical areas with implementable solutions becomes possible	Solution-providers have experience, i.e., they have already solved related problems. Idea generation is excluded
Analogical paths	The *raison d'etre* of the problem is understood and "translated" into a language other industries can understand	Domain-specific applications are understood in order to later identify opportunities for recombination	Technical terms that are common to industries and areas across knowledge-seeker boundaries are selected	Boundaries and potential misunderstandings are made clear to solution-providers
Sophisticated path	The scientific problem is written using a competing problem formulation to allow a scientific explanation of the problem	The proper filters are applied to receive reasonable responses and not miss out on opportunities—a difficult task	A small network of solution-providers in different scientific fields are targeted	A reduced number of solvers, i.e., an expert ecosystem, comes from diverse areas
Scientific paths	The generic scientific need is detailed and the particular expectations are specified using a competing problem formulation	Content involves corporate, technical and researcher perspectives	Academically rigorous scientists in broad scientific areas are targeted	Search includes solution-providers without off-the-shelf solutions

involves codifying a technology need, and describing it so that it appeals to solution-providers in the vicinity of previous technological solutions to feedback into or solve a problem. It also involves some level of knowledge codification and abstraction to engage solvers in adjacent industries. Natura's senior R&D manager explained:

> The description is an important success factor because if you do not describe it well, you will have a proposal that is already being used in the market. How you describe it and the possible approaches should not limit these [proposed solutions] so you can receive approaches not previously thought of.

It is also important not to define the technological need too narrowly. A NineSigma R&D manager explained:

> In fact, it [too narrow technology problem] only creates disappointment because expectations are high and the criteria and specifications are too strict, and if you have 10 specifications and you satisfy 9 but not the last one, you have not filled them all. And by doing that all you do is create disappointment.

The boundary spanning mechanism involves identification of solution-providers with experience in solving problems from similar technological domains that are able to provide refined solutions. A senior manager from NineSigma explained how he had designed a specific network for a situated path project in a natural sciences firm:

> When you get into life sciences or chemistry that is very focused, usually the solutions do not come from engineering or other areas. In those cases, we will find people who are working in those specific fields but are unknown to our clients, in countries such as India and China. We try to find people who have already solved the problem, and are not just generating ideas. In fact, we tend to stay away from idea generation. We find our clients have more ideas than they know what to do with, for the most part.

Situated paths and analogical paths differ in the specification of problems and identification of solution-providers. An example of an analogical path is Kraft's search for an innovative packaging to minimize the melting of chocolate bars in warm climates. While solutions to situated path problems come from local technology fields, analogical path problems require distant technology fields to be solved, e.g., those involving products affected by temperature or light. An innovation manager from Kraft gave an example of the analogical path:

> I find them [NineSigma] best at technology development, in areas where we are looking for solutions that is not ready available to us through our normal channels. So, we are looking for ideas, for someone who has an approach to solving the problem. It is not short-term at all; we usually use NineSigma for medium- to long-term initiatives and strategic initiatives. Right now, we are running in melting chocolate; it is directed to a business unit but it is a difficult problem to solve. It is not something anyone knows how to solve at this point.

Sophisticated and situated paths differ in the selection of problems that need to be solved using distinct concepts and theories. An example of a sophisticated path is Akzo Nobel's problem of finding an alternative chemical method to improve the sustainability and safety of paint. An Akzo Nobel manager highlighted the characteristics of sophisticated path problem:

> One area is looking at environmental or safety areas: these are things about paint that are currently not sustainable or not safe, or could generate some toxicology problems in years to come. We saw the problem before it was recognized publicly and legislation came into place to say, "You cannot use lead as a chemical ingredient."

4.2.2. Analogical paths

An analogical path is used to identify new medium-to long-term processes or technologies from technologically unrelated and previously unexplored domains, which can be recombined and implemented to resolve the predefined problem. Complex problems requiring an analogical path to their solution attract greater interest and support from top management since they are likely to be aimed at entry to new markets and exploitation in multiple products.

In Fig. 2, we identified the projects that employed analogical search paths. The example of Sherwin William's analogical search path to delay the drying process in water-based emulsions is illustrative. This operational problem arose as a result of new government regulations requiring firms to reduce the content of volatile organic compounds. Since the regulation affected a number of industries, the solution might potentially come from unrelated industries such as food or paper, or a related industry such as cosmetics, and might involve novel processes or methods such as delayed water-retention technologies. The solution criteria included use of environmentally friendly and non-toxic materials that would be safe for users.

