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Enhancing Technology Learning Capabilities for Catch-up and Post Catch-up Innovations[*]

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Motivation and activities for technological learning, entrepreneurship, innovation, and creativity are driving forces of economic development in Asian countries. In the early stages of technological development, technological learning and entrepreneurship are efficient ways in which to catch up with advanced countries because firms can accumulate skills and knowledge quickly at relatively low risk. In the later stages of technological development, however, innovation and creativity become more important. This study aims to identify a) the factors (learning capabilities) that influence technological learning performance and b) barriers to enhancing innovation capabilities for the creative economy and organizations.

The major part of this study is related to learning capabilities in the post-catch-up era. Based on a literature review and observations from Korean experiences, this study proposes a technological learning model composed of various influencing factors on technological learning. Three hypotheses are derived, and data are collected from Korean machine tool manufacturers. Intense interviews with CEOs and R&D directors are conducted using structured questionnaires. Statistical analysis, such as correlation and ANOVA are then carried out. Furthermore, this study addresses how to enhance innovation capabilities to move forward. Innovation enablers and barriers are identified by case studies and policy analysis.

The results of the empirical study identify several levels of firms' learning capabilities and activities such as a) stock of technology, b) potential of technical labor, c) explicit technological efforts, d) readiness to learn, e) top management support, f) a formal technological learning system, g) high learning motivation, h) appropriate technology choice, and i) specific goal setting. These learning capabilities determine firms' learning performance, especially in the early stages of development. Furthermore, it is found that the critical factors for successful technological learning vary along the stages of technology development.

Throughout the statistical and policy analyses, this study confirms that technological learning can be understood as an intrinsic principle of the technology development

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process. Firms perform proactive and creative learning in the late stages, while reactive and imitative learning prevails in the early stages.

In addition, this study identifies the driving forces or facilitating factors enhancing innovation performance in the post catch-up era. The results of the preliminary case studies and policy analysis show some facilitating factors such as a) the strategic intent of the CEO and corporate culture, b) leadership and change agents, c) design principles and routines, d) ecosystem and collaboration with partners, and e) intensive R&D investment.

Keywords *: Technology Learning, Innovation, Learning Capability, Innovation Barrier, Entrepreneurship*

Ⅰ. Introduction

According to Kim (1997), technological learning is regarded as a key enabler of Korea's rapid technological and economic development. Technological learning, a key element in understanding technological innovation, is regarded as an efficient way in which to enhance technological knowledge and performance. Moreover, technological mastery can be achieved by technological learning. Technological mastery is the effective use of technological knowledge, by continuing technological efforts to assimilate, adapt, and/or create technology.

Because technological learning can be understood as the development process of technological capacity (Lall, 1980), it provides important implications for catching-up countries. Following studies of technology development in developing countries, some research has been carried out on the stage and process of technological development (Lall, 1980; Bell, 1984; Lee, Bae, and Choi, 1988; Gil, Bong, and Lee, 2003). However, those works are insufficient for explaining performance differences or developing velocity among countries and firms. This study thus started from the premise that the technological development process results from technological learning activities. It aims to answer the following research question: what are the determinants of different levels of learning performance and what kinds of contextual variables should be considered to explain the relationship?

Types of technological learning vary by development stage. The influencing factors of such learning are also dynamic rather than static, meaning that they may change after the learning process and technological development stages. Another question arises from these assumptions: what critical factors influence technological learning performance in each stage of technological development, and how do these types of learning change?

Taken together, this study aims to identify the factors that influence technological learning performance in the catch-up innovation era and analyze whether these influencing factors vary along the stages of technology development. In this regard, this study posits following three research questions a) what is relations between learning capabilities and technological performance? b) Does critical technological learning capabilities change according to the technological development stages? and c) what is relations between technological learning levels and technology development stages?

Through this study of technological learning in catching-up countries, we can extend our understanding of the mechanism and underlying principle of technological development. In addition, this study suggests some influencing factors in promoting post catch-up innovations.

II. Conceptual Framework on Technological Learning

2.1 Technological Learning

Technological learning can be defined as "the acquisition of improved technological capabilities" (Bell, Scott-Kemmis, and Satyarakwit, 1982) or "the process of cumulating the technology and management abilities to be needed to a production environment" (Bell, 1984). It is understood as a part of organizational learning (Kim, 1998). Learning takes place at two levels: individual and organizational. Here, we view technological learning as organizational-level learning in that it is an embodied change that creates organizational technological knowledge or production skills. Kim (1997) identified the pattern through which Korean firms acquire foreign technologies, assimilate and improve these technologies, and, eventually, invest in their own R&D.

