Radical innovation: triggering initiation of opportunity recognition and evaluation

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The gap between a firm's reservoir of technical knowledge and the formation of a project to explore the commercial potential of a breakthrough technical insight or discovery is the first major discontinuity in the radical innovation lifecycle. The first step toward bridging that gap occurs when the researcher with the technical insight recognizes that it might have commercial potential and decides to alert a research manager. In our longitudinal study of eight radical innovation projects in six large, multi-national, R&D-intensive firms, the initiation of a radical innovation project was neither frequent nor routine. In fact the participants in the study indicated that the initiation of a project – in their terminology, the 'fuzzy front end of innovation' – was the most challenging and uncertain part of the lifecycle. In this paper we explore the case data to illuminate the nature of the initiation gap. In addition we present an assessment framework that can help researchers decide whether or not to bring their technical idea to the attention of management. If the decision is positive, the assessment tool can help them prepare for the discussion with management and identify the strengths and weaknesses of the case to submitted for evaluation.

1. Introduction

Radical innovation involves the application of significant new technologies or significant new combinations of technologies to new market opportunities (Tushman and Nadler, 1986). It results in new product classes, product substitution, or fundamental product improvements (Tushman and Anderson, 1986). That firms need to periodically invest in new technologies and engage in the process of radical innovation is well-recognized (Tushman and Nadler, 1986; Morone, 1993; Betz, 1993; Myers and Rosenbloom, 1993). Yet this is not a simple undertaking for these firms. Radical innovation is a risky, costly, and lengthy process that threatens and disrupts existing organizational structures (Galbraith, 1982; Abernathy and Clark, 1985; Utterback, 1994). Established firms are deemed too bureaucratic (Hamel and Prahalad, 1991), complacent (Tushman and Nadler, 1986), or entrenched in processes that address current customer needs and provide quicker returns (Bower and Christensen, 1995) to be effective in the development of radical innovations.

Recent findings have revealed that the major problem for established firms lies not in the radical technology creation process, but in advancing these technologies toward commercialization (Christensen and Bower, 1996; Tushman and O'Reilly, 1996). Contributing to this problem is the high uncertainty that characterizes the radical technology development

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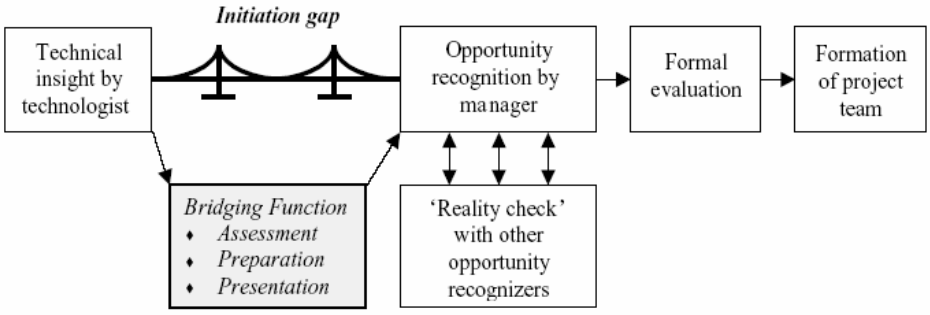


Figure 1. Initiation of a radical innovation project.

process (Schon, 1967; Kline and Rosenberg, 1986). Particularly at the front end of the radical innovation lifecycle, it is difficult to envisage the development path and to have confidence that the chosen path will lead to dominance in an industry (Quinn, 1985).

The firms in our study reported particular difficulty in getting radical technical ideas across the gap between the reservoir of technology and the start up of a commercialization project. Our observations have led us to represent the initiation process at the front end of the radical innovation lifecycle as indicated in Figure 1.

This research paper seeks to illuminate the initiation phase of a radical innovation project and to report on the development of an assessment tool that may increase the likelihood and success of project initiation activities. The assessment tool or framework, when applied by the idea-generating technologist, can serve as the bridging function highlighted in Figure 1. In the majority of our case studies, the technologist who discovered the technical insight that was the basis for radical innovation did not have the experience and knowledge to recognize the business opportunity that derived from the innovation (Rice *et al.*, 1997). Thus opportunities associated with radical innovations may not be recognized, or opportunity recognition may be delayed until a research manager stumbles across the innovation. The problem is exacerbated in those cases in which the technology development is deliberately pursued via bootstrapping and outside the view of managers because the innovation is unrelated to the current mainstream business of the firm. When these projects fail to gain organizational support, they typically flounder and the organization forfeits its chance to benefit from potentially lucrative technologies.

