ORGANIZATIONAL LEARNING IN THE UPSTREAM PETROLEUM INDUSTRY

Loren Falkenberg
Jaana Woiceshyn
Faculty of Management
University of Calgary
Calgary, Alberta Canada

Abstract

This research examined organizational learning through the adoption of new technologies. Geophysicists in the upstream petroleum industry were interviewed to identify the learning processes associated with identifying and evaluating new technologies. Learning processes and learning outcomes were compared across five firms, involved in the exploration for oil and gas. In the 1990s the geophysics area of the upstream petroleum industry shifted from internal research and development laboratories to dependence on external vendors for new technical developments. As a consequence competitive advantages were not created through proprietary research and development, but rather by learning processes and outcomes that aligned with the strategic goals of the firm. This research examined how firms structured learning processes that identified and assessed new technologies. Each firm had a unique combination of boundary spanning activities, assessment criteria and processes, and coordinating structures, which led to different learning outcomes.

Introduction

Firms need to continually acquire knowledge to retain and improve competitiveness, productivity, and innovativeness in uncertain technological and market circumstances. In order to remain competitive firms need to intentionally develop strategies and structures that facilitate and coordinate knowledge acquisition (Dodgson, 1993). However the learning processes underlying knowledge acquisition within a firm are not always easy to observe as they may be haphazard, occur over long time periods, and involve a variety of individuals or groups.

As knowledge is embodied in technology, we suggest the decision to adopt or not adopt a technology is a tangible form of knowledge acquisition. During the decision process firms learn about new ideas in the external environment, learn more about their own needs, and use this knowledge to improve their own competitiveness. Adopting new technologies is a normal event within firms, yet relatively little is known about organizational processes that facilitate this type of knowledge acquisition (Iansiti & Clark, 1994; Woiceshyn, 2000).

Knowledge acquisition may be differentiated into learning processes and outcomes. Learning processes are the ways firms build, supplement and organize knowledge and routines to develop organizational efficiency, while outcomes are simple, quantifiable improvements or some form of abstract and vaguely defined positive outcome (Dodgson, 1993). We suggest that the learning processes underlying a technology adoption decision include the exploration for new technologies and the evaluation of their potential value for the firm (Falkenberg & Woiceshyn, 1999) while the learning outcomes are the changes in efficiency or effectiveness arising from the adoption of a technology. We recognize that firms may adopt inappropriate technologies, or fail to adopt important technologies and thus learning outcomes can be negative as well a positive.

This research examined the activities within a firm that led to the exploration for and evaluation of new technologies, the differences between firms in how they structured these learning processes, and how different learning processes led to outcomes that facilitated or limited achievement of strategic goals.

Research Design

This paper was part of a comprehensive research project. The overall design involved a comparison of firms within the upstream petroleum industry[1]; more specifically how geophysicists[2], within each firm, used technologies to improve their interpretation of seismic data to model the earth's substructures. Geophysical work tends to be technically driven, and involve a high degree of uncertainty in terms of the application of current and new technologies. For this particular paper, we focused on activities that led to the identification of new technologies, the assessment of these technologies in terms of potential to improve the decision making of the geophysicist or the overall effectiveness of the firm, and how the outcomes of these learning processes aligned with each firm's strategic goals.

Qualitative data was collected through interviews with 15 geophysicists in five firms. Each interviewed geophysicist applied geoscience knowledge to identify potential reservoirs of hydrocarbons or was involved in the identification and assessment of new geoscience technologies. The firms were chosen according to size and general success in the industry. Two smaller firms, one medium sized, and two larger firms were selected. The first interviewed geophysicist in each firm was identified through the researchers' contacts. The researchers then interviewed other geophysicists through referrals from the first interview. Every request for an interview was granted.

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[1] The upstream petroleum industry is comprised of firms that explore for hydrocarbons (i.e., oil and gas reservoirs). The term "exploration" in this paper has a dual meaning: the exploration for new oil and gas reservoirs and the exploration for new technologies. It is difficult to substitute a different term for exploration in either case, as they are labels used both in the academic literature and in the petroleum industry.

[2] Geophysicists interpret seismic data to create models of the earth's structural formations for the purpose of finding hydrocarbons.

Two additional interviews were conducted at the University of Calgary with professors of geophysicists who participated in research consortia. These geophysicists had worked in research and development laboratories of two large international petroleum firms, and each held a doctorate in geophysics. These interviews were conducted to confirm the information obtained in the other interviews regarding the shift from high internal research and development to dependence on external research and development (see the discussion Research and Development in Geophysics).

The interviews lasted for one hour and were tape recorded. An initial letter, outlining the purpose of the study as "identifying differences among firms in their technological approaches to exploring for hydrocarbons", was sent to the geophysicists. In order not to lead the geophysicists during the interviews, and to prompt their own interpretations and stories, the interviews were semi-structured. The initial questions were based on the geophysicist's past and current experiences with new technologies. Questions about the firm's strategy for exploring for hydrocarbons and the firm's general orientation to technology were also asked. Both researchers attended each interview.

