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An empirical investigation of the roles of prior knowledge and learning activities in technology transfer

Abdelkader Daghfous *

School of Business and Management, American University of Sharjah, Sharjah, United Arab Emirates

Abstract

This study analyzes 120 university–industry technology transfer projects. A significant positive relationship was found between the learning activities performed by the firm during the development and implementation stages of the technology transfer project and the benefits to that firm from the project. In contrast, prior knowledge of the firm about the existing technology was found to have only a marginal contribution to the project benefits. However, further exploratory analysis based on high and low levels of technical and organizational uncertainty revealed more provocative relationships.

Keywords: Prior knowledge; Learning activities; Knowledge transfer; University–technology technology transfer; Uncertainty; Learning benefits

1. Introduction

Knowledge-based competition has magnified the importance of learning alliances as a fast and effective mechanism of capability development. The early literature on strategic alliances focused primarily on alliance structuring and outcomes. Starting in the late 1980s, more research attention has been directed to the processes of learning and knowledge transfer, especially in the context of technology transfer (e.g., Leonard-Barton, 1995), R&D collaboration (e.g., Amabile et al., 2001), and strategic alliances (e.g., Sen and Egelhof, 2000; Mowery et al., 1996). This growing attention, fueled by the global race for a sustainable competitive advantage through superior dynamic capabilities, has produced significant conceptual work and anecdotal evidence, but relatively few empirical studies.

Conceptually, for instance, the literature on innovation and technological change frequently reminds us that it is very difficult to improve a process that is not well understood (Yeung and Ulrich, 1994); and that it is very important to collect all the relevant and knowable information before addressing uncertainty in product and process innovation projects (Daghfous and White, 1994). In this study, prior knowledge refers to the degree of understanding by the recipient organization of the technical and organizational context of the technological change. The basic premise that explains the importance of this construct (i.e., prior knowledge) is best articulated by Yeung and Ulrich (1994) who quoted West Churchman's (1968) question: 'how can we design improvement without understanding the whole system?' *Understanding* is interpreted in this study as prior knowledge and divided into its technical and organizational components. That is, a distinction is made between the technical system and the organizational context of that system. This distinction is useful because: (1) technological change involves the mutual adaptation of the new technology and the user environment (Leonard-Barton, 1988), and (2) it parallels the distinction between the moderating roles of both technical and organizational uncertainties related to the project.

This study is also motivated by an unpublished comprehensive case study of a technology transfer project from a US based university's engineering research center to a nearby division of a multinational microelectronics manufacturer. The case illustrated the role of learning processes and the prior knowledge of the recipient firm as important determinants of the project's success, which was evaluated in terms of the level of achievement of intended as well as unintended benefits to the firm. Empirically, Lane and Lubatkin (1998) introduced and

* Tel.: +971-6-515-2335; fax: +971-6-558-5065
E-mail address: adaghfous@aus.ac.ae (A. Daghfous).

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empirically tested the effect of the dyad-level construct 'relative absorptive capacity' on inter-organizational learning, thereby reconceptualizing learning alliances as a student-teacher relationship.

This study builds on such research by empirically deriving patterns of learning behavior within the recipient firm so that technology transfer from a university results in substantial tangible and intangible benefits to the firm. The main research question in this study is: how do learning activities and prior knowledge of the recipient firm contribute to the benefits to that firm from a university–industry technology transfer project? More specifically, this study seeks to address the following three questions: (1) how does the prior knowledge the recipient firm has about its existing technology and the organizational context where the transferred technology will reside relate to the benefits of the transfer project? (2) how do learning activities undertaken by the recipient firm increase the benefits of the technology transfer project? And (3) how does uncertainty associated with the technology to be transferred and the organizational impact of that technology affect the relationships between prior knowledge, learning activities, and the benefits of the transfer project?

2. Theoretical background

The streams of literature on technology transfer and on organizational learning are quite similar along various dimensions, such as outcomes, processes, barriers, and facilitators. Although both streams of literature address those same aspects, the organizational learning literature appears to subsume most the contributions of the technology transfer literature. More importantly, the organizational learning perspective adds much needed rigor (depth and breadth) in the conceptualization of the technology transfer process, which I consider in this study as essentially a knowledge transfer process. Hence, the organizational learning literature is a necessary and a complementary component of the more complete view of (1) technology transfer as a learning process (e.g., Levin, 1993), and (2) recipient organizations as learning systems (e.g., Nevis et al., 1995). For instance, the transfer of technology literature addresses barriers and facilitators to transfer mostly in terms of the characteristics of the technology, the technical skills required, and cultural differences. In comparison, the organizational learning literature addresses those issues and adds in-depth analyses of factors such as system thinking (Senge, 1990), institutional and social dysfunctions (Kofman and Senge, 1993), anxieties that affect the speed of learning (Schein, 1993), and methods to create a learning organization (Garvin, 1993).

The organizational learning literature also provides the technology transfer process with new dimensions that can be used to attain a more complete conception of it. For instance, incorporating organization memory (Huber, 1991) and mental models (Senge, 1990) in the study of technology transfer adds complexity and depth that it necessary to address issues such as 'unlearning' unproductive procedures and cultures (Imai et al., 1989), codification of tacit knowledge (Nonaka, 1994), and dissemination of new technological knowledge (Garvin, 1993; Leonard-Barton, 1995).

Technology transfer projects are often considered as joint R&D activities involving the recipient firm and the university. Cohen and Levinthal (1989) found empirical evidence that R&D not only generates new information for the firm, but also enhances its ability to assimilate and exploit existing information. They argued that R&D provides a spillover benefit, which consists of enhancing the firm's ability to learn from external sources of knowledge and, subsequently, its ability to create new knowledge. For inter-organizational collaborations in general, intangible benefits are primarily of the learning type, such as learning how to transfer knowledge across alliances and learning how to locate the firm in capability enhancing network positions (Powell et al., 1996).