Selection of this specific problem required the involvement of a Sherwin Williams technology scout responsible for coordinating priorities and resource availability from different business units, and making use of management tools to develop an internal, non-confidential needs list. In relation to the delayed drying processes problem, an open innovation manager from Sherwin Williams explained:

> Open innovation is really about going out and identifying solutions to those ideas that you have never thought about, from specific areas. So, I think it is important to have the capability to be able to define broadly what your problem is. Let me tell you that we went back and forth through nine revisions from different RFPs, and even more. So, we are not too segregated. We want [solution-providers] to understand what the problem is, but we do not want to define it in a way that people will pass on it because they do not understand the terminology in their area. You need to have a clear understanding of what your problem is and be able to define it in broad enough terms that you can go into multiple areas and to the fundamentals.

As mentioned by this interviewee, the problem framing mechanism entailed collaboration between internal technology scouts and a NineSigma PM in order to document the problem in the form of a technology need in order to make it understandable by other sectors and industries. It required an understanding of domain-specific applications to identify opportunities for recombination. For example, Sherwin Williams's knowledge-seekers do not have routine internal processes in place that allow them to connect a problem to distant technology areas:

> We are a coding company; I know how to say something in my pink coding language. But that could limit the responses from others in the cosmetics or oil industry that can say "I have a technology that has that fundamental issue." Getting it back into those fundamental definitions has been a struggle. I think NineSigma pushes their clients, so they receive more responses and successful responses. On the flipside, it is hard for me as a client to write an RFP that way.

The boundary spanning mechanism involves identifying opportunities in distant technological domains or industries, and selecting a network of solution-providers to connect to unrelated technology domains. To avoid potential misunderstandings across technological domains, boundary spanning includes the use of technical terms common to several different industries. A NineSigma manager explained:

> So, NineSigma tries to look at problems objectively: a "why" view of things. We are able to translate that need into a language that people in other industries may be able to understand, and we have this capability to be able to broadcast these needs to people we research on the Internet, databases, etc.

Analogical path and situated path problems differ in the dimensions of their search space, i.e., local or distant. While knowledge-seekers use an analogical path to identify new processes and technologies to enter new markets or improve existing products, a situated path is used to solve a narrow and latent technological problem in one specific product. Goodyear's search for new membrane technologies highlights how a situated path narrows down the possible solutions:

> What I was looking for was membrane technologies, and I did not know who the main players were, or the main technologies. I wanted to use the RFP to understand about other technologies that were out there. I wanted to explore other technologies that could reduce my costs, major players, anything else out there, and put pressure on our internal chemical engineers for other possibilities.

Analogical and scientific search paths involve cross-unit identification and selection of problems, i.e., heterogeneous teams to frame a technology problem. Analogical paths are used to identify new processes or materials to improve an existing technology or process. Scientific paths are used to search for radical solutions that may change the knowledge-seeker's business model. An example of a scientific path is L'Oréal's search for a substitute for formaldehyde in its hair care products. An open innovation manager exemplified the scientific path:

> We have a problem and we try to work through it to search for new ideas, new solutions, new concepts which could answer that problem but also could be applied transversally across the company. By doing that, we have a process of inspiration and creativity.

4.2.3. Sophisticated paths

Sophisticated paths are used to search for short-to medium-term insights into visible market and industry trends that will add value to existing products. The characteristics of expected solutions include application in existing markets and in multiple related products: proof of concept, pre-launch phase, and prospective innovations. A sophisticated search path can identify potential solutions that add value in the form of improvement to an existing product or improved firm performance.

Some examples of problems resolved by using a sophisticated path are presented in Fig. 2. An example is the foam component in Philips's electric shavers, which was a technology area in which Philips had no experience. In the case of the foam component, the solutions had to include a sample solution that could be tested in the product. Ultimately, only one of the proposed solutions delivered the requested functionality. A Philips's engineer described the use of NineSigma for sophisticated path problems:

> At the beginning, when Philips was hesitant about posting a request, we actually started with holy-grail questions that included things that were in people's minds for years and seemed impossible to solve. Now, we recognize it is more about technology solutions outside our field of expertise that we do not actually have here in-house. We think about those projects that we have not worked on before and also accept that we cannot start reading papers and going to conferences, that it takes two to three years to learn how it may work, or even just to set up a proposal.