Data Analysis

Established qualitative data analysis methods (e.g., Miles & Huberman, 1984; Strauss, 1987; Yin, 1989), including coding, data categorization and pattern identification were employed. Initial codes were developed prior to any analysis of the transcribed interviews. These codes were based on the types of search or monitoring activities described in the interviews, the types of review activities and criteria applied in the assessment of new technologies, the types of coordinating structures used to manage both the allocation of resources and dissemination of information, and the learning outcomes. Codes were also developed inductively as needed during the analysis process; this was done to prevent forcing data into codes that did not fit (Miles & Huberman, 1984; 60). Both researchers coded the data independently to increase reliability.

Based on the coding, we grouped the interview transcript data into categories, and identified patterns (Strauss, 1987; Miles & Huberman, 1984), such as external and internal boundary spanning activities, centralized versus decentralized coordinating structures, and assessment criteria and processes. We first recognized patterns within firms, and then looked for cross-firm patterns. Each researcher analyzed the data, then comparisons between the individual researcher's categories were made, and then each researcher reviewed the transcripts to verify the identified patterns. Both researchers had to agree on the existence of a pattern before it was included as part of the findings.

Findings

Prior to examining the activities within individual firms, general contextual factors for geophysical work are reviewed. During the time of the interviews the international price for oil and gas was relatively high, with an average of $21.17/barrel for crude oil, $2.48

/million cubic feet for natural gas, and $15.82/barrel for natural gas liquid. All the firms, with the exception of the American (the largest) had their head office in Calgary, the centre of the oil industry in Canada. the researchers' city. American's head office was in a European city. All of the interviewed geoscientists focused on exploration for hydrocarbons in the Western Canadian sedimentary basin. Three of the firms had significant international operations; however the focus of this research was on the technologies used to explore in the Western Canadian basin. To maintain confidentiality and anonymity pseudonyms were given to each of the firms, and each geoscientist was assigned a number. Information on the size of the firm, along with the pseudonyms is provided in Table 1.

Upstream Petroleum Industry Context

Geophysical Work

Geophysical work occurs in the initial stages of the exploration for oil and gas. Geophysicists interpret seismic data, the recording of underground sound waves, to identify where specific wells should be drilled. Geophysicists require a minimum of an undergraduate degree in physics, engineering or geology, and extensive experience in the interpretation of seismic data. All the geophysicists interviewed had a minimum of ten years experience in the industry. Geophysicists in some of the larger firms described the extensive in-house training provided for new geophysicists. Calgary (at the time of the data collection) was the home of the largest group of geophysicists in the world, thus there were a number of different professional societies for the geophysicists to join. Professional associations and vendors (the label used for companies that developed technologies used by geophysicists) regularly held seminars on new technical developments.

Research and Development in Geophysics

All firms depended on external vendors for new technologies. The two small firms did not engage in internal research and development activities, whereas there were a few small internal research and development projects in the three larger firms. This finding reflected a new approach for research and development in the Canadian upstream petroleum sector. At one time the larger upstream petroleum firms had major internal research and development laboratories to develop proprietary technologies. Approximately 75 percent of the geoscientists interviewed had previously worked in firms that had large in-house research and development laboratories. However these laboratories were gradually closed in the 1980's and 1990's. One geophysicist estimated that 90 percent of new upstream oil and gas technology was being developed by external vendors.

Three different reasons were identified for this shift in dependence on vendors for the development of new technologies. The first reason was the need for industry level or broad based research rather firms developing esoteric technologies with narrow applications. One geophysicist noted

> When I worked for [firm X] they had a very prominent research center, state of the art with a large number of Ph.D.s working on extremely esoteric problems, and they finally realized not too many people were using the research. *Geophysicist 2, Cowboy*

A second reason was the expense of operating a laboratory. Stream had had a significant internal research and development laboratory. Each of the three geophysicists interviewed in Stream noted the laboratory had been useful in providing advice and assistance in problem solving. However, the company found it was too expensive to maintain.

> We could not justify or compete with [vendors] in terms of developing new technologies, nor could we afford to hire the staff…you can, quite honestly, get the same service externally. *Chief Geophysicist, Stream*

Other geophysicists noted that the technology was becoming so complex that it required skill bases that a petroleum firm could not justify developing or maintaining; they could only be financially justified on an industry-wide basis (i.e. through specialized vendors that provided technologies to several firms or through industry supported research consortia). In all the firms the geophysicists recognized the shift to external research and development meant there was little proprietary technical knowledge. One geophysicist noted:

> … so many ideas have come out of the research consortia with the university. A couple of them have turned into standard industry practice around the world…so this whole process is now research being done across company boundaries and the uptake is across companies. *Chief Geophysicist, Cross*

However, this was not perceived as a disadvantage to the firm or the industry. All the geophysicists interviewed recognized that working with vendors led to cross-fertilization of ideas among firms within the industry, and led to an improvement in technologies. Vendors learned how to solve problems within one firm and then transferred this knowledge to other firms having similar problems. This cross- fertilization was viewed as a benefit.