Many researchers have defined and classified types and levels of technological learning. Technological learning has been divided into classes according to the predictability of outputs (Fransman, 1982), while learning-by-doing, learning-by-using, and learning-by-failing have been classified through studies of new product development (Maidique and Zirger, 1985; Rosenberg, 1982). Bell (1984) explained that different mechanisms are needed in the growth stage of firms and proposed two broad groups, namely doing-based learning and non-doing-based learning. This study of the technology exports of a developing country (India) showed that technology capacity improvement has three stages (i.e., elementary, intermediate, and advanced) and classified six types of technological learning for each stage in more detail (Lall, 1980).

As for the levels of learning, double-loop learning is emphasized compared with single-loop learning (Argyris and Schon, 1978). Subsequent studies have followed Argyris' concept (Fiol and Lyles, 1985; Watkins and Marsick, 1993; Kim, 1993). Meyers (1990), explaining learning with a firm's life cycle and technology life cycle, proposed four levels of learning. Although the concept of organizational learning is rather inclusive, existing studies can be integrated with the perspective of technological learning.

There are several types of learning from reactive learning to proactive learning, as shown in Table 1. Reactive learning is low-level, costless, and an incremental development type, while proactive learning is high-level, radical development, and requires a systematic learning mechanism.

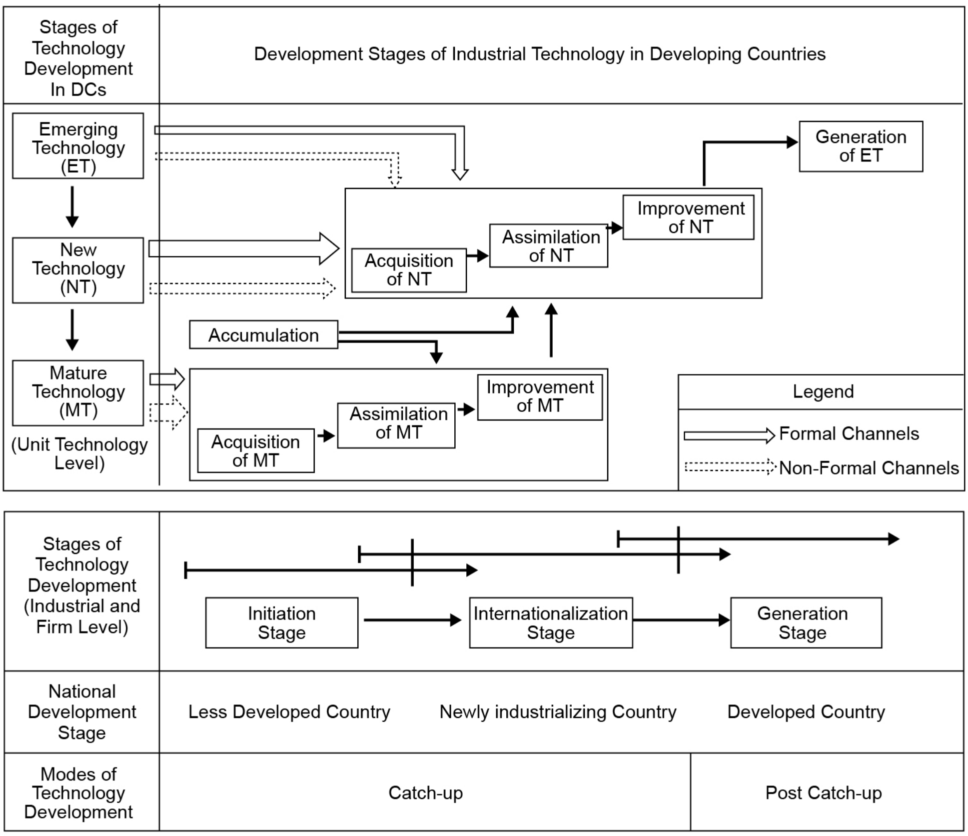
Table 1
Types and Levels of Technological Learning

Types	Reactive Learning			Proactive Learning		
Levels / Researchers	Learning by imitating	Learning by changing	Learning by modifying or adapting	Learning by self-designing	Learning by improved design	Learning by R&D
Lall (1980)	Learning-by-doing	Learning-by-adapting		Learning-by-designing	Learning-by-improved design	Learning-by-innovation
Bell (1984)	Doing-based-learning		Non-doing-based-learning			
Maidique and Zirger (1985)	Learning-by-doing		Learning by using	Learning by failure		
Argyris and Schon (1978)	Single-loop-learning			Double-loop-learning		
Adler and Clark (1991)	First order learning			Second order learning		
Senge (1990)		Adaptive learning		Generative learning		

According to Bell's (1984) definition, technological learning includes the concept of process. To analyze the technological development process, the micro-level view shows that technological learning activities are inherent in the technological development process. Lee et al. (1988) proposed three stages of the technology development process: initiation, internalization, and generation (Figure 1). Their propositions support that technological learning is an underlying principle of the development process. Reactive technological learning corresponds to the initiation stage, while proactive learning to the internalization stage. Furthermore, the initiation and internalization processes belong to the catch-up innovation era, while the generation stage belongs to the post-catch-up innovation era.