The new product development literature cites a host of analytical tools for evaluating new opportunities (Johne and Snelson, 1989; Kuczmarski, 1992; Cooper, 1993). These include calculating the probability the project will meet the firm's profitability objectives, predicting market size and growth rate, and assessing the risks of alternative scenarios, in which various environmental contingencies are imposed on the project. But these familiar and often prescribed practices are more appropriate for incremental than for radical innovations, or for radical innovation projects that are more mature. For a truly radical innovation, it is unlikely that the technologist will be able to envision and assess the business opportunity associated with the innovation – particularly at the very front end of the radical innovation lifecycle.

Other researchers offer tools specifically aimed at technology evaluation. This activity, however, typically constitutes an ad hoc, firm-wide planning exercise, in which the firm evaluates its existing technologies and future technology requirements, generally in relation to its current products and the competitive environment (Dohrmann, 1978; Metz, 1996; Koen, 1997). These tools and techniques are less relevant for the individual researcher assessing an individual technical insight in order to decide whether to solicit the attention of a research manager.

In this paper, we address the following research question: how should a technologist evaluate a radical new technology to determine whether broader organizational support should be sought for the initiation of a radical innovation commercialization project and to prepare the technologist for a discussion of the breakthrough with a research manager?

2. Research method

Research design and sample

The framework in this paper was developed through a research study of the management processes associated with radical innovation (Rice *et al.*, 1998; McDermott, forthcoming). This study involves a team of researchers from a variety of management and technical disciplines. Heterogeneous research teams provide robustness in the evaluation of case data, offering different perspectives and increasing the likelihood of gaining novel insights (Eisenhardt, 1989). Over the course of five years, this team has examined radical

innovation projects in large, multi-national, R&D-intensive industrial organizations. Data have been collected as the projects are under development, to guard against inaccuracies in participants' recall, a frequent criticism of studies relying on historical anecdotes (Loftus, 1979; Yin, 1989; Brown and Eisenhardt, 1995).

The research design is multiple-case, which enables us to examine cross-case patterns and view our research question within different contexts (Eisenhardt, 1989). The initial research sample included eight projects in six firms. The companies and their radical innovation technologies are listed below:

1. Air Products	Oxygen separation technology
2. DuPont	Biodegradable polymer
3. DuPont	Display technology
4. General Electric	Digital X-ray
5. General Motors	Hybrid vehicle
6. IBM	Silicon Germanium devices
7. IBM	Electronic book
8. Texas Instruments	Digital micro-mirror device

At the start of our research study, the participating firms projected the development of the technology would result in innovations with one or more of the following characteristics: an entirely new set of performance features, a 5–10 fold (or greater) improvement in performance, and/or a 30–50% (or greater) reduction in cost. The firms describe these projects as different from existing efforts within the firm, and recognize they may require different development structures and management practices. Company personnel have characterized these projects as long and costly, with a high degree of uncertainty and risk along technical, market, organizational and resource dimensions.

Although the eight cases were the primary source of data for this paper, the researchers benefited from participation in a series of workshops and committee meetings under the sponsorship of the Industrial Research Institute. These interactions confirmed and extended insights derived from the thousands of pages of transcripts of interviews with participants in the eight radical innovation projects. In addition, subsequent to the development of the framework reported in this paper, four additional projects were added to the sample:

- Nortel Networks' internet based software activation technology;
- Otis Elevator's bi-directional elevator;
- Polaroid's high density computer memory storage device; and
- Analog Devices' MEMS accelerometer chip.

Nortel Networks launched the most comprehensive investment and business development organization targeted at commercializing breakthrough innovations among all ten firms, including an aggressive approach to uncovering promising breakthrough technical ideas. Hence, we asked the head of Nortel Network's radical innovation initiatives to serve as a reviewer of our framework. (For a comprehensive review of the research methodology, including the processes of collaboration among the members of the research team and the Discontinuous Innovation Subcommittee of the Research-on-Research Committee of the Industrial Research Institute, see O'Connor *et al*., 1999.)

Data collection and analysis

Each firm in the sample hosted a minimum of two site visits. During these visits, interviews were conducted with various technical and managerial staff associated with the projects: senior technical and business managers, project managers, and project team members. These individuals provided both historic and current information, and their own insights with regard to the research questions. Each representative from the firm participated in multiple interviews. The interviews were conducted by at least two members of the research team, each representing a different functional discipline. Three authors of this paper were present at site visits to the six firms.

To develop the framework for this study, we reviewed transcripts of interviews conducted by the entire research team, centering our analysis on the initiation of the process. We focused on discussions in which interviewees identified the issues with which they struggled during project initiation and in which they indicated how they decided to move forward, rather than abandon, their projects. In addition we extensively reviewed the literature and incorporated the insights of other researchers regarding the important issues to be confronted when considering the launch of a breakthrough innovation project.

We used qualitative analysis methods suggested by Miles and Huberman (1994) and Eisenhardt (1989). In an effort to avoid bias stemming from project familiarity, a researcher/author not involved in the data collection process prepared summary sheets for each project based on a review of the transcripts, and developed initial questions relating to project initiation. Additionally, this author constructed matrix displays to present the projects along various dimensions, and to catalyze discussions among the other three researchers.