In a sophisticated path, problem framing involves the innovation intermediary formulating the technology need in a rather abstract way to allow a scientific explanation of the problem. A senior Philips research manager explained:

> If you ask a broad question: "Who can help me with shaving foam?" you will get responses that are too broad. At the same time you need to avoid being too restrictive and not receiving responses. You need to apply some filters, so that you can expect reasonable responses but not miss out on opportunities.

Since the unfamiliar formulation of problems requiring a sophisticated path result in difficulties for the knowledge-seeker in defining the scientific boundaries to the problem, the boundary spanning mechanism is crucial for identifying a sufficiently narrow network of solution-providers. In order to increase the chances of finding a solution, the innovation intermediary targets a small number of solution-providers from scientific domains with valuable expertise for the problem. For example, one of NineSigma's corporate directors explained:

> This is something only for very sophisticated customers... We will create a specific expert ecosystem of maybe 20 people from very diverse areas. We manage it this way when it is a very specific targeted problem that we are looking to solve We ask them to provide a very brief background: "What are your capabilities?" Do you have any particular interest in the topic-yes or no?"

While sophisticated and scientific paths might seem similar, the search for solutions to a problem differs. One example is the case of PepsiCo, when it was searching for either alternative sources of sodium or methods to reduce the sodium in its Frito-Lay potato chips that would still maintain a salty flavor. In their attempt to identify a new formulation for a micro-particular halite or drying technique from an unknown scientific field, PepsiCo and NineSigma formulated the problem to include a broad range of technological domains and business models distant from the knowledge-seeker's snack business domain.

Sophisticated search paths differ from situated paths in terms of the maturity of the requested solution, i.e., whether a quick win or a proof of concept. In the Natura example involving an aluminum-free deodorant, Natura requested solutions already mature enough to be implemented, rather than early-stage solutions. This problem required a situated path to provide a short-term solution derived from a technologically related sector. Natura's research manager explained the problem and the absence of mature solutions:

> For one of the problems we were trying to find a new way to work with deodorants-not using aluminum salt. Currently, all the products use aluminum salt, and because of its toxicity, we were trying to find another way to solve this problem... For the deodorant, we had a lot of proposals but they were very similar to what were thinking and imagining already. The project failed because solution-providers proposed solutions that were already tested or not technologically mature. It was very early stage research.

4.2.4. Scientific paths

The adoption of a scientific path is aimed at finding breakthrough solutions from unrelated scientific fields to problems that may require either knowledge recombination or exploitation of a distant scientific network. These problems specify input and output parameters, which differentiates them from "holy grail" problems that are beyond the scope of innovation intermediaries. Connecting the proposed solutions from unknown scientific communities to the focal problem involves using charts and assessment matrices to highlight the issues of interest to the knowledge-seeker while bearing in mind the novelty of the problem. Some identified case examples are provided in Fig. 2. In our sample, only PepsiCo's halite problem was resolved. By formulating the problem broadly, PepsiCo received a solution involving a new approach to the continuous production of halite nanoparticles, i.e., crystal salt, from a European university spin-off (a medical lab) working on techniques to treat osteoporosis.

In scientific paths, the problem framing mechanism recognizes that specification of the technology need should be generic and scientific; in the PepsiCo problem, it remained specific in terms of what PepsiCo needed to meet particular manufacturing requirements, i.e., a significant reduction in salt content. By understanding the knowledge-seeker's problem, problem framing was aimed at finding a breakthrough technology to feed-forward to new representations of the problem. In another example, Arçelik A.Ş.'s technology need for a washing machine that does not require the use of water was too broadly defined, and did not explain why an alternative solution was needed. A NineSigma manager elaborated:

> The angle of the RFP will get adapted according to the finality the client has in posing the question... If you are looking for a washing machine that washes without water, then they do something completely different. It comes from the analysis beforehand, if you do not do that analysis beforehand, all you have at the end is disappointment.