Kim (1997, 1998) suggested a three-stage technological development and learning process model for developing countries: acquisition, assimilation, and improvement. Each stage of the technological catch-up process matches the learning process: reactive learning can be matched with acquisition, while proactive learning with the assimilation stage and the improvement/application stage. It is also reasonable to make a correspondence between the organizational learning process and knowledge acquisition, knowledge sharing, and knowledge exploitation (McKee, 1992; Nevis, DiBella, and Gould, 1995; Nonaka, 1994) and the technological lear-

Figure 1
Global-Perspective Model of Innovation and Learning in Developing Countries



Source: Adopted from Lee et al. (1988).

ning and development process.

2.2 Influencing Factors on Technological Learning Performance

Many firms that have learned imported technologies and internalized them successfully in catching-up countries have distinctive characteristics. The purpose of this study is to find those characteristics and explain technological learning with them. It is somewhat difficult to accomplish this purpose, however, because there is little empirical research on the performance of learning at the organizational level. The difficulty of operationalization on learning performance is an obstacle to studying the influencing factors (Slater and Narver, 1995). Here, studies of learning activities and critical factors at the individual and organizational levels are used to analyze technological learning performance and its influencing factors.

By applying the characteristics of professionals in cognitive psychology (Larkin, 1979) to the organizational level, we can have implication that firms need cooperative information management systems and technological learning systems to acquire technologies efficiently and improve learning performance. When organizations generate the system and process to support learning activities and integrate them to structure of ordinary operational activities, learning is more effective (Garvin, 1993).

Studies on technological capabilities in the developing world allow us to understand the influencing factors. Technological capability is the ability to make effective use of technological knowledge. It is the primary attribute of human knowledge and the know-how that effectively combines human skills with the physical ability to meet human needs. Because of the complexity of technology, there are many distinct technological capabilities, classifiable in different ways, each corresponding to a different way of distinguishing the aspects of technological knowledge and its applications. Fransman (1982) divided technological capabilities into the following six types after defining and measuring them in the developing world: 1) to search for available alternative technologies, 2) to master imported technologies, 3) to adapt, 4) to further develop adaptive technologies, 5) to institutionalize, and 6) to carry out basic research. The Thailand Development Research Institute (TDRI) proposed four types of technological capabilities based on a revision of a World Bank study, namely acquisitive capability, operative capability, adaptive capability, and innovative capability (1989). Technological capability is similar to absorptive capacity (Cohen and Levinthal, 1990). Cohen and Levinthal (1990) argued that prior related knowledge and experiences are important to the future acquisition and exploitation of technology. That is, accumulated technological capacity affects learning significantly. Top management is another important factor. Top management plays a key role in the learning process because its position in the organization allows it to understand the gaps between recent and targeted performance (Wick and Leon, 1993). For amicable organizational learning, top management must furnish all organizational members with creative tension that makes them think experimentally (Nevis et al., 1995). In addition, many studies show that the support of top management influences technology development performance (Rubenstein, Chakrabarti, and O'Keefe, 1974; Rothwell, Freeman, Horlsey, Jervis, Robertson, and Townsend, 1974).

Countries have pointed out that explicit technological efforts and learning motivation are important to development performance (Bell, 1984; Dahlman and Westphal, 1981). Firms that devote their efforts to the internalization of the acquired technology have higher performance (see also Cohen and Levinthal, 1990). In addition, organizational objectives may affect the performance of learning in many ways. The relations between goal setting and performance have been in focus since strategic management developed and innovations accelerated. In general, performance is better when there are concrete goals (Locke, Shaw, Saari, and Latham, 1981).

Ⅲ. Research Framework and Hypotheses

This study assumes that the extent of technological learning capabilities results in differences in technological performance among products, firms, industries, and countries. Thus, it concentrates on the relation between technological learning capabilities and performance. Technological learning performance, then, appears as technological and commercial success. Because technological learning performance and technological development performance have similar concepts, we reviewed not only studies of learning but also those of technological development. We needed to integrate and arrange the multitude of key success factors of technological development proposed by different researchers and influencers of learning into one conceptual framework. With the above existing studies and preliminary examination, this study suggests nine technological learning capabilities that influence technological learning performance. Table 2 shows the proposed elements of learning capabilities in more detail.