Two additional steps were taken to test and refine the framework. As indicated above, subsequent to the start of the analysis for this paper, four additional projects were added to our sample, one of which was Nortel Networks. The company was at that time implementing its own web-based tool for stimulating idea generation and assessment among its technologists. The objective for Nortel Networks was increasing the flow of new ideas into its newly formed business development organization. The manager of this

organization provided an in-depth assessment of our preliminary framework. Second, the Industrial Research Institute – a professional association of senior technology managers of R&D-intensive firms – has partnered with the research team through its Research on Research Committee. The lead author made a presentation to the radical innovation subcommittee, composed of senior technology managers, and engaged all 14 subcommittee members in assessing the importance of the questions included in the preliminary framework. Each subcommittee member completed a survey assessing the importance of the elements of the framework, and in addition 11 of the 14 respondents provided written comments to supplement the survey.

3. Findings from the case studies

Four of the eight projects experienced significant difficulties during the initiation process. Documenting the initiation process in these four cases revealed issues that were embodied in the questions of the assessment and decision making framework. At General Electric, the original idea generator within Central Research and Development – Jack Kingsley – saw a potential application in medical systems for a display technology he was developing for GE Aerospace in 1983. However he was unable to make a convincing case to his contacts within GE Medical Systems, the business unit that would be the likely recipient of products that might emerge from a technology development effort. Receiving a negative response, he opted to not persist. Ironically an inquiry from a potential manufacturing partner four years later caused the business unit to reconsider. This time Kingsley teamed up with his research manager, Bruce Griffing, developed a convincing case, and the project was launched with the support of the business unit. The false start at GE contributed to the inclusion of market-related and corporate strategy questions in our framework. In our view, engaging the framework developed in this paper when the radical idea originally emerged could have helped Kingsley prepare for a discussion with the business unit. It might have led to a more thorough assessment of his radical idea by his contacts in the GE Medical Systems business unit, and the project might have been initiated four years earlier than actually occurred.

The technologist at IBM responsible for a breakthrough discovery related to the silicon germanium chip was unable to trigger formal project initiation successfully. The company tried to force fit the technology into an inappropriate application. The appropriate target applications were outside the current strategic framework of the firm and the business model would require technical capabilities that did not exist in house. The technologist was unable to engage his managers in the initiation process in a way that would get the commercialization project started up. However, he had sufficient technical credibility that he was able to sustain the R&D effort underground with persistence and bootlegged resources. Two organizational initiatives served to overcome the initiation gap for this project. New CEO Lou Gerstner took the reigns of IBM in April 1993. He changed the strategic framework, dictating that IBM would begin selling chips to the outside world – something it had long resisted. Under this new strategic mandate, the microelectronics division dispatched an 'idea hunter', Barry Seidner, to seek out promising ideas. According to Seidner:

> I started looking through our research organization to uncover intellectual property that I could leverage into the marketplace. I was actively scanning and knew that one scientist had been running around evangelizing the technology for two or three years. He hadn't been able to build a case that got it recognized and funded. What we had here was a [Research] Fellow, one of the smartest guys in the world, but he couldn't get the attention to tilt this thing up.

Seidner recognized the potential in the silicon germanium chip technology and worked with the technologist to develop a business case that communicated the opportunity in a way the management review board could understand. In August 1994, IBM's innovation funding board did a complete review of the project and formally established it with full funding. This case revealed the importance of guiding the technologist in consideration of the issues that will be important to management in the project initiation discussion. In this case all three technology-to-organization links were important for that discussion. With the framework proposed in this paper, the idea generator might have been able to develop a sufficiently convincing case to get the attention and support of senior management earlier and thereby shorten the gestation period.

At Air Products the ionic transport membrane project had two false starts. The initial (external) proponent of the technical idea was unable to convince the firm that the technology could be implemented and deliver breakthrough features. By contrast when an internal engineer took a new look at the idea after reading an article in a technical journal, he was able to present the technical concept in a way that gained the support of a senior technical manager, who in turn triggered a new, more favorable review by the business development organization. The issues confronted in the initiation activities were daunting. As in the previous two false starts, there was high uncertainty regarding whether the ionic transport membrane could be manufactured, but this time technical capabilities were identified internally and through an external partner. There was a high degree of fit with the strategic core of the firm and the strategic intent to be

the innovation leader in the industry. The innovation could result in a substantial cost reduction in the firm's core business, thereby transforming the competitive landscape. However, the economics depended on the willingness of the customer to utilize waste heat for co-generation, and at the time of project initiation only one additional, non-core application alternative had been identified. In this case market-related and technology-related issues were an important part of the discussion that ultimately led to the initiation of the project. If the original (external) idea generator had been presented with the framework in this paper by the business development organization at Air Products, perhaps the case for the idea would have been presented in a more compelling way and the two false starts could have been avoided.