The boundary spanning mechanism involved in PepsiCo's problem required a stronger focus on the scientific community, e.g., universities and labs, rather than on industry solution-providers, since there was no expectation of an off-the-shelf solution. Solution-providers are expected to provide long-term solutions that offer novel alternative ways to solve a technological need. Moreover, the boundary spanning mechanism identifies a specific network of solution-providers that will need time to respond to the challenge since they must evaluate the potential success of the technology solution. A NineSigma manager detailed how the boundary spanning mechanism was used in the halite problem:

> You can tell immediately where it stands. It is very much upstream-you could not expect to get anything off the shelf, ready, just drop in an ingredient and that's it. In this particular case, when we selected the broadcast pool of contacts, we focused a little bit more on the scientific community at the university level, the lab level, rather than going to industrial parties. So, we made sort of a balance between the pure scientific community and the industrial one.

The main difference between the scientific and sophisticated paths is the knowledge distance to diverse scientific fields, which, in the case of sophisticated paths, have clearly specified input and output parameters. In scientific paths, the scientific fields are unknown and distant, while in sophisticated paths, the technology fields are local and aim to provide solutions that add value to existing products. For example, 3M's alternative use of roofing granulates to address their post-consumer asphalt shingles problem appeared to be a scientific path. A 3M manager explained why this problem required a sophisticated path instead:

> What we were trying to evaluate was the potential of a better-value solution in going all the way back to the basic asphalt shingles, and whether that would be more economically valuable. We did not have enough information to understand how you would make that separation and recovery. We did not have a good-enough understanding of the asphalt that would be incorporated.

Scientific paths differ from analogical paths in terms of the impact of the requested solution, i.e., whether breakthrough or disruptive solutions or new processes or technologies. An example is Sealy's effort to redefine its foundation mattress. A senior process engineer from Sealy described this project as having specific characteristics that warranted an analogical path:

> Most projects are very linear and include process improvement stages. This is a long-term initiative, and a lot of creativity has to go into the actual activities of a project such as this. So, it is not only about analytical reasoning, but also some team-building and facilitating skills in order to make sure things are organized and the momentum stays there. It is long term, and you make it to a point where you realize that is not the best thing to do, and even though time has been invested, you have to make sure you have enough data to know that it is still a good initiative.

To sum up, each search path has specific objectives, characteristics, selection criteria, and expected types of solutions (see Fig. 2), and the problem framing and boundary spanning mechanisms are applied differently (see Table 1). In the following section, we discuss our findings in light of the extant literature on search and open innovation.

5. Discussion

The present study adds to conceptual developments related to the breadth and depth of the search space (Knudsen and Srikanth, 2014; Levinthal and March, 1993), and investigates how decisions about search heuristics (Gavetti, 2012; Grandori, 2013; Nickerson and Zenger, 2004) can increase the possibility of identifying novel solutions to problems. Based on the existing search literature (cf. Ahuja and Katila, 2004; Fleming and Sorenson, 2004; Gavetti and Levinthal, 2000; Laursen, 2012), we propose a depiction of search in open innovation represented by a combination of two search dimensions: the search space, which can be either local or distant (Garriga et al., 2013; Laursen and Salter, 2006; Piezunka and Dahlander, 2015), and the search heuristics, which can be either experiential or cognitive (Felin and Zenger, 2014; Sieg et al., 2010; Spradlin, 2012).

In the proposed typology of search paths, we found that the combination of search space and search heuristics helps to explain organizational search in open innovation by reinforcing the importance of refinement search (exploitation) and innovative search (exploration) (Levinthal and March, 1981; March, 1991), or situated and scientific paths, respectively. We introduce two previously neglected search paths (analogical paths and sophisticated paths). Moreover, combined with the use of innovation intermediaries (Chesbrough, 2006; Roijakkers et al., 2014), we propose that the mechanisms of problem framing (Baer et al., 2013; Kaplan, 2008; Von Hippel and Von Krogh, 2015) and boundary spanning (Fleming and Waguespack, 2007), in relation to the knowledge-seeker's problem, are integral to each search path.

The problem framing mechanism offers the possibility to formulate a technology problem by using familiar terminology, or an alternative or competing problem understanding (Baer et al., 2013). More specifically, our study revealed how innovation intermediaries interact with knowledge-seeking clients to formulate their problems into addressable technology needs for solution-providers. While this does not imply that interactions between intermediaries and knowledge-seekers lead to complete problem decompositions, the articulation into an RFP zooms in on specific needs that are bottlenecks to progress in technology development. The contribution of problem framing is twofold: (a) it facilitates the identification of critical issues to solve problems, and (b) it articulates a distinct technology need that can be communicated to a community of solvers not currently familiar with the specific problem setting.