The technology transfer and organizational learning literatures have been further augmented by the advent of the now well-established *knowledge management* research stream (e.g., see Alavi and Leidner, 2001) and the increasingly used knowledge-based perspective (e.g., see Steensma and Corley, 2000). Indeed, a technology transfer project is essentially a knowledge accumulation task, which Gupta and Govindarajan (2000) further disaggregated into knowledge creation, acquisition, and retention. Meanwhile Davenport and Prusak (2000) argued that the knowledge transfer process consists of transmission and absorption, culminating in a behavioral change by the recipient. They considered lack of absorptive capacity in the recipient as friction, which slows or prevents transfer.

Kim (1998) argued that the success of organizational learning depends on the firm's absorptive capacity, which itself is determined by the firm's prior related knowledge. This prior related knowledge confers to the recipient firm an ability to recognize the value of new knowledge or information, assimilate it, and apply it to commercial ends. This ability was labeled *absorptive capacity* by Cohen and Levinthal (1990). Since then, a theory of absorptive capacity has emerged and several studies have aimed at augmenting this firm level construct. Boer et al. (1999) added two organizational determinants, namely organization forms and combinative capabilities. In comparison, Kim (1998) added intensity of effort to prior knowledge, as determinants of a firm's absorptive capacity.

3. Model and hypotheses development

3.1. The role of prior technical knowledge

Lane and Lubatkin (1998) introduced and empirically tested the effect of the dyad-level construct 'relative absorptive capacity' on inter-organizational learning. They added to prior related knowledge the similarities in compensation practices and organizational structures, as well as the student (i.e., knowledge recipient or buyer) firm's familiarity with the teacher (i.e., knowledge source or seller) firm's set of organizational problems. Prior knowledge has also been explored in other contexts, such as entrepreneurship and technological innovation. For instance, Shane (2000) found that prior knowledge of entrepreneurs plays a significant role in the number of opportunities that they discover following a technological change.

Bohn (1994) presented a creative conceptual framework for understanding and evaluating the technical knowledge the firm has about its production process. He proposed an eight-stage scale to measure the technical knowledge the firm has about a particular input variable's impact on the output of the production process. To illustrate the importance of prior knowledge, he explained that General Motors' $40 billion investment in automation in the early 1980s never worked properly mainly because the firm lacked adequate process knowledge. The firm automated a large, complex, and poorly understood manufacturing process. The result was a large, complex, poorly understood, and unreliable automated manufacturing process. He stated that: 'If workers do not understand a process, they cannot handle unanticipated situations, nor can they do much to improve the process, even if they are motivated' (1994: 64). This is also the focal point of process mapping, which is a critical step in business process reengineering (e.g., Hunt, 1996). A high level of prior knowledge, then, permits the formulation of appropriate project specifications that reduce the likelihood of delays and increase the likelihood of achieving effective technical solutions. That is, in order to achieve significant technical improvements, the firm should enter the project with an adequate level of knowledge about what is to be improved.

> Hypothesis 1. During the project specification stage, the greater the prior technical knowledge the recipient firm has about its existing technology, the greater will be the operational benefits from the university–industry technology transfer project.

However, Cohen and Levinthal (1990) found that a firm's absorptive capacity is less important in cases where external knowledge can be assimilated and exploited without any specialized expertise. They defined absorptive capacity in terms of the firm's ability to recognize the value of new knowledge, assimilate it, and exploit it. Prior related knowledge, which can be increased though in-house R&D, contributes to this ability. Therefore, the contribution of prior related knowledge to operational benefits can also be expected to vary according to the complexity and the newness of the new technology being transferred. Hence, one can expect technical uncertainty, defined in terms of technical newness and complexity, to affect the strength of the relationship between prior technical knowledge and operational benefits. However, since uncertainty decreases as the project progresses, the construct refers to the level of uncertainty, as it is perceived by the recipient firm at the beginning of the project (i.e., at the project specification stage).

> Hypothesis 2. If, during the project specification stage, the recipient firm perceives that there is high uncertainty about the technology to be transferred, then it is even more important for the firm to understand its existing technology in order for the transfer to achieve expected operational benefits.

3.2. The role of prior organizational knowledge

Managers often make assumptions about the organizational context into which the new technology is introduced. The organizational context here refers to the local environment and infrastructural support within the firm where the new technology will reside. For instance, Duimering et al. (1993) studied the implementation of JIT and CIM in a number of firms. They found that organization structures that are highly functional and do not emphasize cross-functional teams are likely to exhibit poor communication and coordination of interrelated organizational tasks. Organizations may also rely on certain types of communication systems (computerized or otherwise) to generate, disseminate, and process information. Duimering et al. (1993) noted that if information is 'soft' (i.e., cannot be easily codified), then computerization may not help to generate, disseminate, or process useful information and subsequently useful knowledge.

Leonard-Barton (1988) addressed the value of knowledge about the organizational context during the project implementation phase. She emphasized the value of continuous, ongoing mutual adaptation of technology and organization during the implementation of new technology, since the new technology never exactly fit the user environment. She also emphasized the value of the original definition phase of the project. During this phase, she argued, a better understanding of the user environment would decrease disruption and the cost of adaptation cycles. Iansiti (1995a,b) also argued that technology integration during product development projects involves the integration of deep knowledge of the existing environment (context specific knowledge) with the specification of project tasks.

The model proposes that, similar to technological knowledge, firms must attain a certain level of knowledge about the organizational context of the technology transfer project in order to acquire the appropriate technology and to be adequately prepared to integrate the new technology into the organization.

Hypothesis 3. During the project specification stage, the greater the prior technical knowledge the recipient firm has about its existing organizational context where the transferred technology will reside, the greater will be the operational benefits from the university–industry technology transfer project.

Hypothesis 4. If, during the project specification stage, the recipient firm perceives that there is high uncertainty about the organizational impact of the technology to be transferred, then it is even more important for the firm to understand its existing organizational context in order for the transfer to achieve expected operational benefits.

3.3. The role of learning activities

This study adds a secondary technology transfer outcome. This outcome goes beyond adoption and implementation of new technology and beyond the characteristics of the transfer process. This study argues that it is useful and insightful to evaluate the outcome of a technology transfer project in terms of learning benefits. Learning benefits (also referred to here as *non-technical, unintended,* or *spillover* benefits) include: (1) the acquisition of new skills and knowledge, and (2) the discovery of performance gaps, which present opportunities to explore other improvement initiatives. The recognition of these benefits is based on Tyre and Orlikowski's (1994) conception of events, which are viewed as windows of opportunities that must be recognized and exploited quickly.