At Texas Instruments, the technology had been in development for 12 years. Only solicitation of external funding by research managers had kept the technology development effort alive. Two key organizational changes created a favorable climate for consideration of the technical idea as a catalyst for the initiation of a radical innovation project. The CEO of the firm became a powerful proponent for developing new businesses in the white spaces between the current lines of business. In addition he championed the establishment of a new corporate business development organization, which in turn issued a request for proposals. These initiatives signaled the receptiveness of the firm to radical ideas and provided an organizational mechanism to review proposals, which in turn provided guidance about the appropriate form of a business case to technologists. When TI issued the request for proposals and provided its version of the framework developed for this paper, it received two thousand submissions. In this case there were substantial issues related to all three technology-to-market links included in our framework.

The remaining four cases, in which project initiation was not problematic, revealed additional organizational approaches for bridging the project initiation gap. At General Motors, an ad hoc evaluation team composed of two research managers and a senior research engineer met periodically over lunch to review externally submitted ideas. One externally submitted idea was deemed impractical by the research engineer, but in the process of explaining his analysis, he came up with an idea that did receive a favorable reaction from his colleagues. In the case of IBM's electronic book project, the idea was initiated through a technology forecasting exercise conducted by a research manager, who had the authority to initiate the project. Thus he served as both idea generator and opportunity recognizer. Dupont had implemented organizational entities aimed at stimulating, receiving and evaluating promising ideas. These served to 'pull' ideas out of the research organization. In each of these cases the initiation gap was lessened by proximity to the idea receiver, and/or by the activism of the receiving unit. Thus, the bridge across the initiation gap can be built from both sides – by the idea generator and by the idea receiver. Also, the gap is jumped when the idea generator and idea receiver are the same individual. Hence firms increase the rate of project formation by encouraging research managers to take on the dual roles.

The technologist who generates the radical idea must reach a decision to bring it to the attention of his organization – usually to his research manager or perhaps to an 'idea receiver' in a business development organization. Of course, in the eight projects in our study this decision was reached by the idea generator; otherwise the projects would not have been included in our study. But it was clear that the firms in our study – and those that participated in our workshops – were interested in increasing the flow rate of promising ideas. Each of the firms saw project initiation as a challenge and expressed frustration about how few projects were initiated, given their substantial commitments to R&D. Inevitably our participants were left to wonder how many potentially promising ideas never saw the light of day because the technologist either did not recognize the promise in the idea or chose not to engage a research manager in a discussion of the idea.

When a technologist opts to expose a technical idea that may lead to a breakthrough innovation, he or she should recognize and be prepared to discuss the multiple uncertainties associated with the breakthrough. This is important for gaining the attention of the idea receiver and getting a productive hearing.

It is clear from the case studies that establishing a receptive context and developing receiving organization mechanisms are also important for bridging the initiation gap. Ultimately bridging the initiation gap is a communication challenge. It is our expectation that the preliminary framework we developed based on the issues identified in the case studies can be used to catalyze readiness to transmit and receive. It can sensitize the idea generator to be alert to the potential for breakthrough innovations that might develop from technical ideas, provide a tool for a 'back-of-the-envelope' assessment of issues that will be important for the idea receiver, and prepare the idea generator for a productive discussion. Similarly, the framework provides an opportunity for the idea receiver to customize the tools to address issues of specific relevance to the firm. By providing the framework to technologists, the research manager signals receptivity and communicates to the technologist how to prepare for the discussion.

4. Discussion and evaluation of the proposed framework

The comparison of initiation activities across the eight projects allowed us to identify three primary

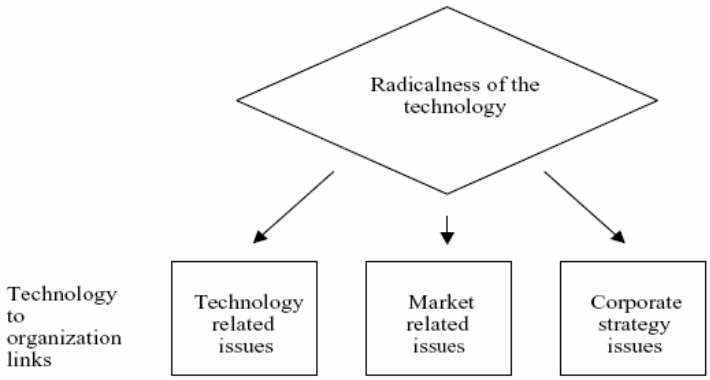
technology-to-organization links. Our framework, illustrated in Figure 2, starts with an assessment of the radicalness of the technology and then incorporates the three links connecting the radical technology and the firm's capacity for pursuing commercialization of the innovation.