Although firms no longer supported internal research and development laboratories, some internal research activity still occurred through a variety of processes. Some of these processes included the formation of a task force to solve a problem, financially supporting a vendor to do proprietary research or to develop a product specific to the firm's needs. One example, in Cross, involved an accidental discovery of a solution to a problem. A group of geophysicists were reviewing the problems they were experiencing and during the discussion realized they could solve one problem through combined efforts. A task force was created and a solution developed. Another form of internal research and development was the support of a vendor to develop proprietary technology. A small vendor had developed an idea, which if it became feasible would be applicable to the firm's entire exploration activities. The vendor needed financial support for approximately three years, and Stream entered into a contract to support the vendor in return for proprietary access to the technology.

A geophysicist, at Cross, provided an interesting example of the potential limitations of having vendors develop specific technologies for the firm. Cross had a long-term contract with a large international vendor to supply software for the interpretation of geological and geophysical data. They had shifted to one vendor in order to integrate many of their data bases and interpretation processes. At one point Cross paid the vendor to develop software specific to its needs. The vendor developed the software but was not interested in integrating the software into the other programs used by Cross, and supplied by the vendor. The vendor could not justify the time and expense that it required. Essentially the new software was useless to Cross without integration into other programs; because of this problem Cross changed its approach. They agreed to support the vendor in the development of new software that would be available to all firms in the industry, on the condition that Cross would have first access to the software.

These initial findings highlight the need to understand how firms acquire knowledge through the exploration of their external environment for new technologies and evaluate them for internal use. We suggest that competitive advantage, in this kind of industry context, arises from the alignment of learning processes with the firm's strategic goals.

Geological Exploration Strategies

Each firm approached the exploration for hydrocarbons using different strategies and technologies, and each firm was considered successful within the industry. Some of the factors that influenced a firm's strategy were its land position (i.e, the size of land holdings within a given area), types of geological structures being drilled (i.e., simple versus complex), the depth of wells drilled (i.e., shallow versus deep), financial position (i.e., amount of debt, cash flow), types of hydrocarbons (i.e., heavy or medium crude oil versus gas), and availability of seismic data. Each firm also varied in the technologies used to explore for hydrocarbons. The variations included types of vendors used (i.e., local versus international), perceived value (i.e., to solve specific problems versus improve overall effectiveness), and location on the technology curve (i.e., leading edge versus conservative proven technologies). The number of wells drilled in one year, see Table 1, does not necessarily reflect more or less activity, as variation in wells drilled will occur with the depth of the wells, types of geological structures, and whether they are heavy or medium crude oil or natural gas.

The discussion now shifts to a review of the individual firms, specifically in terms of the activities associated with the exploration for and evaluation of new technologies, and the dissemination of new knowledge within the firm.

Knowledge Acquisition in Individual Firms

Star

Star was the smallest company, and had a conservative strategy, both in assuming financial risk and adoption of new technologies. The overall strategy was to control costs by increasing the proportion of successful wells through intensively analyzed geoscience (i.e., seismic and geological) information. They had a combination of heavy oil and gas wells. Star monitored technological developments but usually waited to adopt new technologies until benefits could be observed in other companies. They had an alliance with one local vendor to develop technologies that solved specific problems.

Star had a centralized structure for the review, assessment, and dissemination of information on new technologies. A chief geophysicist was responsible for monitoring new technological developments and reviewing those identified by geophysicists within the firm. He felt his role was to monitor for technologies that would be needed in the future, while the individual geophysicists searched for technologies that would solve specific problems. The chief geophysicist could provide financial support for trial projects; however many individual geophysicists built the costs of a trial project into the budget for the well. Formal meetings were organized by the chief geophysicist to review new technologies and their relevance to problems within the firm. Individual geophysicists monitored for new technologies by attending vendor demonstrations, professional meetings and reading professional journals.

If a trial project was successful the chief geophysicist assessed the technology in terms of the firm's future needs, success in other firms, the number of geophysicists willing to work with the new technology, the time required to learn the technology and the type of problem that it solved. The training requirements for a new technology seemed to be a critical factor. One geophysicist noted that most new technologies were adopted when the price of oil was down because the focus was on increasing efficiency and there was more time to learn how to use the technology. Te chief geophysicist noted

> We don't want them to be experts on computers or software, so if they have to hire somebody to come and sit next to them and actually drive the program that's fine. *Chief Geophysicist, Star*

Once a decision was made to adopt a new technology it was introduced into one group, and then pushed out to other groups in incremental steps. See Appendix 1 for a summary.