3.3.1. The role of experimentation

The construct *experimentation* is widely used in the literature on organizational learning, innovation, and technological change to denote an activity whose aim is to collect and create information and knowledge that does not already exist. In the technological innovation literature, this activity has also been called *learning by doing*, *learning by trying*, *learning by using*, and *trial and error.* In this study, the term *experimentation* is chosen as it is used to denote a learning activity by Garvin (1993) and by Yeung and Ulrich (1994).

This study considers experimentation as a learning activity that is performed by the recipient firm during both the development and the implementation of the new technology. The case study that preceded this survey showed that experimentation might occur during the development as well as the implementation phases of the university–industry technology transfer project. It is rather difficult to separate development from implementation, especially when the delivery of the new technology is not a discernible event (also see Tornatzky and Fleischer, 1990). The development and implementation processes usually consist of a series of iterations (development–implementation–development), wherein information and knowledge produced through experimentation and other learning activities are fed back to the design function for further improvements. Moreover, the higher the levels of technical and organizational uncertainty experienced by the firm in the beginning of the project, the more knowledge the company needs to acquire through experimentation. Although experimentation may result in learning benefits, this study focuses primarily on the operational (or technical) benefits.

Hypothesis 5. The greater the experimentation undertaken by the recipient firm during the university–industry technology transfer project, the greater will be the operational benefits from that project.

Hypothesis 6. If, during the project specification stage, the recipient firm perceives that there is high uncertainty about the technology to be transferred, then it is even more important to undertake experimentation in order for the transfer to achieve expected operational benefits.

Hypothesis 7. If, during the project specification stage, the recipient firm perceives that there is high uncertainty about the organizational impact of the technology to be transferred, then it is even more important to undertake experimentation in order for the transfer to achieve expected operational benefits.

3.3.2. The role of system focus

System focus is viewed as a learning activity wherein the organization purposefully: (1) relies on cross-functional organizational arrangements to solve important product and process problems, and (2) takes into consideration the impact of design choices on other existing technologies within the organization. For instance, Iansiti (1995a,b) investigated the role of system focus and problem solving on product development performance. System focus is also expected to increase the spillover effects of the technology transfer project. More specifically, as the recipient organization uses cross-functional teams and other cross-functional arrangements and takes into consideration the impact of product and process design choices on other existing technologies within the organization, non-technical spillover benefits can be expected. These spillovers are additional improvement opportunities that follow the technology transfer project or are discovered during the project. Borrowing from Tyre and Orlikowski's (1994) idea of window of opportunity, the university–industry technology transfer project can be considered as an event that can trigger new spurts of adaptive activity. Hence, the project can be considered as an 'interruption' or a 'disruption' that organizational actors can benefit from through improvements in other parts of the organizations.

To recognize and exploit potential areas of improvement, the recipient firm must have the system focus that provides the broad perspective needed to look beyond the narrow technical boundaries of the project. Such a firm can be expected to benefit from the project's spillovers significantly more than firms that lack such system focus, ceteris paribus. In addition, it is expected that the more organizational uncertainty associated with the project, the broader will be the scope of that project. Hence, a system focus would be greatly needed to address challenges and opportunities that go beyond the technical focus of the project.

Hypothesis 8. The greater the system focus undertaken by the recipient firm during the university–industry technology transfer project, the greater will be the discovery of additional improvement opportunities as spillover from that project.

Hypothesis 9. If, during the project specification stage, the recipient firm perceives that there is high uncertainty about the organizational impact of the technology to be transferred, then it is even more important to develop a system focus so that additional improvement opportunities might be discovered.

3.3.3. The role of competency acquisition

Firms develop both individual and group skills and knowledge by promoting learning at every level. Nevis et al. (1995), reported that the EDF company had been developing both individual and group skills. Whereas EDF employees followed individual training programs for certification and promotion, teams learned by using simulators. The acquisition of cutting-edge and relevant knowledge may accelerate teams' and individuals' capability to assimilate more new knowledge and subsequently develop innovative new products and processes (Cohen and Levinthal, 1990).

Competency acquisition is considered here as an organizational learning activity that aims at augmenting the skills and knowledge of individuals and teams. A firm acquires new competencies and enhances existing ones by encouraging individuals and teams to do so and by demonstrating a commitment to such forms of learning (Yeung and Ulrich, 1994). This can be done by making competency acquisition a part of the firm's business strategy.

However, knowledge is often tacit and cannot be transferred through blueprints and documentation (Leonard-Barton, 1995). This type of knowledge is usually transferred through informal processes and communication channels. Hence, it is quite difficult to focus on a specific way or a set of activities that all firms can perform or use to acquire new competencies during a technology transfer project. Instead, the main focus here is on the strategic intent and commitment by the firm to acquire competencies during the technology transfer project.

Hypothesis 10. The greater the commitment of the recipient firm to training and the greater the use of cross-functional teams during the development and implementation of the university–industry technology transfer project, the more will skills and knowledge acquisition develop during the project.

Hypothesis 11. If during the project specification stage, the recipient firm perceives that there is high uncertainty about the new technology to be transferred, then it is even more important for the firm to create a nurturing environment and adopt cross-functional teams for the acquisition and development of skills and knowledge.

Hypothesis 12. If during the project specification stage, the recipient firm perceives that there is high uncertainty about the organizational impact of the technology to be transferred, then it is even more important for the firm to create a nurturing environment and adopt cross-functional teams for the acquisition and development of skills and knowledge.

3.3.4. The role of learning from past experiences

Product and process development projects, as well as other organizational change initiatives, often fail. Whether they succeed or fail, these experiences offer valuable learning opportunities for the firm. Often, though, firms use only informal and ad hoc procedures to learn from the past successes and failures. Garvin (1993) described a variety of systematic ways in which some renown firms review and assess past experiences, then record and disseminate these lessons. He also made the very important distinction between a productive failure and an unproductive success. He defined a productive failure as one that leads to insight, understanding, and thus addition to the commonly held wisdom of the organization. Hence, processes aimed at learning from past experiences are a valuable process of knowledge acquisition and accumulation. Such a process converts internal stimuli into new knowledge and firm-specific competencies, which are central to the enhancement of the firm's competitive advantage. High levels of uncertainty magnify such stimuli and provide a bigger opportunity for learning. In addition, highly uncertain projects are more risky and, hence, the relative degree of success or failure can be expected to be quite high in either direction.