The boundary spanning mechanism consists of identifying potential areas, i.e., scientific and technological, as well as crowds of solution-providers that might be interested in solving the specific problem. This mechanism facilitates the knowledge-seeker's access to a distant network of solution-providers (Jeppesen and Lakhani, 2010). Our findings suggest that boundary spanning by innovation intermediaries contributes to bridging three types of boundaries: (a) boundaries between areas of application and knowledge domains, (b) organizational boundaries between knowledge-seekers and solution-providers and (c) boundaries between known and unknown solutions.

The intersection between the problem framing and boundary spanning mechanisms addresses two gaps in the literature. First, while distant search seems beneficial for breakthrough innovations, the large number of irrelevant solutions makes the evaluation of distant solutions cumbersome (Piezunka and Dahlander, 2015). We propose that more precise problem framing could reduce the number and heterogeneity of proposed solutions, and increase the possibility of finding an applicable solution. Second, Jeppesen and Lakhani (2010, p. 1031) report that up to two-thirds of broadcast problems remain unsolved. We suggest that the mechanism of problem framing could be used to provide an alternative understanding to a specific problem and also increase the chances of identifying an acquirable solution.

The four search paths and two proposed search mechanisms have implications for scholarship in organizational search generally, and open innovation in particular. While the benefits of innovation intermediaries performing search for external knowledge in local and distant technological fields in relation to problems, or ideation and expertise-based projects, have been documented previously (c.f. Sieg et al., 2010; Spradlin, 2012), relatively little attention has been given to how search takes place, and what alternative search heuristics are applied in open innovation (Felin and Zenger, 2014; Jeppesen and Lakhani, 2010). These observations reinforce the need for a more refined understanding of how search takes place in relation to open innovation projects (Du et al., 2014) and problem solving (Von Hippel and Von Krogh, 2015). The empirical findings from our study of 18 open innovation projects shed light on when knowledge-seekers and innovation intermediaries employ the four search paths in their quest for external knowledge.

In the case of situated search paths, the literature highlights their benefits for "clearly defined, well-structured and simple problems (i.e. non complex) or sub-problems" (Felin and Zenger, 2014, p. 921). Here, early stage or not-quickly implementable solutions are not desirable. Analogical search paths involve reasoning via recombination across different knowledge domains (Gary et al., 2012). Although analogical search paths are beneficial for technology-development problems, search across distant technological boundaries requires combinative and collaborative capabilities (Jeppesen and Lakhani, 2010).

While situated and analogical search paths are more advantageous for problems that exploit feed-back from the problem at hand, a routine development process, or learning-by-doing (Nelson and Winter, 1982; Pisano, 1994), some authors suggest that the use of different search heuristics, i.e., problem redefinition, decomposition, and knowledge abstraction from the knowledge-seeker's industry context, would improve the chances of obtaining successful solutions to more complex problems (Sieg et al., 2010; Von Hippel and Von Krogh, 2015).

Sophisticated search paths are aimed at novel solutions based on concepts, theories, and models in adjacent domains (Tripsas and Gavetti, 2000). Their success depends on the problem formulation, which requires abstract representations or deductive reasoning. We showed that innovation intermediaries can be helpful partners with sophisticated paths, the framing of problems in abstract terms, and the targeting of networks of potential solution-providers. Hence, sophisticated search paths are suitable for decomposable problems since they build upon path-deepening (Ahuja and Katila,

2004) and abstract reasoning, as these do not require extensive boundary spanning due to commonalities with current solutions.

Scientific search paths are used to identify solutions to complex and novel problems involving substantial uncertainty. These types of search paths require theory-driven conjectures, which involve searching and exploiting distant knowledge domains. Although some previous studies suggest using firm-hosted user and innovation communities to engage expert solution-providers to find inexpensive solutions to complex problems (Felin and Zenger, 2014), these scenarios do not take into account expensive and confidential problems with very low hit rates, such as a need for alternative sources of sodium (PepsiCo) or substitutes for formaldehyde (L'Oreal).

6. Conclusions

In this paper, we analyzed how search takes place when knowledge-seeking firms use innovation intermediaries in open innovation projects to solve technology problems. We summarize our main arguments, primary contributions, some limitations, and suggestions for future research as (1) problems, (2) paths, and (3) projects.