Cowboy

Cowboy was the second smallest firm in terms of average daily production of oil and natural gas field liquids (see Table 1). The strategy was to drill as many low cost and low risk wells as possible, that is shallow gas wells with relatively simple geological structures. This is noted in the following comment.

> Cowboy's strategy is big volume and low margins… a lot of the stuff you find is serendipitous. You are not going to find anything if you don't drill…Most of the plays are shallow gas…they are not expensive. *Geophysicist 2, Cowboy*

Cowboy hired experienced geophysicists, usually with a minimum of ten years experience. There was a general belief that the experience of the geophysicist was as important, if not more important, than use of leading edge technology, as reflected in the following comment.

> Just looking at the data means nothing. Looking at the data with the right kinds of glasses is what makes it. *Geophysicist 1, Cowboy*

Coordination at Cowboy was decentralized; the focus was on controlling the costs of individual wells. As a result, information dissemination on geophysical issues was not coordinated across geographic areas or business units, and new technologies were not centrally monitored. It was the only firm without a centralized, Chief Geophysicist, position. Depending on the size of a geographic area one or two geophysicists were assigned to work in it.

Individual geophysicists monitored local vendors for technologies that would solve specific problems they were experiencing. Geophysicists attended lunch seminars held by local vendors, professional meetings, and read journals. If a geophysicist wanted to experiment with a new technology, he or she independently tried it on a specific well. There were no formal guidelines or decision criteria used to assess the potential value of the technology. Usually a geophysicist built the cost of the technology into the budget for the well, and if it appeared to work the technology would be used again, particularly if the costs were considered reasonable. Minimal information was disseminated across geographic units about the new technologies. A summary of these findings is provided in Appendix 1.

<u>Stream</u>

Stream was a mid-sized firm in relation to the five firms. It had the third largest production of the five firms, and the smallest number of employees. It experienced two ownership changes in the last ten years. As a result, it was saddled with significant debt. As part of their plan to reduce the debt they sold oil properties and exploited core properties in Western Canada. Exploration occurred in both simple and complex geological basins, and involved shallow and deep wells. The focus was on controlling overall exploration costs.

There was an overriding belief shared by all the geophysicists we interviewed in this firm that technology would facilitate further development of its existing landholdings and improve the interpretation of their existing seismic data bases. New technologies were assessed for their potential to improve decision making or to solve a specific problem. Stream felt a strategic advantage was the extensive seismic data bases they held. Significant resources were directed to digitizing and integrating old seismic data in order to use new technologies that would integrate the technologies used by geophysicists, geologists and engineers.

Coordination was a mixture of decentralized monitoring for new technologies and centralized assessment and dissemination of information. Individual geophysicists were encouraged to monitor the external environment for new technologies. The geophysicists worked with the chief geophysicist in reviewing the information, identifying resource and training needs, and disseminating information. The chief geophysicist persuaded management to allocate the necessary funds to experiment with a new technology.

Some of the critical factors considered in the assessment of a new technology were the availability of a champion to run test projects, compatibility with current systems and availability of technical support. The champion was expected to experiment with the technology and then disseminate the information. One champion described his role as

> Someone has to be the first to run with it and find out what's involved, what doesn't work, what does work, and in the end give demonstrations to show other groups how they could be working with it…. It is important to move in small steps....moving into the company one step at a time *Geophysicist 2, Stream*

Geophysicists regularly participated in professional association activities, attended large conferences where international vendors displayed new technologies, monitored professional journals, monitored local vendors and attended professional meetings. Stream geophysicists informally communicated on new technologies regularly; this was facilitated by a base of long-term employees who had worked together in functional departments prior to the shift to business units. For a summary see Appendix 1.

<u>Cross Resources</u>

Cross had massive land holdings in Western Canada and did not have significant debt. It had the second largest number of employees, and the second largest daily production. Due to its massive land position, exploration occurred in geological basins of varying complexity, and both low and high cost wells were drilled. Cross focused on adopting leading edge technologies to reduce overall costs and increase effectiveness of decisions, as reflected in the following comment:

> There was a conscientious decision by the leadership to place itself on the leading edge of the technology curve…. We deliberately say we want to be at this point on the technology curve. And (Cross) is fairly up without being too far *Geophysicist 2, Cross*

In order to remain at the leading edge Cross collaborated closely with large international vendors to develop new technologies, fully recognizing the technologies would not remain proprietary. Cross supported university research consortia to monitor and support the development of new ideas. Individual geophysicists at Cross engaged in extensive monitoring activities for technologies that would enhance their decision making. They regularly participated in professional association activities, monitored journals and worked with large international and small local vendors.