Hypothesis 13. The greater the learning from past experiences in regards to university–industry technology transfer projects, the greater will be the discovery of additional improvement opportunities during the current transfer project.

Hypothesis 14. If, during the project specification stage, the recipient firm perceives high uncertainty about the organizational impact of the transferred technology, then it is even more important for the recipient firm to have systematic mechanisms for learning from past experiences so that the current transfer project will result in the discovery of additional improvement opportunities.

Hypothesis 15. If, during the project specification stage, the recipient firm perceives high uncertainty about the technology to be transferred, then it is even more important for the recipient firm to have systematic mechanisms for learning from past experiences so that the current transfer project will result in the discovery of additional improvement opportunities.

4. Methods

4.1. Sample and procedures

The unit of analysis in this study was a technology transfer project from the Pennsylvania State University (Pennsylvania, US) to companies. The Office of Sponsored Programs at Penn State University has a database of all the projects that are funded by outside contractors. A list of 4600 projects constituted the initial population from which a number of projects would be chosen. This list was further reduced since the pilot study showed that many recent projects have not progressed enough to be included in the survey. Therefore, to reduce the effect of data recall problems, project selection was limited to those that have started three years before this study.

That list was, subsequently, sorted by Penn State University departments to eliminate projects that were conducted in non-technology oriented departments such as Social Sciences and Arts departments. The list of departments then reduced the number of considered projects to 900 projects. This list of projects was then printed on paper and final selection was based on the title of the project and on the sponsoring organization. The projects that were further eliminated from the list were either sponsored by a non-private firm (such as research institutions or professional associations) or showed no indication of technology transfer (such as fellowships to graduate students or consortium membership payments).

The final number of mailed surveys was 465. This number constitutes the maximum number of accessible technology transfer projects that took place between Penn State University and private firms over the past three years. The mailing procedure also ensured that only one survey is mailed and potentially received from each project. A survey questionnaire was mailed for each project to an individual informant who was believed to be the most knowledgeable about the transfer project in their firms. I mailed the questionnaires to the plant manager or the contact person listed in the university database. They were asked to identify the would-be respondent and forward the questionnaire to that person. To further ensure this, I asked respondents to describe their role in the project. Of the 148 surveys returned, usable responses were received from 120 projects. A typical project consisted of the joint development of a new product, process technology, or some form of new knowledge.

A comprehensive case study of a single project and an in-depth analysis of a pilot survey of 12 projects were used to obtain the final version of the questionnaire. For instance, one respondent from the pilot run complained, in a telephone interview, that the word 'systematic' did not allow for informal and continuous ways of learning from past experience. Therefore, I added '(formal or informal)' to the word systematic.

4.2. Measures

Multi-item scales were developed to measure the constructs used in the conceptual model. Nine of the eleven measurement scales used in this exploratory research are newly developed based on the literature and a comprehensive case study. All of the construct-related items of the questionnaire followed a seven-point Likert scale. A total of 36 items were developed to measure the eleven constructs used in the hypothesized model.

The reliability of each scale was assessed using the internal consistency method by calculating Cronbach's alphas, which were calculated before and after performing the factor analyses. Hence, reliability was checked before and after validity (Sakakibara et al., 1993). I maintained the content validity of the scales by referring back to the literature and discussing the changes with knowledgeable academics and practitioners. Then, to ensure construct validity, I used principle component factor analyses with varimax rotation. After subjecting the original items and scales to reliability tests and factor analyses, the variable 'system focus' was dropped from the study. In addition, two items were dropped and changes were made to the original item groupings of the scales. The scales used in the empirical analysis, including their respective Cronbach's alphas, factor loadings, and eigenvalues are listed in the Appendix.

4.2.1. Prior technical knowledge

The level of prior technical knowledge of the firm was evaluated at the beginning of the project. Hence, the three items in this scale required that respondents recall data from the beginning of the project. The first item ('documentation') was designed to capture the extent to which the technical knowledge available in the company at the beginning of the project has been documented. This item was based on Zander and Kogut's (1995) measurement of the codifiability of the firm's knowledge. The second item ('performance drivers') was based on Bohn's (1993) scale of measuring the technological knowledge of the firm about a production process prior to a process change initiative. This item was designed to capture the extent to which the company could, at the beginning of the project, measure the performance drivers of the existing technology that is targeted by the technology transfer project. While the first item measures the know-how component of the firm's prior technical knowledge and the second item measures the know-what part of that knowledge, the third item ('individual knowledge') was designed to capture the know-why component of technical knowledge. The third item, then, was designed to measure the extent to which individuals in the company understand the science and engineering that explain *why* the existing technology works as it does.

4.2.2. Prior organizational knowledge

Here also, the firm's knowledge was evaluated at the beginning of the project, while recognizing that this knowledge also increases as the project progresses. However, as with the previous variable (i.e., prior technical knowledge), this variable seeks to capture the level of knowledge prior to the development stage. The first item ('documentation of incentives and rewards') was also based on the Zander and Kogut's (1995) idea of *codifiability* of knowledge. This item, however, was designed to capture the extent to which knowledge about the company's evaluation and reward systems is documented. The second item ('a job's relationship to other organizational activities') was based on Zander and Kogut's (1995) measurement of the *teachability* of organizational knowledge. This item contributes to the measurement of prior organizational knowledge by capturing the ease with which knowledge about how a specific job relates to other functional activities can be transferred to new employees. Like the first item, the third item ('documentation of skills and technologies') was based on the same idea of *codifiability* (Zander and Kogut, 1995). The third item, however, focuses on another component of the company's knowledge about the organizational context of the technology transfer project.

4.2.3. Experimentation

This construct was operationalized using the four learning activities described by Chew et al. (1991). These activities are: (1) formal and informal efforts to learn from the experience of other groups or firms with similar technology, (2) construction of an artificial model of the new technology to run experiments, (3) building a small scale prototype of the new technology in a controlled environment to identify potential problems and opportunities, and (4) examination of a full-scale working model of the new technology under actual conditions. In addition, these activities may be performed by the firm sequentially or simultaneously.