First, the findings reported here contribute to recent theorizing on search in open innovation that uses a problem-solving perspective (c.f. Afuah and Tucci, 2012; Jeppesen and Lakhani, 2010; Piezunka and Dahlander, 2015; Von Hippel and Von Krogh, 2015). We add to this literature by showing the combined effects of both search space and search heuristics dimensions when knowledge-seekers assisted by open innovation intermediaries search for solutions to problems through innovation contests. As empirical research on open innovation intermediaries is scarce (Chesbrough, 2006; Roijakkers et al., 2014), we suggest that future studies can use this setting to further empirically examine the viability and effectiveness of different search options in problem solving.

Second, we conclude that the combination of search space and search heuristics previously discussed in the literature (e.g. Gavetti and Levinthal, 2000) makes four distinct search paths available: situated, analogical, sophisticated, and scientific. 18 open innovation projects were examined and classified according to these search paths. We argue that one-dimensional search path constructs (Tippmann et al., 2013) fail to recognize the range of search paths available in open innovation (Felin and Zenger, 2014). Moreover, there is little acknowledgment in the literature of analogical or sophisticated search paths, while our study shows that they represent important search options. We also indicated how the mechanisms of problem framing (Baer et al., 2013; Kaplan, 2008) and boundary spanning (Fleming and Waguespack, 2007; Rosenkopf and Nerkar, 2001) operate in these search paths. As we merely identify these search paths, future research could examine contingencies that influence their use, rate, and direction. This should include variables identified in the recent literature on search in open innovation such as problem complexity (Felin and Zenger, 2014), incentives for solution-providers to contribute their solutions (Boudreau et al., 2011), attention of knowledge-seekers (Piezunka and Dahlander, 2015), accumulated experience of knowledge-seekers with open innovation (Sieg et al., 2010), and business models used by innovation intermediaries or third-party platforms (Afuah and Tucci, 2012; Howells, 2006).

Third, despite the characteristics of search paths being general, we conclude that much search takes place in projects. We argue that empirical observation and analysis of search paths requires in-depth, project-level data to reveal both the search heuristics applied and the search space covered. In projects, problems are framed and boundaries are spanned. Our findings draw upon only 18 open innovation projects, and we recognize ample opportunity for future research on the project level to provide further explanations of the processes and mechanisms in operation (see e.g. Du et al., 2014). For instance, since successful open innovation also involves the integration of external knowledge subsequent to search (Lakemond et al., 2014), future research using both larger and smaller samples of projects could investigate the conditions under which project governance and project routines are applied in different search paths.

Acknowledgements

The authors acknowledge insightful conversation on the topic of this paper with editor Ashish Arora and two anonymous reviewers. Extensive and constructive comments on previous drafts were provided by Lars Frederiksen, Keld Laursen, Ann Majchrzak, Peter Murmann, Ammon Salter and Jonathan Wareham. Previous versions were presented in seminars at Aarhus Univ., Erasmus Univ., Linköping Univ., Univ. of New South Wales, Univ. of Zurich, and the Special Conference on Open Innovation, London, 2012 and the Organization Science Winter Conference, Steamboat Springs, 2012. The authors want to thank the seminar and conference participants for their helpful feedback on earlier drafts. The support from ESADE Business School and NineSigma, and the funding provided for this research by Handelsbanken's Research Foundations and Riksbankens Jubileumsfond is gratefully recognized. The usual disclaimers apply.

Appendix 1. Interviewed companies

No. of interviewees	Name of the organization	Position	No. of interv.	Name of the organization	Position	No. of interv	Name of the organization	Position
1	L'Oreal	Open Innovation Manager	1	Xerox	Open Innovation Manager	1	Kimberly-Clark Health Care	Product & Technology Development Manager
1	Carl Zeiss AG	Senior Manager, Scientific Affairs	1	Kraft Foods	Senior Associate & Principal Scientist	1	Natura	Director of Advanced Research
1	Rheem Manufacturing Company BP PLC, Refining Technology	Principal Engineer	1	Ferrero	Packaging Development Director	1	Sealed Air	Research Scientist (Open Innovation Manager)
1		Process Tools and Analytics Manager	1	Sherwin Williams	Technology Scout	1	International Copper Association	Assistant Director of Technology
1	Sealy	Senior Process Engineer	1	The Goodyear Tire & Rubber Company	Senior R&D Associate	2	Hallmark Cards, Inc.	Product Innovation Manager, Senior Engineer II