Cross had one of the more centralized structures. The chief geophysicist acted as a gate keeper, monitoring for new technologies, evaluating the potential of the technologies and allocating resources for trial projects. He was responsible for disseminating information about new technologies, and formally coordinating groups to solve problems and assess new approaches. As well individual geophysicists received needed financial and technical resources to experiment with new technologies. Assessment of these technologies was decentralized in that individual geoscientists conducted their own reviews. Of the five firms Cross had adopted or purchased the largest range of technologies, with many of the technologies being used by a single geophysicist or a small group.

The Chief Geophysicist noted

> We want diversity. We may say: We don't think this technique is worth the money, but we want the diversity in a business unit so that someone can say 'I think it is worth the money' and have the money for it. Furthermore it is presumptuous to say the new technology won't work. *Chief Geophysicist, Cross*

American

American was a large international firm, with operational sites in locations throughout the world. The site studied in this research focused on exploration in the Western Canadian basin, with a strategy of drilling a large number of wells into known basins. Overall technical strategy was to adopt technologies that would reduce decision time and thereby reduce overall costs.

Of the five firms examined, this firm, at both the corporate level and the Canadian operations, had the most centralized structures. The Canadian operations had just gone through 'technology rationalization' to reduce the number of vendors and technologies being used. The corporate head office made many technology decisions and then expected the local sites to follow. At the time of the interviews the head office had adopted a complex new technology, and the expectation was that all local sites would also adopt it as noted in the following comment:

> There were no direct orders to adopt the technology; however the CEO made a speech that every site was going to have this technology so we knew we had to adopt it. *Geophysicist 2, American*

The geophysicists we interviewed indicated the new technology was not well suited for the type of geological exploration conducted at this site, and consequently there was frustration with the technology. The frustration is reflected in the following comment

> Forcing one large scale technology has slowed down decision making, the technology is not always appropriate for this location, and now there is little time to meet with vendors and monitor other developments. *Geophysicist 1, American*

In order to facilitate the adoption of the new centralized technology, significant resources were directed to providing technical support, training, and internal monitoring of the progress at each local site. Significant time was spent identifying the right match of people and project to experiment with the technology. There was extensive internal monitoring of the adoption process throughout the local sites. All sites were linked through video conferencing and internet, and facilitators of the technology met in the different sites on a regular basis.

Some monitoring occurred by individual geoscientists who could suggest other new technologies. However, the decision to try a technology had to go through three different managers. The basic criteria for reviewing a new technology were its potential to reduce decision time, compatibility with the current technologies, and the need to meet regulatory requirements. The costs of adopting technologies that were not compatible with current technologies were so high that it was almost impossible to consider adopting. For a summary see Appendix 1.

Discussion

The purpose of this research was to examine the activities within a firm that led to the exploration for and evaluation of new technologies, the differences across firms in the structure of these exploration and evaluation learning processes, and how differences across learning processes influenced the achievement of strategic goals. Prior to this study we were not aware of the dependence of upstream petroleum firms on external research and development for new technologies. This dependence, however, reinforced the need to examine the learning processes underlying technology adoption decisions, and how these processes led to effective organizational learning.

According to various economic and strategy theories, internal research and development is considered necessary to maintain a competitive advantage (Barney, 1991; Cohen & Levinthal, 1990; Zander & Kogut, 1995). However, within the upstream petroleum industry in Western Canada firms found the costs of obtaining proprietary technologies higher than the benefits received. Working with external vendors reduced the costs while expanding the range of available technologies. We suggest that the role of proprietary technologies differs across industries; in some industries, such as manufacturing, firms should invest in developing new technologies, whereas in other industries it may be the application of technologies that leads to a competitive advantage.

If competitive advantage is not achieved on the basis of proprietary technologies other sources must be developed. We suggest that one form of competitive advantage is the alignment of learning processes with the strategic goals of the firm. Our initial findings suggest that within the upstream petroleum industry competitive advantage was created by adopting technologies that addressed specific needs or opportunities, and these technologies were identified through the firm's exploration and evaluation learning processes.

Learning Processes

This research suggests that firms vary in the structure of their learning processes and the variations lead to differences in learning outcomes. Exploration activities include two types; the on-going monitoring of the external environment for new technologies and focused searches for solution to specific problems. In the first type of search members of the firm collect information on new developments or technologies prior to the recognition of a problem or opportunity (Langley & Truax, 1994). For example, they may talk to vendors of technologies just to be aware of new developments rather than intentionally looking for a solution. We suggest this is a form of gestation or slack monitoring that involves a broad sensing of the environment (Huber, 1991). The second type of search occurs once a problem or opportunity has been identified and formal search activities are initiated to find a solution. This type of activity parallels Huber's (1991) focused or problem search, that is looking for a narrow response to an actual or suspected problem.

Information on new technologies was collected through boundary spanning activities. Boundary spanning involves regular scanning of the external environment for specific sources of information (Raffa & Zollo, 1994; Levinthal & March, 1981). Boundary spanning activities by geophysicists included meetings with vendors, attending seminars held by vendors and professional associations, attending international conferences, reviewing professional journals, and supporting research consortia.