4.2.4. Competency acquisition

Questionnaire items were developed based on Yeung and Ulrich (1994) scale that they used to measure knowledge acquisition, which they considered as a *type* of organizational learning. These activities are: (1) encouraging individuals to acquire new competencies, (2) encouraging teams to acquire new competencies, and (3) making learning new competencies a critical part of the firm's business strategy. In the empirical study by Yeung and Ulrich (1994), these items had a Cronbach's alpha of 0.87, which is quite high and, hence, makes it attractive for this study to use these items. Conceptually, both constructs (i.e., competency acquisition and knowledge acquisition) are quite similar in that they are both designed to capture the extent of the firm's encouragement (i.e., strategic intent) for activities that aim at enhancing the skills and knowledge of individual employees as well as teams.

4.2.5. System focus

Each of the three items used here was designed to capture the extent to which the recipient firm has an important process or routine that seeks to probe the systemic (i.e., in the broad context of the project) impact of the technical options faced by the recipient firm during the development and implementation phases of the project. Three system focus indicators were translated into the following items: (1) recipient firm relied on cross-functional teams to solve important problems, (2) design choices by the recipient firm took into account their impact on and their interface with other existing technologies within the organization, and (3) recipient firm had a systematic (formal or informal) way of identifying and anticipating the potential changes that the new technology might require in other functions (e.g., in manufacturing, accounting, purchasing, incentives, rewards, team structure, or operator jobs).

4.2.6. Learning from past experiences

The three items used here were designed to capture the extent to which, during the development and implementation phases of the project, the recipient firm used a systematic (formal or informal) procedure for analyzing *failed* as well as *successful* initiatives and for retaining and recording the lessons learned from past projects. The choice of these items was primarily based on Garvin's (1993) characterization of this activity. Nevertheless, the third item ('retaining and recording lessons') also draws from the literature on organizational memory (e.g., Huber, 1991; Sinkula, 1994).

4.2.7. Operational benefits

Three questionnaire items were developed to measure the operational (or technical) benefits to the recipient firm from the university–industry technology transfer project. Operational benefits relate to the technical output of the project. These items were based on Tyre and Hauptman's (1992) instrument that emphasized the degree to which operating and technical objectives of the project were achieved. The questionnaire items that were used to measure the operational and learning benefits did not specify a certain phase of the project. Hence, respondents were expected to report learning benefits that were achieved *throughout* the project duration.

4.2.8. Skills and knowledge acquisition

This learning benefit represents an increase in the 'technical knowledge' and the 'organizational knowledge' of the recipient firm. The first item ('acquisition of new technical skills') was designed to capture the extent to which the recipient firm acquired new skills such as computer skills, design skills, and production management skills, that were related to the company's business. Similarly, the second item ('acquisition of new scientific knowledge') was designed to capture the extent to which the recipient firm acquired new scientific knowledge related to the company's business. In contrast, the third item ('gaining a better understanding of product/process') was designed to capture the extent to which the recipient firm gained a better understanding of its production process (or product characteristics).

4.2.9. Discovery of additional improvement opportunities

These learning benefits are called improvement 'opportunities' because they do not constitute direct improvements in products, production processes, management systems, or the bottom-line. Rather, these benefits constitute a critical step towards concrete improvements in these areas. The first item ('weakness in product/process development procedure') was designed to measure the extent to which the recipient firm discovered, during the project, areas of weaknesses in its product/process development procedures. The second item ('better ways to manage collaborative projects with a university') was designed to measure the extent to which the recipient firm discovered, during the project, better ways to manage collaborative projects with a university. The third item ('university as a source of knowledge') was designed to measure the extent to which the recipient firm discovered, during the project, additional opportunities to benefit from a university, as a source of knowledge. The fourth item ('potential improvement in product/process') was designed to measure the extent to which the recipient firm discovered, during the project, other areas of potential improvement in its product design, production technology, or production management. The fifth item ('need for new competencies') was designed to measure the extent to which the recipient firm discovered during the project that it needed additional competencies to keep up with relevant new science and technology.

4.2.10. Moderating variables

Technical uncertainty and organizational uncertainty were considered moderating variables because they are quantitative variables that affect the strength of the relation between independent and dependent variables (see Baron and Kenny, 1986). The respondents were instructed to report on uncertainty as it was perceived at the *beginning* of the project (i.e., at the project specification phase). This is because this study seeks to investigate the role of uncertainty, which can also be conceptualized as a lack of knowledge about the new technology and its impact on the organization, at the time the main technical objectives of the project were being specified. Therefore, each type of uncertainty captures a specific type of knowledge that the recipient firm was lacking at the beginning of the project. These two types of knowledge were deemed sufficiently distinct to warrant the use of two separate variables.

4.2.11. Technical uncertainty

The first item ('known scientific concepts and engineering principles') was designed to capture the extent to which the recipient firm perceived the new technology as based on well known scientific concepts and engineering principles. The second item ('prior experience with the technology') was designed to capture the extent to which the recipient firm had prior experience with the type of technology transferred during the project. The third item ('proven technology') was designed to capture the extent to which the new technology was proven at the lab level (i.e., at the university and prior to delivery to the firm).

4.2.12. Organizational uncertainty

The first item ('impact on other functions') was designed to capture the extent to which the recipient firm had a clear idea about the impact of the new technology on other functions in the organization. The second item ('impact on product/process technologies and skills') was designed to capture the extent to which the recipient firm had a clear idea about the potential impacts of the new technology on other critical product and process technologies (and skills) in the organization. The third item ('impact on other major organizational dimensions') was designed to capture the extent to which the project was expected by the recipient firm to significantly affect many of its major organizational dimensions (e.g. organizational structure, incentives, skill requirements).

5. Results and discussion

Table 1 shows the Cronbach's alphas, means, standard deviations, and correlation matrix for all variables. Prior technical knowledge is highly correlated with operational benefits ($P < 0.01$), whereas prior organizational knowledge is only moderately correlated with operational benefits ($P < 0.10$). In comparison, training and cross-functional teams is highly correlated with all of the outcome variables ($P < 0.01$). These results suggest that this learning activity plays a far bigger role than previously hypothesized.