A case study was conducted mainly through in-depth interviews with experts and managers. During these interviews, we made sure or modified the learning capabilities proposed

Table 2
Technological Learning Capability

Learning Capability	Relations between Capabilities and Performance	Related Studies
Stock of Technology	The higher the accumulated knowledge and experience, the more effective performance is.	Bell and Hill (1978) Cohen and Levinthal (1990) Ettlie and Rubenstein (1981)
Potential of Technical Manpower	The higher the potential of technical manpower, the higher is performance.	Caiazza and Volpe (2016) Mohaghar, Monawarian, and Raassed (2012)
Intensive Technical Efforts	The more explicit technical efforts for internalizing imported knowledge, the higher is performance.	Bell (1984) Cohen and Levinthal (1990) Dahlman and Westphal (1981)
Readiness to Learning	The readier for adaptation, the more successful the performance.	Guglielmino, Guglielmino, and Long (1987) Hintzman (1978) London and Sessa (2007) Waldman, Glover, and King (1999)
Top Management Support	The higher top management support, the higher is a firm's performance.	Kim (1998) Wick and Leon (1993) Nevis et al. (1995) Rothwell et al. (1974) Radnor, Rubenstein, and Tansik (1970)
Systemization of Technological Learning	Firms with formal and systemized technological learning mechanisms have higher performance.	Bell (1984) Cooper (1979) Garvin (1993) Larkin (1979)
Learning Motivation	The higher the motivation of technical manpower, the higher is performance.	Gray and Meister (2004) Steers and Porter (1979) Nadler and Lawler (1983)
Appropriateness of Technology Choice	When appropriate technologies depend on situations, the performance is high.	Dahlman and Westphal (1981) Marcy (1979) Veugelers and Cassiman (1999)
Stretched Goal Setting	The more concrete and difficult the goals, the higher is performance.	Kim (1998) Locke et al. (1981) Sitkin, See, Miller, and Lawless (2011)

Figure 2
Technological Learning Capability Matrix

Attributes of Learning Capability	Experiential (past to present)	↔	Systematic (present to future)
Concrete	Stock of Technology	Potential of Technical Manpower	Intensive Technological Efforts
↕	Readiness to Learning	Top Management Support	Systemization of Technological Learning
Abstract	Learning Motivation	Appropriateness of Technology Choice	Stretched Goal Setting

Timing of Capability Building and Application

based on the results of other researchers. Applying the learning capabilities that were confirmed in a preliminary case study of Kolb's (1974) learning model, we could thus provide a learning capabilities matrix in Figure 2.

Kolb (1974) explained learning using two dimensions: abstractness and application time. In terms of technology learning capability, the attributes of learning capabilities represent the degree to which the characteristics of each capability are concrete or abstract. Further, the timing of capability building and application indicates when capabilities are built and applied. In this learning capabilities matrix, the dimension of the timing of capability building and application consists of how they are experiential (past to present) or systematic (present to future). In addition, Christensen and Kaufman (2009) suggested that capabilities are composed of resources, processes, and priorities. Under their framework, all learning capabilities are closely related to resources, processes, and priorities. Stock of technology, potential of technical manpower, and intensive technological efforts all belong to resources. Readiness to learning, top management support, and systemization of technological learning can be matched to processes. Lastly, learning motivation, appropriateness of technology choice, and stretched goal setting are related to priorities. The learning capabilities matrix provides an important implication. That is critical factors will change according to the technology development process. Hence, the influencing factors are dynamic rather than static. Thus, another important concern of this study focuses on this point.

Another research question of this study is how technological learning types and levels are related to the technology development stages. Through the above research model, we propose the following three hypotheses.

Hypothesis 1: Firms' technological learning performance in a developing country is dependent on learning capabilities. 1) The higher the accumulated technologies, which is related to the acquired technology, 2) the larger the potential of technical manpower, 3) the more explicit the technological efforts and investment to internalize the acquired technology, 4) the larger the readiness to learning when new technology is imported, 5) the higher the support of top management, 6) the more formalized the technological learning system, or more systematic technology accumulation and technological learning, 7) the higher the motivation to learn, 8) the more appropriate the technology choice, and 9) the more concrete and difficult the goal, the higher the performance of technological learning is.

Hypothesis 2: Critical influencing factors change according to the technological development stage. In the early internalization stage, learning motivation, top management support, and appropriate technology choice are more important, whereas in the late internalization stage, explicit technological efforts, technology accumulation, and formal learning systems are more critical.