Each of the elements of the assessment and decision-making framework is tested with a set of subsidiary questions, derived from a review of the case data and from the literature. We next discuss the three links within the context of existing literature to illuminate the connection between our findings and past work.

Technology related issues

The evaluation of the link between the technology and the organization's technology capabilities begins with an examination of the relationship between the technology and the firm's technological core. The firm's technological core represents the foundation of technologies that distinguish the firm and provide the key to its competitiveness. The technologists in these projects recognize the importance of leveraging key capabilities – creating advantage from what the company does best technologically. Empirical studies of radical technology development in established firms have found that commercialization of these technologies is more likely successful when there is a link to existing technological capabilities (Green *et al.*, 1995; Christensen and Bower, 1996; Granstrand *et al.*, 1997). This assessment needs to look beyond a simple match of the technology's characteristics with the organization's technology development capabilities, however. In all of the cases we studied, the development of radical technologies moved the firm's core technologies into uncharted territory, thereby stretching the firm's technology development capabilities.

Our framework next asks how gaps in technology development capabilities can be filled, either through internal development or external sources. Building new capabilities in technologies peripheral to the firm's core was neither timely nor strategically sound for many of



Technology related issues: radicalness of the technology

- Can this technical insight lead to a 30% or greater reduction in cost in a current product platform?
- Does this technical insight offer opportunities to open up a whole new line of business?
- Can this technical insight lead to a five to ten fold improvement in known features of a current product platform?

Technology related issues: technology capabilities

- Does the firm have or can it acquire the capabilities required to develop this technology?
- Is the technology related to the firm's current technological core?
- Are existing technology capabilities strong enough to develop this technology?
- Can needed technologies be developed or acquired easily and rapidly?
- Are there external sources for needed technologies?
- Is there confidence that technical problems can be overcome and feasibility proven?

Market related issues

- Can application of the technology create a leap over substitutes in the market?
- Is there a robust set of application possibilities?
- Will application of the technology displace a current application for the firm?
- Can a prototype be developed early/quickly to demonstrate the technology's applicability?

Corporate strategy issues

- Is the technology applicable to the firm's core business?
- Can the technology extend the firm's core business in new directions?
- Can the technology be an important contributor to the firm's strategic intent (future vision)?

Figure 2. Framework for bridging the initiation gap.

our projects. External sources of technological capabilities were accessed in seven of the eight projects. Hence, technologists who are preparing to initiate a radical innovation project need to consider internal and external sources of technology development capabilities.

The assessment of the technology capabilities link ends by asking whether the evaluator feels confident about overcoming technical problems and achieving technical feasibility. The technologists in our sample could not be certain technology development could be completed nor whether the outcomes would prove useful. Although some of the technical hurdles could be specified, it was not certain that they could be cleared. In addition, the technologists had to assume that some hurdles would only become apparent as technology development proceeded. Where this confidence could be exhibited, it is summarized as follows: (1) there was an understanding about which tasks were needed to accomplish feasibility, and (2) there was a sense that the technology team possessed, or had access to, the capabilities needed to accomplish these tasks or, an alliance partner could be found to help provide that expertise.

An expression of this confidence can be found in the following quote from an R&D director on one of our projects:

> Your ability to take a risk has to be based on your knowledge, and your confidence that you will succeed. Anybody who takes a risk has some feel or estimate or experience in what that risk costs him, and that he can succeed and solve these problems. But you have that only if you are experienced in that system. If you don't have any experience, you have nothing to draw on.

By considering these individual questions, the technologist can be prepared to answer the main question with regard to the technology capabilities link: 'Are we capable of developing this technology?'

Market related issues

The evaluation of the link between the technology and the organization's application prospects starts with an assessment of the potential impact of the technology's applications on the market and within the firm. A leap over competitive offerings or substitutes in the market was envisioned for each of the eight projects. These projects had the potential to produce major market impact, rewarding the firms for their proactivity. If substantial benefits to the market could not be envisioned, the commitment of financial and other resources would be difficult to defend.

The second question encountered in this link addresses the issue of application richness assessing a technology's potential value based on the robustness of the technology's application alternatives (Clark, 1987). This concept reflects the opportunity for the company to gain value from a technology through multiple applications, even if there are individual application failures. With radical innovation, the firm faces a high risk of market failure. Early applications often fail or come up short, and success is eventually achieved in markets not originally envisioned (Twiss, 1986). In fact, in each of our eight cases, the original target applications failed or did not materialize as expected, requiring a search for alternate applications, or a temporary 'shelving' of the technology. Multiple application alternatives enable the firm to experiment and develop the technology further, gaining experience to apply to later applications. This was a common theme in our study, and a concept supported by the literature (Myers and Rosenbloom, 1993; Bowman and Hurry, 1993; McGrath, 1997). One of our respondents termed this phenomenon 'application migration'. Hence, potential application richness was viewed as important in initial evaluation.