5.1. Canonical correlation analysis

This analysis was first performed to explore the general relationships among the two sets of independent variables (i.e., prior knowledge and learning activities) and the set of dependent variables (i.e., operational benefits, skills and knowledge acquisition, and discovery of additional improvement opportunities). The canonical correlation is 0.490, which is significantly different from zero at the 0.01 level by the chi-square test. The redundancy coefficient for the technology transfer benefits set is 0.128, indicating that 12.8% of the variance in thatset is accounted for by the variability in the learning activities set. These two sets are, then, significantly related. According to Hair et al. (1992), cross-loadings provide a more direct measure of the dependent-independent variable relationships by eliminating an intermediate step involved in conventional loadings. Also Lambert and Durand (1975) suggested that cross-loadings greater than 0.30 are acceptable loading values. Based on these guidelines, an examination of the canonical cross-loadings indicates that the composite score for the learning activities variables is significantly related to: operational benefits (0.444), skills and knowledge acquisition (0.312), and moderately related to discovery of additional improvement opportunities (0.297).

The canonical correlation analysis relating the two prior knowledge variables to the three technology transfer benefits variables showed that the canonical correlation is 0.308, which is significantly different from zero at the 0.10 level by the chi-square test. The redundancy coefficient for technology transfer benefits set is 0.038, indicating that only 3.8% of the variance in the technology transfer benefits set is accounted for by the variability in the prior knowledge set. These two sets are, then, only moderately related. An examination of the canonical cross-loadings indicates that the composite score for the Prior Knowledge variables is marginally related to operational benefits (0.292) but not significantly related to either skills and knowledge acquisition (0.095) or discovery of additional improvement opportunities (0.136).

5.2. Hypotheses testing and split sample analyses

For each multivariate regression analysis used in the tests, residual scatterplots were examined to test the assumptions of normality, linearity, and homoscedasticity. These plots showed no violation of any of these assumptions. In addition, there was no evidence of outliers or autocorrelation. The sample size was also sufficiently large to perform the required regression analyses. However, multicollinearity was found in the tests of moderation effects. This problem was eliminated by standardizing the independent and moderating variables.

Split sample analysis was also used to explore how the direct effects might change for projects with high and low levels of technical uncertainty and high and low levels of organizational uncertainty. This was performed by splitting the sample at the median into two groups of high and low technical uncertainty. The same split sample analysis procedure was also performed for organizational uncertainty (see Table 2 for results).

5.2.1. Prior knowledge

Although they were significantly correlated ($P< 0.01$), prior technical knowledge had a significant effect on operational benefits only before the inclusion of technical uncertainty in the regression model. The role of prior technical knowledge was further investigated using subgroup analysis. The effect of prior technical knowledge remained non-significant for projects characterized by either high or low technical uncertainty. However, the effect of prior technical knowledge was found to be significant for projects with a high level of organizational uncertainty ($P < 0.01$). The absence of a significant effect of prior technical knowledge on operational benefits for projects with high technical uncertainty may

Table 1
Cronbach's alphas, means, standard deviations, and correlations[a]

Variables	Alpha	Mean	Std Dev.	1	2	3	4	5	6	7	8	9
1. Prior tech. knowledge	0.80	4.93	1.41									
2. Prior organizational knowledge	0.68	4.27	1.39	0.45***								
3. Experimentation	0.66	4.21	1.74	0.06	−0.09							
4. Training and cross- functional teams	0.82	4.91	1.28	0.21**	0.27***	0.14						
5. Systematic learning from past experience	0.80	4.11	1.19	0.22**	0.38***	0.13	0.39***					
6. Technical uncertainty	0.62	4.43	1.30	0.39***	0.12	0.17*	0.20**	0.06				
7. Organizational uncertainty	0.87	4.55	1.55	0.35***	0.42***	−0.00	0.32***	0.40***	0.27***			
8. Operational benefits	0.82	4.57	1.51	0.29***	0.17*	0.27***	0.36***	0.36***	0.37***	0.27***		
9. Skills and knowledge aquisition	0.80	4.21	1.33	0.10	−0.00	0.20**	0.30***	0.19*	0.12	0.20**	0.40***	
10. Discovery of add. improvement opport-unities	0.74	4.47	1.36	0.14	0.03	0.15	0.25***	0.22**	0.13	0.36***	0.20**	0.45***

[a] $N = 120$ (for correlations, listwise deletions of missing values gives $N = 107$). $^{*}P < 0.10$; $^{**}P < 0.05$; $^{***}P < 0.01$.

Table 2
Results of split sample analysis: high and low levels of uncertainty[a]

	High tech. uncer. $N = 53$	*Low* tech. uncer. $N = 67$	*High* org. uncer. $N = 59$	*Low* org. uncer. $N = 61$
Dependent variable = operational benefits				
Prior tech. knowl.	0.09	0.08	0.50^{***}	-0.02
Experimentation	0.20	0.04	0.12^{*}	0.09
Training and CFT	0.15	0.10	0.28^{***}	0.10
Systematic LFPE	0.01	0.241^{**}	-0.185^{*}	0.30^{**}
Dependent variable = skills and knowledge acquisition				
Experimentation	0.13	0.11	0.07	0.18^{**}
Training and CFT	0.45^{***}	0.02	0.37^{***}	0.01
Dependent variable = discovery of additional improvement opportunities				
Training & CFT	0.50^{**}	-0.13	0.38^{***}	-0.04
Systematic LFPE	-0.09	0.17	-0.11	0.21

[a] $^{*}P < 0.10$; $^{**}P < 0.05$; $^{***}P < 0.01$.

be explained by the possibility that the new technology is so different from the existing one that prior technical knowledge about the existing becomes unimportant. Prior technical knowledge may even become irrelevant if the new technical knowledge is intended to replace the existing one.