Assessment of new technologies included reviewing the technology in terms of potential to solve a specific problem, potential to improve decision making, potential to improve overall effectiveness, development of a business case, compatibility with current technologies, training requirements, and availability of a champion. The actual review process of a technology ranged across the firms from immediate adoption to trial projects and controlled incremental steps.

An important element of the exploration and evaluation learning processes were the coordinating structures. For the purposes of this research coordinating structures are defined as the degree of formalization and centralization used to allocate task, responsibilities, including the location of decisions and the dissemination of information (Child, 1984; Dougherty, 1996; Lane & Lubatkin, 1998). Coordinating structures may direct information flows to a centralized position (e.g., chief geophysicist) where the value of the information is assessed and formal dissemination of the information occurs. The other extreme is the complete lack of coordinating structures, where information may or may not be shared with a very small group, and decisions are decentralized.

Comparison of Learning Processes

One of the goals of this research was to compare how firms structured learning processes, and how differences in the structures aligned with the firm's strategic goals. Each of the five firms in this research project varied in their boundary spanning and assessment activities, and in coordinating structures (see Table 2). With the exception of American, each firm had developed learning processes (i.e., exploration and evaluation) that supported the strategic goals of the firm, that they led to the adoption of technologies that aligned with the firm's strategy.

Geophysicists in Cowboy spent relatively little time, in contrast to the other firms, in boundary spanning activities, and coordination of problem solving and information dissemination was decentralized. Boundary spanning activities were focused on finding specific solutions to problems, and were limited to local vendors. The costs of trying new technologies were built into the operating budget for the business unit. Geophysicists conducted minimal review activities, they tried the technology and it either worked or didn't. These combinations of boundary spanning and coordinating structures, and minimal assessment and coordinating structures, led to learning processes that aligned with the strategy of controlling costs of individual wells, and drilling a large number of shallow (i.e., geologically simple) wells. Cowboy was not focused on developing overall effectiveness in terms of exploration for hydrocarbons or identifying complex new technologies.

In contrast to Cowboy, Star (the other smaller firm) had broader boundary spanning activities, in that both slack monitoring and problem searches were conducted, and coordinating structures involved both centralized and decentralized elements. Boundary spanning activities to solve specific problems occurred at the operational level, while the chief geophysicist engaged in slack monitoring. Information gained through the boundary spanning activities was evaluated and disseminated through the chief geophysicist and formal meetings of the geophysicists. Extensive assessment activities were conducted to ensure the technology was appropriate for use by geophysicists across the firm. Both the exploration and evaluation learning processes aligned with the firm's strategy of controlling overall costs by increasing the proportion of successful wells through intensive and conservative analysis of geoscience information.

Cross and Stream were similar in their boundary spanning activities in that both firms continually monitored the external environment for new technologies, particularly complex technologies that would improve the geophysicists' interpretation of seismic data and integrate the work of different geoscientists. Minor differences in the boundary spanning activities were that Stream provided more support for decentralized monitoring, and Cross supported research consortia which developed more complex technologies.

The major difference in the structure of learning processes between these firms was in the assessment process for a given technology, and the degree of centralization of information flows and technology decisions. Cross provided support for individual geoscientists to adopt specific technologies, with minimal review for their implications across the firm. The more complex technologies were adopted through centralized decisions, and with less assessment than occurred in Stream. The assessment activities of simple and more complex technologies were extensive in Stream. Although the assessment process was more extensive, it was decentralized in that it was managed through a selected geophysicist, a champion of the technology.

Through their exploration and evaluation learning processes both Stream and Cross were able to identify and adopt complex new technologies that improved their overall effectiveness. Both firms required technologies that addressed exploring in a range of geological structures and drilling high and low cost wells. Stream, which was more focused on controlling overall costs, had more significant review processes for a given technology.

American, in its Canadian operations, was the one firm that had the least alignment of learning processes with strategic goals. It had the most centralized structures, and minimal boundary spanning and assessment activities. Because of the centralization of technology decisions, geophysicists were working with technologies that were not appropriate for the types of geological exploration being conducted. The firm's strategy was to improve effectiveness through reducing decision time, yet the centralized technology decisions (i.e., rationalization of technologies and adoption of the complex new technology) had increased decision time. The strategy of drilling a large number of wells was limited by the misalignment of the new technology with the specific needs of the geophysicists.

American had one important learning process that was different from the other firms, and that was the formalization of internal boundary spanning activities. These activities facilitated learning to use and application of the new technology, and reduced the potential of repeating mistakes previously made by other local sites.