While these technologies have the potential for radical leaps in the market, they may present differing implications for the firm. The next two questions address the impact of the application on the current product lines of the firm, i.e. whether the new technology would displace a current application or create a new application domain. When current applications are displaced, the radical innovation project must face the prospect of substantial resistance from one or more existing business units, or redirection, retraining and/or restructuring. When the innovative technology results in new applications, the firm enters an unfamiliar market domain, requiring new market learning and market infrastructure development. In either case, the technologist should be ready to discuss the organizational and marketing/distribution implications of the new technology.

The final question in this link asks about the ability to construct early prototypes. For many of the projects in our sample, a prototype helped sell the project to the organization's upper management and was a key to early learning about potential markets. One of the project managers commented: 'If we didn't build our prototype and show them what could be done and show them there was a customer out there that really had a need for the technology, then management may not be interested in pursuing this thing'. We observed that if it could be demonstrated that there were clear applications benefits within a set of economic constraints, management would pay attention. Hence, it is important for the technologist to be prepared to discuss how and how soon a prototype can be developed to demonstrate feasibility and to test attractiveness to potential customers.

This set of questions address the issue of the application prospects link, 'Can this technology offer significant market value?'

Corporate strategy issues

The evaluation of the link between the technology and the organization's strategic outlook begins with an assessment of the applicability of the technology to the firm's core businesses. Where the technologies propose a direct impact on the firm's core business, the projects represent a relevant strategic direction for the firm. The value of connecting innovation projects with a firm's strategy is well recognized in the literature (Johne, 1984; Burgelman, 1986; Twiss, 1986; Strebel, 1992; Spender and Kessler, 1995; Dougherty and Hardy, 1996).

When the technical direction diverges from the organization's current businesses, however, management may be reluctant to support development of the new technology. It is then up to the technologist to consider the possible new business directions the technology may offer the firm, within familiar market domains. Thus the next question in this link asks whether the technology can extend the firm's current core business in new directions. Strategy researchers recognize that technology development can lead the firm down new strategic paths (Itami and Numagami, 1992) and that firms need to be flexible in their strategic decision making, allowing for experimentation (Burgelman and Sayles, 1986).

Given the anticipated long-term investment and expected returns for radical innovation, the next question addresses the firm's strategic intent – whether the technology contributes to the development of capabilities the firm anticipates needing for future strategic pushes (Gillett and Stekler, 1995). The following account describes how a radical technology, although strategically related, can stretch a firm's core business:

> The technology is radical in the sense that some of the things that we're doing are way ahead of where we would be following the usual kind of road map. We're trying to make it happen sooner, but it's not stuff that we don't think would happen eventually anyway. This is not something totally off the wall, in a totally different direction from how one would expect technology to go. It's in the same direction, but we're trying to speed it up significantly compared to how it would ordinarily happen.

Burgelman (1986) adds that while firms need to allow for initiatives that do not fit the firm's current strategy, they also need guidance for determining which proposals to adopt. In some of our projects, the technologies exhibited qualities relevant to businesses the firms had not envisioned. Where these technologies proposed new strategic directions, the technologist needed to think about the appropriateness of these directions for the firm. The organization's strategic orientation relative to future competitive placement was a major driver. One firm in our study, for example, felt it was less important to stay on the same business path than to leverage off existing technology capabilities. Another company may consider selling the technology if these efforts diverge too far from their strategic direction.

These questions address the main question with respect to strategic outlook, 'Does this technology make sense within the strategic framework of the organization?' The relative importance of the issues embodied in the proposed framework's questions was tested with the Industrial Research Institute's Radical Innovation Subcommittee. The issues and the results of the assessment by the members of the subcommittee are provided in Table 1 below.

Only items I.6, II.3, II.6 and III.5 exhibited means below 3.0 and in all four cases the number of responses below 3 (somewhat important) was less than 35%. Each of these items refers to the relatedness of the innovation idea to the core capabilities and the established lines of business of the firm. The respondents were also offered the opportunity to provide written comments about the framework and 11 out of 14 respondents opted to do so. The responses to these four survey items and the written responses indicated a concern about the willingness of the organization to undertake the risks of developing new technical capabilities, of cannibalizing existing product lines and of challenging the current strategic framework. Because the majority of respondents rated every question in the proposed framework 3 (somewhat important) or 4 (very important), we have retained all of the items in the framework. Research managers who choose to convey the instrument to prospective idea generators should carefully consider whether the four items with a mean importance rating below 3 should be included, and if so, in what form.

The review by the VP in charge of innovation at Nortel Networks reinforced the importance and value of the assessment framework. Her overall evaluation is reflected in the comments below:

> In summary, I believe you have designed an excellent assessment tool. I really like all the questions. I see them as appropriate and well-structured for the intended scientific audience.