Projects with high technical uncertainty may also involve the development and implementation of a totally new product or technical system that does not have a predecessor to know about and understand. However, in this type of radical projects, prior organizational knowledge might be relevant and useful to anticipate the potential impact of the new technology on other aspects of the organization. Hence, future research should explore the effect of prior organizational knowledge on the operational benefits from projects characterized by a high level of technical uncertainty. Firms should, at least, adopt a formal process of evaluating the level and quality of prior knowledge that they have during the project definition stage to increase the quality of problem diagnosis and anticipation of future challenges and opportunities. Bohn's (1994) scale of measuring technological knowledge can be adapted to that effect.

Prior organizational knowledge did not have a significant effect on operational benefits. This result could be an artifact of the data collection. For instance, the respondents might have been mostly engineers and scientists who may not have sufficient knowledge about 'non-technical' matters such as incentives, rewards, skills, and other functions in the organization. It is also important to note that the variable prior organizational knowledge had the highest proportion of missing values among the main variables used in this study (5 out of 120). This may indicate that the items used to measure this variable may have been the most difficult to respond to in the questionnaire. It is also possible that the instrument developed to measure the construct prior organizational knowledge included items that did not accurately represent the phenomenon being measured. Hence, this scale probably lacked content validity, which is not a statistical property. Although an extended literature search is often suggested to increase content validity, the literature on organizational knowledge is relatively scarce and conceptual at best (e.g., Nonaka, 1994; Huber (1991)). It might also be beneficial to use multiple informants who are carefully chosen to respond to such non-technical questionnaire items.

5.2.2. Learning activities

Experimentation had a significant effect on operational benefits ($P < 0.01$). However, neither technical uncertainty nor organizational uncertainty significantly moderated the relationship between experimentation and operational benefits. Split sample analysis showed that the effect of experimentation on operational benefits was not significant for projects with low technical uncertainty and in projects with high organizational uncertainty. Low technical uncertainty implies that little knowledge can be gained by experimentation. Therefore, experimentation was not critical for the achievement of high operational benefits. Conversely, experimentation contributed significantly to the operational benefits of projects that were characterized by high technical uncertainty or low organizational uncertainty.

These results were expected, based on the type of experimentation (i.e., the type of knowledge it intended to add through such a learning activity). Indeed, the results of the factor analysis performed on the 13 learning activities (see Appendix) showed that the factor corresponding to the scale *experimentation* was clearly dominated by the following two items: (1) constructing an artificial model of the new technology and experimenting with it, and (2) building a small scale prototype of new technology in a controlled environment to identify. This learning activity perhaps should have been termed 'technical experimentation' to differentiate it from experimentation activities that seek to solve problems and produce knowledge than spans various functions and technical systems in the organization (or 'organizational experimentation'). Nevertheless, Table 2 shows that experimentation had a moderately significant effect on operational benefits for projects characterized by high organizational uncertainty ($P < 0.10$). This is especially likely in small firms, where the domain of technical experimentation is the entire firm.

Experimentation also had a significant effect ($P < 0.05$) on skills and knowledge acquisition for projects with a low level of organizational uncertainty. Future research in this area may try using three different scales for skills acquisition, technical knowledge acquisition, and organizational knowledge acquisition. These separate measures of learning benefits might enable researchers to identify more precisely the effects of various types of experimentation (and other learning activities) as well as test the potential moderating effects of technical versus organizational uncertainty. Also, it would be insightful to determine whether or not different types of projects (i.e., product, process, or production management system) would be characterized by different types of uncertainty (i.e., technical or organizational).

The learning activity 'training and cross-functional teams' had a significant effect on skills and knowledge acquisition ($P < 0.10$). However, training and cross-functional teams had a significant effect on operational benefits but only for projects characterized with high organizational uncertainty ($P < 0.01$). It is quite surprising to find that training and cross-functional teams were not important for the operational benefits of projects with high technical uncertainty. However, such projects tend to make many skills in the recipient firm obsolete. Consequently, the firm might choose to replace people with such skills with new people or new technology, both of which can be more effective and less costly. Hence, this 'creative destruction' may not involve or require the training of individuals and teams during the project.

The effect of and usefulness of training and cross-functional teams, then, partly depends on the nature of the uncertainty faced by the firm in a given project. Tyre and Hauptman (1992) found similar results which showed that the higher *the technical complexity* (i.e., similar to technical uncertainty) of a new manufacturing process, the less benefit was gained by forming multi-functional project teams. However, they did not find a significant relationship between *systemic shift* (i.e., similar to organizational uncertainty) and the effectiveness of forming multi-functional project teams. They explained this unexpected finding by the use of near-term success measures that may not capture the long-term benefits of team structure.

Systematic learning from past experiences was hypothesized to have a significant direct effect on the learning benefit 'discovery of additional learning benefits'. In addition, this learning activity remained non-significant for projects with high and low technical uncertainty, and organizational uncertainty (see Table 2). These results, which are somewhat surprising, suggest that systematic learning from past experiences does not affect the discovery of better ways to manage collaborative projects with the university or of additional ways to benefit from the university as a source of knowledge. One possible explanation of this robust and stable result is that the systematic procedure that firms put in place to learn from past experiences may not be effective in diffusing information and knowledge throughout the organization for future use.

Also, most of these systematic ways of learning from past experiences may not cover university–industry technology transfer projects. Moreover, such systematic processes are unlikely to apply to the technology transfer process itself and how it can be improved and made more beneficial. In addition, the frequency of interaction of the firm with the university during the two years prior to the project, a contextual variable, did not have a significant direct impact on this intangible benefit, nor did it moderate that relationship. Nevertheless, systematic learning from past experiences had a significant effect on operational benefits ($P < 0.05$). However, this positive effect did not hold for projects with high technical uncertainty. And for projects with high organizational uncertainty, the effect was negative ($P < 0.10$). The effect of systematic learning from past experiences on operational benefits was, however, significant for projects with low technical uncertainty ($P < 0.05$) as well as those with low organizational uncertainty ($P < 0.05$).

While learning from past experiences is generally believed to be useful, these results show that this is not always the case. For radical projects, lessons from previous projects may not be relevant enough to be useful. However, for incremental projects, previous experiences are much more likely to be relevant to the current project and, hence, more useful. Although it is quite surprising to find a negative impact of a learning activity, this result is consistent with Leonard-Barton's (1992) concern about the negative impact of *core rigidities*, which are core capabilities that become counterproductive. Hence, some lessons should be unlearned, otherwise they may lead to the 'internal hardening of organizational arteries', which can cause resistance to change and paralysis (Leonard-Barton, 1995). Firms, then, should distinguish between what needs to be remembered and what needs to be forgotten.