Table 2 provides a summary of the similarities and differences in the coordinating structures, boundary spanning activities, assessment activities, learning processes and learning outcomes. The descriptive labels (i.e., minimal, medium, high) were developed as a comparison across the five firms, and do not have a quantifiable variable associated with them. The intent of this study was not to identify a most effective approach, but rather to examine how firms within one industry vary in the activities that underlie learning processes and how these variations lead to different outcomes.

As noted in the introduction little is known about the learning processes that support technology decisions. On the basis of these findings we suggest that the learning processes supporting technology decisions in the upstream petroleum industry include exploration for new technologies and evaluation of these technologies. A broad range of activities support each of these learning processes and firms vary in these activities and the coordinating structures used to disseminate information, provide resources and the location of decisions.

The two most observable differences across the firms was in the degree of centralization of decisions and information dissemination, and the level of assessment activities. The formalization and centralization of organizational processes can lead to well-designed procedures or communication flows that facilitate task performance, cooperation and goal accomplishment, or enabling formalization (Adler & Borys, 1996). The differences in centralization across the five firms highlights the limitations and benefits of centralized decision structures. In the most decentralized firm, Cowboy, all of the interviewed geophysicists Cowboy expressed concern over the lack of dissemination of information on new technologies within their firm. They felt cost control would be improved if there was more sharing of information. In contrast the highly centralized structure of

American limited its flexibility and ability to adopt technologies that facilitated the geophysicists' performance.

Part of the learning that should occur through technology adoption decisions is learning more about their own needs or opportunities. Firms that engage in relatively few assessment activities learn less about their own internal state of affairs. The geophysicists in Stream, which was the one firm classified as high in evaluation, more openly discussed the limitations and benefits of the different technologies adopted by the firm, and discussed the technologies in terms of their ability to solve problems and increase overall effectiveness.

Conclusions

In this study we observed how five oil firms acquired knowledge and learned during exploration for and evaluation of new technologies. Based on the findings, we suggest that firms need to align their learning processes (exploration and evaluation) with their strategic goals. Learning processes vary according to the types of activities supported by firms (boundary spanning and assessment) and by the types coordinating structures used for disseminating information and technology. Different learning processes lead to different outcomes, which should be consistent with the firm's strategic goals. Companies with low risk strategies operating in relatively simple technical environments will have different learning needs than companies taking more risk in more complex environments.

The study is of course limited by its focus on only one industry, oil and gas, and within it, only the upstream technologies. We also studied only five firms, all of which were relatively successful in their oil and gas exploration. We therefore did not gain any information for example on the consequences of misaligning firms' learning processes and strategic goals.

While we cannot make broad generalizations from our study, we believe that we have identified learning processes that are applicable to at least other oil and gas companies, and potentially to adoption of other than geophysical technologies. This can be tested in further research. But we are able to conclude from our study and from previous research that the processes of knowledge acquisition vary across industries, particularly in terms of internal or external development of new technologies. Therefore we suggest that theories on creation and maintenance of competitive advantage through knowledge acquisition need to take industry differences into account. Our study has been a one step toward that direction, and will hopefully alert researchers and managers alike to study the impact of the industry context on knowledge acquisition further.

Table 1

Employment and Production Data
1999

Firm	Number of Employees	Average Daily Production[3]	Number of wells drilled (Canada)
Star	561	78.4	337
Cowboy	762	90.4	276
Stream	558	156.4	176
Cross	1757	199.4	1543
American	80,400	2067.7	-

[3] Average daily production includes oil and natural gas (000 barrels of oil equivalent/day)

Table 2

Summary of Learning Processes and Outcomes for Each Firm

Firm	Coordinating Structures	Boundary Spanning Activities	Assessment Activities	Learning Processes	Learning Outcomes
Cowboy	• Decentralized monitoring • Decentralized evaluation	• High problem searches • Minimal slack monitoring • Minimal internal monitoring	• Main criteria was potential to solve a problem • Individual trial projects	• Minimal exploration • Minimal evaluation • Minimal dissemination	• Minimal dissemination of low cost simple technologies that resolve problems for a given geological structure • Cost control on specific wells
Star	• Centralized and decentralized monitoring • Centralized evaluation	• Medium slack monitoring • High problem searches • Medium external monitoring • Medium internal monitoring	• Main criteria was potential value to firm • Trial projects managed by chief geophysicist	• Medium exploration • Medium evaluation • High dissemination	• High dissemination of low cost and simple technologies • Reduction in overall costs
Stream	• Centralized and decentralized monitoring • Centralized assessment • Centralized and decentralized dissemination	• High slack monitoring • Medium problem searches • High external monitoring • High internal monitoring	• Main criteria was potential value to firm • Trial projects managed by a champion	• High exploration • High evaluation • High dissemination	• High dissemination of complex and simple technologies • Increased effectiveness of geological exploration
Cross	• Centralized and decentralized monitoring • Centralized dissemination	• High slack monitoring • Medium problem searches • High external monitoring • Medium internal monitoring	• Main criteria was potential value to firm • Trial projects managed by designated group	• High exploration • Medium evaluation • Medium dissemination	• Medium dissemination of complex and minimal dissemination of simple, problem specific technologies • Minimal influence on overall effectiveness, increased effectiveness of geoscientists
American	• Centralized monitoring • Centralized assessment • Centralized dissemination	• Low slack monitoring • Low problem searches • High internal monitoring	• Main criteria was potential value to firm • Training and support to facilitate adoption	• Minimal exploration • Minimal evaluation • Medium dissemination	• Medium dissemination of complex technologies that did not improve effectiveness at this site • Local problems not solved