Appendix 1(*Continued*)

No. of interviewees	Name of the organization	Position	No. of interv.	Name of the organization	Position	No. of interv	Name of the organization	Position
2	3M Display & Graphics Laboratory	Senior Laboratory Manager, Laboratory Head	2	Akzo Nobel Decorativ e Coatings	Paints Research Associate, Open Innovation Leader	12	NineSigma	Chief Executive Officer; Vice President, Strategic Programs; Chief Sales Officer; Vice President, Technology solutions; Director, Global Programs; Director, Technology Solutions; Principal Program Architect; Consulting and Sales Executive; Program Manager (x4)
2	Philips	Director of Open Innovation; Senior Engineer, Metals and Ceramics (Cluster Process Technology) Technology)						

References

Afuah, A., Tucci, C.L., 2012. Crowdsourcing as a solution to distant search. Acad. Manage. Rev. 37, 355–375.
Ahuja, G., Katila, R., 2004. Where do resources come from? The role of idiosyncratic situations. Strateg. Manage. J. 25, 887–907.
Baer, M., Dirks, K.T., Nickerson, J.A., 2013. Microfoundations of strategic problem formulation. Strateg. Manage. J. 34, 197–214.
Boudreau, K.J., Lacetera, N., Lakhani, K.R., 2011. Incentives and problem uncertainty in innovation contests: an empirical analysis. Manage. Sci. 57, 843–863.
Carnabuci, G., Operti, E., 2013. Where do firms' recombinant capabilities come from? Intraorganizational networks, knowledge, and firms' ability to innovate through technological recombination. Strateg. Manage. J. 34, 1591–1613.
Chesbrough, H., 2006. Open Business Models: How to Thrive in the New Innovation Landscape. Harvard Business School Press, Boston.
Cyert, R., March, J.G., 1963. A Behavioral Theory of the Firm. Blackwell, Oxford.
Dosi, G., 1982. Technological paradigms and technological trajectories. Res. Policy 11, 147–162.
Du, J., Leten, B., Vanhaverbeke, W., 2014. Managing open innovation projects with science-based and market-based partners. Res. Policy 43, 828–840.
Felin, T., Zenger, T.R., 2014. Closed or open innovation? Problem solving and the governance choice. Res. Policy 43, 914–925.
Fleming, L., Sorenson, O., 2004. Science as a map in technological search. Strateg. Manage. J. 25, 909–928.
Fleming, L., Waguespack, D.M., 2007. Brokerage, boundary spanning, and leadership in open innovation communities. Organ. Sci. 18, 165–180.
Garriga, H., von Krogh, G., Spaeth, S., 2013. How constraints and knowledge impact open innovation. Strateg. Manage. J. 34, 1134–1144.
Gary, M.S., Wood, R.E., Pillinger, T., 2012. Enhancing mental models, analogical transfer, and performance in strategic decision making. Strateg. Manage. J. 33, 1229–1246.
Gavetti, G., 2012. PERSPECTIVE – toward a behavioral theory of strategy. Organ. Sci. 23, 267–285.
Gavetti, G., Levinthal, D., 2000. Looking forward and looking backward: cognitive and experiential search. Adm. Sci. Q. 45, 113–137.
Gavetti, G., Rivkin, J.W., 2007. On the origin of strategy: action and cognition over time. Organ. Sci. 18, 420–439.
Gentner, D., 2002. Analogy in scientific discovery: the case of Johannes Kepler. In: Magnani, L., Nersessian, J. (Eds.), Model-Based Reasoning: Science, Technology, Values. Kluwer, New York.
Grandori, A., 2013. Epistemic Economics and Organization: Forms of Rationality and Governance for a Discovery Oriented Economy. Routledge, London.
Hargadon, A., Sutton, R., 1997. Technology brokering and innovation in a product development firm. Adm. Sci. Q. 42, 716–749.
Hedström, P., Swedberg, R., 1998. Social Mechanisms: An Analytical Approach to Social Theory. Cambridge University Press, Cambridge.
Howells, J., 2006. Intermediation and role of intermediaries in innovation. Res. Policy 35, 715–728.
Jeppesen, L.B., Lakhani, K.R., 2010. Marginality and problem-solving effectiveness in broadcast search. Organ. Sci. 21, 1016–1033.
Johnson-Laird, P.N., 2001. Mental models and deduction. Trends Cognit. Sci. 5, 434–442.