The implications of her detailed comments, which provide insights into the development of follow on tools that can support the continuation of the initial assessment process, are presented in the concluding section of this paper.

5. Conclusions: applying the integrated framework

To properly apply our framework it is necessary to view the framework in total, to assess the relationship among the three dimensions, and to reveal weak links

Table 1. Assessment of framework for idea generation and opportunity recognition.

Instructions: Assume that a research scientist in your organization comes up with a novel idea or makes a technological discovery that could turn into a radical innovation. Naturally your business development organization will want to know about the discovery. You would like the scientist to be prepared for presenting the idea and for discussing its potential. Please rate the importance of the following issues in the preparation process.

4 = *Very Important*. The scientist greatly improves his chances of gaining the attention of business development people if he is prepared to discuss his discovery in light of this issue.
3 = *Somewhat important*. The scientist improves his chances of gaining attention if he is prepared to discuss his discovery in light of this issue.
2 = *Not important*. The scientist neither improves nor hurts his chances of being heard if he is prepared to discuss his discovery in light of this issue.
1 = *Negative*. The scientist hurts his chances of being heard if he talks about his discovery in terms of this issue.

I. Technology-related issues	Mean	S.D. (n − 1) (n = 14)
I.1 The degree to which the scientists believe that this technology could lead to a 30% or greater reduction in cost in a current product platform	3.57	0.51
I.2 The degree to which the scientists believe that this technology offers opportunities to open up a whole new line of business	3.50	0.52
I.3 The degree to which the scientists believe that this technology could create a five to ten fold improvement in known features of a current product platform	3.71	0.61
I.4 The degree to which the technology is related to the firm's current technical core	3.00	0.68
I.5 The degree to which the firm's current in-house capabilities are strong enough to develop the technology	3.07	0.62
I.6 If the technology is outside the firm's current technological core capability set, the degree to which the scientist can provide compelling reasons to argue for an expansion of the firm's technological capabilities in this direction	2.64	0.93
I.7 If the technological capabilities needed are not available in house, the degree to which they can be accessed through external partners. (How easily might they be acquired?)	3.14	0.66
I.8 The degree to which the scientists believe that the technical challenges can be overcome and feasibility can be proven.	3.43	0.65
II. Market application issues		
II.1 The degree to which the scientist believes this technology can create a leap over substitutes in the market for the right economics	3.43	0.85
II.2 The degree to which there is a robust set of applications possibilities	3.14	0.77
II.3 The extent to which the technology would displace a current technology application for the firm	2.71	0.61
II.4 The extent to which the technology could take the firm into new application arenas.	3.00	0.88
II.5 If multiple applications are not apparent, then the extent to which the scientist believes that the market is big enough to justify investment in this technology for a single application	3.21	0.70
II.6 The degree to which the scientist can discuss/provide compelling business reasons for seeking to cannibalize current technology, if that's what the new discovery does	2.50	0.94
II.7 The ease with which the technology can be displayed in a prototype form to demonstrate its applicability.	3.57	0.65
III. Corporate strategy issues		
III.1 The degree to which the technology is applicable to the firm's core business	3.14	0.66
III.2 The degree to which the technology can extend the firm's core business in new directions	3.07	0.62
III.3 The extent to which this technology could be an important contributor to the continued development of the firm's	3.21	0.80
III.4 The extent to which the scientist can present ways in which the business case could be made to extend the core business in new directions based on this technology	3.14	0.66
III.5 The extent of the scientist's understanding of the organization's willingness or lack thereof to pursue promising breakthrough innovations even outside its strategic intent. (Note: n = 13 for this item only)	2.93	0.86

where a project may exhibit difficulties. One of our respondents explains his firm's integrative vision for evaluating projects:

> If you have an existing business platform from which you can launch, that's a positive. If you have a technical competency base from which you can launch the project, that's a positive. The third thing is if it is strategically related ... that's a positive. If it's not meeting these things, we walk. It has to be built on platforms of strength that are inside of the company or else we just don't do it.

The questions in this framework allow the technologist to assess level of confidence in each of the three technology-to-organization links of the framework and to prepare for a discussion with a research manager. These responses, however, will need to be interpreted within the context of the technologist's organization. For example, a technology that may displace an existing application may gain organizational acceptance if the existing application is facing obsolescence; on the other hand, it may face resistance if the existing application is still perceived to be relevant and profitable.

The technologist may additionally need to consider particular organizational or environmental issues that would compel the firm to consider the project. The organization may be operating under a mandate from senior management to expand into new growth opportunities (TI, IBM, Dupont); it may be facing competitive threats (GM); or it may want to gain or maintain leadership in a particular technology or market arena (Air Products, GE). There are many contextual factors that may override an unfavorable evaluation along one or more of the dimensions incorporated into the assessment and decision making framework.