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Appendix 1

Summary of Each Firm's Strategy, Activities and Technological Outcomes

Firm	Strategy	Coordinating Activities	Monitoring Activities	Review Activities	Technology Outcomes
Cowboy	•Aggressive drilling of low cost and low risk wells •Simple geological structures • Focus on controlling costs of individual wells	• No centralized geophysicist position • Costs of new technologies built into operating budget • Minimal communication across geoscientists in the firm	• Individual geoscientists searched for solutions to problems • Monitored local vendors, attended professional meetings, read professional journals	• Individual geoscientists evaluated new technologies • Two criteria were costs of technology and effective solution to a problem	• Adoption of low cost technologies that solve specific problems • Large variety of simple technologies used • Minimal dissemination of new technologies throughout the firm
Star	• Conservative drilling of low cost wells • Simple geological structures • Focus on controlling overall exploration costs	• Chief Geophysicist monitored new technological developments and evaluated potential value to firm • Centralized dissemination of information on new technologies • Individual geoscientists tried new technologies by building costs into operating budget	• Chief Geophysicist worked with local vendors to develop specific technologies for the firm • Individual geophysicists monitored for solutions to problems • Monitored local vendors, attended professional meetings, read professional journals • Formal internal discussions of new technologies	• Evaluation criteria included • review of success in other firms • time required to set up and learn new technology • future new needs of geoscientists • type of problem to be solved • Evaluation process was initiated by having one group experiment and then push into other groups	• Development and adoption of relatively low cost technologies specific to the firm needs • Technologies disseminated throughout firm
Stream	• Extensive development of existing properties, focus on controlling overall costs • Drilling of low and high cost, and low risk wells • Simple and complex geological structures	• Chief Geosphysicist provided centralized support through funding of trial projects, support of champions, evaluation of potential, review of training needs and information dissemination • individual geoscientists monitor for new technologies	• Individual geoscientists monitored for technologies that will improve overall effectiveness and solved specific problems • Monitor local and international vendors, attended professional seminars, attended international conferences • Extensive informal,	• Evaluation criteria included • future potential to improve efficiency or effectiveness • availability of a geoscientist to champion technology • compatibility with current technologies • availability of technical support • Evaluation process involved identifying a champion to review, experiment and refine	• Adoption of complex new technologies refined for firm needs and that improved overall effectiveness of geoscience work • Adoption of technologies that solved specific problems • Dissemination of technologies to relevant users throughout firm

Appendix 1

Summary of Each Firm's Strategy, Activities and Technological Outcomes

Firm	Strategy	Coordinating Activities	Monitoring Activities	Review Activities	Technology Outcomes
			internal communication among geoscientists	the technology and move it out into other groups	
Cross	• Focus on improving effectiveness through leading edge technology • Drilling of low and high cost, low and high risk wells • Simple and complex geological structures	• Chief Geoscientist monitored for new technologies, supported pilot projects, and disseminated information • Created task forces to work on solving specific problems • Senior management involved in approval of complex technologies	• Monitored for new technologies to improve overall effectiveness • Selected geoscientists worked closely with large international vendor to develop new technologies • Individual geoscientists monitored for solutions to specific problems • Monitored international vendors, supported university research consortia, attended professional meetings, attended large international conferences, read professional journals	• Evaluation criteria included • belief that technology would improve effectiveness and efficiency • development of a business case by individual geoscientists for technologies that solved a specific problem • availability of technical support • Evaluation of technology through pilot projects with involvement of Chief Geophysicist or by individual geoscientists	• Adoption of complex leading edge technology • Adoption of large range of technologies by individual geoscientists • Depending on technology extensive or minimal information dissemination throughout firm
American	• Aggressive drilling of low and high cost, and low and high risk wells • focus on controlling overall costs	• Centralized through head office and through local senior management • Centralized technology decisions, rationalization of technologies • Significant resources applied to exploitation of current technologies	• Minimal external monitoring activities • Extensive, formal internal communication and dissemination of information on applications of new technology across international operations	• Evaluation criteria for local technologies • ability to reduce decision time • compatibility with current technology • need to meet regulatory requirements • approval of three managers	• Adoption of complex technology that does not address local problems • Focus on exploitation of current technology