6. Conclusions

This research provides more insight into the value and workings of firm knowledge and organizational learning by producing empirical evidence on the relationships between these activities and their benefits. This study developed reliable and valid measures related to knowledge, learning activities, and especially learning benefits. Although the nature of this study is exploratory, the results obtained provide valuable prescriptions for more successful technology transfer projects. Universities also, as partners and sources of knowledge creation, can exploit this expanded view of technology transfer outcome to promote the spillover benefits that they can offer to the recipient firm.

While firms are usually told to implement a variety of organizational learning activities at all times (i.e., the more the better), this study suggests that perhaps some activities should be emphasized over others in certain conditions. This is because learning activities were found to play a different role under different conditions. These conditions relate primarily to the degree and type of uncertainty perceived by the firm at the beginning of the project. This study also suggests that:

- High technical uncertainty: in these projects, firms should emphasize experimentation to increase operational benefits, while also emphasizing training and cross-functional teams to acquire new skills and knowledge and discover additional improvement opportunities.
- High organizational uncertainty: in these projects, firms should establish training programs and cross-functional teams to increase operational benefits, enhance skills and knowledge acquisition, and discover additional improvement opportunities. However, in these projects, firms should also identify counter-productive lessons and 'unlearn' them. Firms can also enhance operational benefits by starting such projects with a high level of prior technical knowledge about the existing technology.
- Low technical uncertainty: in these projects, firms could increase their operational benefits from the project by having a systematic procedure for learning from past experiences. Given that projects involving incremental technological change are generally more frequent than radical ones, firms should establish a systematic way of learning from past experiences for these projects. In addition, these firms should continuously re-evaluate the lessons learned to eliminate (i.e., unlearn) the counter-productive ones.
- Low organizational uncertainty: in these projects, firms should emphasize experimentation to increase operational benefits as well as skills and knowledge acquisition. Systematic learning from past experiences, however, would only contribute to the operational benefits.

In general, firms should determine the type of knowledge the learning activity is intended to create. This understanding, combined with an understanding of the type and level of uncertainty faced at the beginning of the project, would permit the firm to emphasize and enhance the appropriate learning activities to achieve a high level of the desired benefits. Although this study found prior organizational knowledge to have non-significant effects on any of the project benefits, Chew et al. (1991) and Grant et al. (1991) explained the considerable value of 'organizational prototyping,' which is a tool for the anticipation of potential organizational challenges and opportunities. This tool considers prior organizational knowledge as a key ingredient for informed and knowledgeable prototyping and diagnosis.

Appendix (Scales).

Factor loadings are given in parentheses for each item.

Prior knowledge

*Prior technical knowledge (*alpha = 0.80, eigenvalue = 2.89*)*

1. Documentation of existing technology (0.89)
2. Could measure the main performance drivers (0.87)
3. Individual knowledge of existing technology (0.75)

*Prior organizational knowledge (*alpha = 0.68, Eigenvalue = 1.15*)*

1. Documentation of incentive and rewards system (0.73)
2. Understanding a job's relation to other organizational activities (0.85)
3. Documentation of skills and technologies (0.68)

Learning activities

*Experimentation (*alpha = 0.66, eigenvalue = 4.43*)*

1. Construction of artificial model of new technology (0.83)
2. Building small scale prototype of new technology (0.87)
3. Examination of full-scale working model of new technology (0.55)

*Training and cross-functional teams (*alpha = 0.82, eigenvalue = 1.97*)*

1. Encouraged individuals to acquire new competencies (0.86)
2. Encouraged teams to acquire new competencies (0.82)
3. Learning new competencies was critical part of business strategy (0.76)
4. Reliance on cross-functional teams to solve important problems (0.65)
5. Design choices took into account impact on other technologies (0.57)

*Systematic learning from past experiences (*alpha = 0.80*,* eigenvalue = 1.79*)*

1. Systematic procedure to analyzed failed initiatives (0.91)
2. Systematic procedure to analyze successful initiatives (0.92)
3. Systematic way of retaining and recording lessons from past experience (0.77)
4. Systematic effort to learn from experience of other firms (0.41)
5. Systematic of identifying potential changes in all business functions (0.65)

Technology transfer benefits

*Operational benefits (*alpha = 0.82*,* eigenvalue = 4.29*)*

1. Degree to which the new technology met technical objectives (0.84)
2. Utility of the technical solution implemented (0.85)
3. Degree to which the technical solution has been trouble-free (0.86)
4. Acquisition of new scientific knowledge (0.59)

*Skills and knowledge acquisition (*alpha = 0.80*,* eigenvalue = 1.91*)*

1. Acquisition of new technical skills (0.80)
2. Gained a better understanding of existing product/process (0.71)
3. Revealed weaknesses in product/process development processes (0.67)
4. Revealed areas of improvement in product/process design (0.75)
5. Discovered the need for new competencies to keep up (0.66)

*Discovery of additional improvement opportunities (*alpha = 0.74*,* eigenvalue = 1.14*)*

1. Revealed better ways to manage collaboration with the university (0.93)
2. Revealed additional opportunities to benefit from the university (0.76)

Uncertainty

*Technical uncertainty (*alpha = 0.62*,* eigenvalue = 2.33*)*

1. Known scientific concepts and engineering principles (0.82)
2. Prior experience with the type of technology (0.80)
3. New technology is proven at the lab level (0.61)

*Organizational uncertainty (*alpha = 0.87*,* eigenvalue = 1.49*)*

1. Clear idea about the impact of the new technology on other organizational functions (0.85)
2. Clear idea about impact of new technology on other technologies and skills (0.88)

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Abdelkader Daghfous (Ph.D., Pennsylvania State University) is currently an Assistant Professor of Management Information Systems in the School of Business and Management at the American University of Sharjah (United Arab Emirates). His current research interests include knowledge management, organizational learning, and innovation with particular emphasis on absorptive capacity, capability development, and the role of government–university–industry collaboration in regional economic development.