This framework describes a first stage process that can guide the technologist in determining whether or not to seek organizational support for initiating a radical innovation commercialization project. We summarize below five key findings:

- *Project initiation (not evaluation).* Though the framework presented in this paper includes evaluative questions, the focus is on initiation of the dialogue between the technologist (the idea generator) and the research manager (the idea receiver). This research addresses the difficulty firms have in stimulating a flow of radical ideas generated by technologists into the project initiation pipeline.
- *Next steps post-initiation.* Additional assessment and development will be required before the case is sufficiently robust to warrant a formal evaluation, given that most technologists do not have the capacity to fully address all the issues related to the potential of a radical innovation that will be considered. Based on the feedback from the reviewers of the framework, it is anticipated that not all questions in the framework will be fully answered before the technologist initiates the dialogue with the research manager. Thus the research manager must be prepared to receive what is offered, to define next steps for further exploration, and to assist the technologist in taking the next steps.
- *Strategic vision.* Both the Nortel Networks reviewer and the members of the radical innovation subcommittee of the IRI argued strongly for the importance of vision and strategic fit. In our case studies, the technologists had at best a fuzzy sense of these issues. Thus a key task post-initiation and pre-formal evaluation will be clarifying the position of the radical innovation *vis-à-vis* the firm's strategy and the vision for the potential impact of the innovation on the firm and the industry. Senior leadership needs to clearly articulate its strategic vision and define the extent to which radical innovations outside the strategic framework of the firm will be considered.
- *Preparing the technologist.* The framework provided in this paper is a tool. It will only be truly useful in the hands of a skilled tool user. Thus the firm should provide orientation and training for its technologists to provide them with the capacity and the confidence to use the tool in the initiation process.
- *Preparing the research manager.* Likewise, additional facilitating mechanisms and tools should be developed that will allow the research manager (and as appropriate, a business development manager) to work with the technologist in advancing the development of the case. As above, the firm should provide orientation and training that will allow the research managers to engage effectively in project initiation.

6. Implications and future research

Triggering opportunity recognition and initial evaluation of radical innovations typically starts with technologists, who are the generators of radical ideas. The framework presented in this paper can facilitate the triggering process. However, as suggested above, the receiver – the research manager or business development manager – must be prepared to receive. Future research could address the needs of the receivers for an assessment and development tool that can be used to help the technologist further explicate the case in preparation for a formal evaluation. Naturally the receivers would prefer that the technologist come forward with a well-developed case. But insisting on too much detail in the initial presentation by the technologist will likely result in fewer radical ideas being brought forward. The detailed comments offered by the reviewer from Nortel Networks and the members of the Radical Innovation Subcommittee of the Industrial Research Institute support our conclusion that there needs to be additional assessment and development tools that will help bridge the gap between project initiation and the first formal evaluation by the firm. The development and testing of the tools could be part of a follow-on research effort.

We anticipate that additional issues will become important for the formal evaluation process – particularly related to (1) strategic issues that may not be within the purview of the technologist and the research

manager, and (2) investment issues related to the firm's portfolio of innovation projects. We did not assess organizational or environmental circumstances that could drive investments in radical technologies. In some projects, we observed that particular conditions, such as competitive pressures or the threat of regulation, played a critical role in eventually driving acceptance for the project. Future research could adopt a firm-level perspective and expand the list of key issues to be considered in the formal evaluation process.

This research offers academic value by describing the initiation process for converting a new technology into radical innovation and ultimately into a commercial business. Academic research has often treated this activity as an ad hoc planning exercise or a firm-level assessment. We observed that initiation requires idea generation, recognition, assessment, decision-making and communication by a technologist who generally is not prepared by training and orientation to perform this function. Our research context presented us with the task of explaining a process that cannot easily be explained. Yet it engenders a need for understanding how technological discoveries can arise in organizations and how the conversion of an R&D effort into a radical innovation commercialization project can be triggered. When successful, radical innovation projects can cause the firm to stretch its technological capabilities, enter new businesses, and redefine its strategic plan to retain or gain competitive leadership.

This research can offer practical value by presenting a means by which a technologist or manager can assess the relevance of a radical new technology for the organization, and gauge potential organization-wide acceptance for this project. This framework can provide guidance for proceeding with project initiation, helping the technologist identify risks and engage in activities that can resolve weak points in the case before soliciting greater support. This can build credibility for the technologist who can articulate to others in the organization why this opportunity should be pursued.

In applying this framework, a technologist can rely on more than attentiveness or gut instinct as a triggering mechanism for radical innovation. This research challenges technologists and managers to apply the framework to all the technologies they see. The framework presented in this paper may increase the number of radical innovation opportunities recognized, enhance the efficiency of screening opportunities by providing more robust cases, and improve communication and understanding of the reasons for pursuing radical innovation projects.

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