Kaplan, S., 2008. Framing contests: strategy making under uncertainty. Organ. Sci. 19, 729–752.
Katila, R., Ahuja, G., 2002. Something old, something new: a longitudinal study of search behavior and new product introduction. Acad. Manage. J. 45, 1183–1194.
Knudsen, T., Srikanth, K., 2014. Coordinated exploration: organizing joint search by multiple specialists to overcome mutual confusion and joint myopia. Adm. Sci. Q. 59, 409–441.
Lakemond, N., Bengtsson, K., Laursen, K., Tell, F., 2014. Match & Manage: the use of knowledge matching and project management to integrate knowledge in collaborative inbound open innovation. In: 1st Annual World Open Innovation, Napa, USA.
Laursen, K., 2012. Keep searching and you'll find: what do we know about variety creation through firms' search activities for innovation? Ind. Corp. Change 21, 1181–1220.
Laursen, K., Salter, A., 2006. Open for innovation: the role of openness in explaining innovation performance among UK manufacturing firms. Strateg. Manage. J. 27, 131–150.
Levinthal, D., March, J.G., 1981. A model of adaptive organizational search. J. Econ. Behav. Organ. 2, 307–333.
Levinthal, D.A., March, J., 1993. The myopia of learning. Strateg. Manage. J. Winter Spec. Issue, 95–112.
March, J.G., 1991. Exploration and explotation in organizational learning. Organ. Sci. 2, 71–87.
March, J.G., Simon, H.A., 1958. Organizations. Blackwell, Oxford.
Martin, X., Mitchell, W., 1998. The influence of local search and performance heuristics on new design introduction in a new product market. Res. Policy 26, 753–771.
Nelson, R.R., Winter, S.G., 1982. An Evolutionary Theory of Economic Change. Harvard University Press, Cambridge.
Nickerson, J.A., Zenger, T.R., 2004. A knowledge-based theory of the firm – the problem-solving perspective. Organ. Sci. 15, 617–632.
Piezunka, H., Dahlander, L., 2015. Distant search, narrow attention: how crowding alters organizations' filtering of suggestions in crowdsourcing. Acad. Manage. J. 58, 856–880.
Pisano, G., 1994. Knowledge, integration, and the locus of learning: an empirical analysis of process development. Strateg. Manage. J. 15, 85–100.
Roijakkers, N., Zynga, A., Bishop, C., 2014. Getting help from innomediaries: what can innovators do to increase value in external knowledge searches? In: Chesbrough, H., Vanhaverbeke, W., West, J. (Eds.), New Frontiers in Open Innovation. Oxford University Press, Oxford.
Rosenkopf, L., Nerkar, A., 2001. Beyond local search: boundary-spanning, exploration, and impact in the optical disk industry. Strateg. Manage. J. 22, 287–306.
Schumpeter, J.A., 1934. The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle. Harvard University Press, Cambridge.
Sieg, J.H., Wallin, M.W., Von Krogh, G., 2010. Managerial challenges in open innovation: a study of innovation intermediation in the chemical industry. R&D Manage. 40, 10.
Spradlin, D., 2012. Are you solving the right problem? Harv. Bus. Rev. 90, 84–93.
Strauss, A., Corbin, J., 1998. Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory. SAGE Publications, Thousand Oaks.
Stuart, T.E., Podolny, J.M., 1996. Local search and the evolution of technological capabilities. Strateg. Manage. J. 17, 21–38.
Tippmann, E., Mangematin, V., Scott, P.S., 2013. The two faces of knowledge search: new solutions and capability development. Organ. Stud. 34, 1869–1901.
Tripsas, M., Gavetti, G., 2000. Capabilities, cognition, and intertia: evidence from digital imaging. Strateg. Manage. J. 21, 1147.
Von Hippel, E., Von Krogh, G., MIT Sloan Research Paper No. 5071-13 2015. Identifying Viable 'Need-Solution Pairs': Problem Solving Without Problem Formulation.
West, J., Salter, A., Vanhaverbeke, W., Chesbrough, H., 2014. Open innovation: the next decade. Res. Policy 43, 805–811.
Zollo, M., Winter, S.G., 2002. Deliberate learning and the evolution of dynamic capabilities. Organ. Sci. 13, 339–351.