Hypothesis 3: The higher the technology development stage, the higher the level of technological learning is. Learning is more reactive in the initialization stage than proactive; on the contrary, proactive learning is performed much more in the internalization stage.

IV. Research Method

To test these hypotheses, we collected data on technological learning capabilities, technological learning performance and the technology development process from 40 Korean machine tool manufacturers. Intensive interviews with the CEOs or directors of the technology development departments were arranged and carried out. A structured questionnaire was also used in these interviews. Characteristics of sample firms are summarized in Table 3. Table 4 summa-

Table 3
Characteristics of Sample Firms

	Firm Characteristics							
Firm Size	SMEs 30(75%)			Large Firms 10(25%)			Total 40(100%)	
Type of Product	Conventional Machine Tools Only 27(67%)				NC/Conventional Machine Tools 13(33%)			
Number of Employee in Machine Tool Industry		30 ~49	50 ~99	100 ~299	300 ~499	500 ~999	over 1000	Mean
	5(13%)	10(25%)	10(25%)	10(25%)	2(5%)	2(5%)	1(2%)	166
Sales in Machine Tool Industry (billion won)	under 0.5	0.5~1	1~2	2~5	5~10	10~30	over 30	Mean
	4(10%)	7(18%)	14(35%)	8(20%)	2(5%)	2(5%)	3(7%)	5.2
Proportion of Machine Tool in Business Portfolio	under 10%	10~30%	30~50%	50~80%	80~99%	100%	N/A	Mean
	5(13%)	3(7%)	3(7%)	1(2%)	5(13%)	18(45%)	5(13%)	71%

Note) 1 US Dollar is approximately equivalent to 1,000 Korean Won.

Table 4
Description of the Variables

Variables		Measures
Firm Level	Commercial Performance	Growth of sales
	Technological Performance	Number of technology development during the past three years
	Stock of Technology	Number of technology development (from foundation)
	Potential of Technical Manpower	Number of technical professionals as a percentage of the total number of employees
	Intensive Technical Efforts	Degree or types of technology development activities
	Readiness to Learning	Degree of feasibility study for technology development
	Top Management Support	Self-report (five-point Likert scale)
	Systemization of Technological Learning	Five-point Likert scale based on the existence of technological information and technology classification system
	Learning Motivation	Average score of each position on learning motivation (Five-point Likert scale)
	Appropriateness of Technology Choice	Self-report (Five-point Likert scale)
	Stretched Goal Setting	Degree of goal specificity and systematic analysis (Five-point Likert scale)

rizes the definitions of the variables used in this study. The collected data were analyzed by using the SPSS package.

To examine the relations between technology learning capabilities and learning performance in Hypothesis 1, we employed correlation analysis. Because Hypothesis 2 tests the differences of the importance of each technology learning capabilities according to each technology development stage, ANOVA test and Duncan multiple range test were used. Regarding Hypothesis 3, this study employed chi-square test to examine whether there are significant differences of learning level among categories by the types of learning and each technology development stage.

V. Results

Hypothesis 1 explains that a firm's technological learning performance depends on its learning capabilities. This hypothesis may seem similar to the key success factors of other general management studies. However, technological learning is more related to long-term performance than short-term, meaning that the influencing factors include past accumulated knowledge, present capabilities, and future goals simultaneously. In addition, concrete investment in resources and an abstract learning attitude are connected in an integrated and systematic perspective and framework.

The correlation analysis shows that proposed learning capabilities are significantly related to learning performance, as shown in Table 5. Commercial performance, which is the external goal of firms as measured by the growth rate of sales, is high when learning motivation is high (r = 0.39), the goal is settled specifically (r = 0.37), the support of top management for technology development is high (r = 0.30), there is more endeavor toward explicit technological efforts (r = 0.26), and there is a more appropriate technology choice (r = 0.22).

Technological performance, measured as the number of technology development in the past three years, has significant correlations with all learning capabilities. All the considered learning capabilities (influencing factors) are connected with the technology

Table 5
Relations between Learning Capability and Learning Performance

Learning Capability \ Performance	Commercial Performance		Technical Performance		Overall Performance
	Sales Growth Rate (%)	Percentage of Commercial Success	Number of Technology Development	Percentage of Technical Success	Technology Development Stage
Stock of Technology	.19	$.23^{**}$	$.80^{***}$	23^{*}	$.61^{***}$
Readiness to Learning	.21	.04	$.47^{***}$	$.31^{***}$	$.66^{***}$
Learning Motivation	$.39^{***}$	$.27^{**}$	$.41^{***}$	$.27^{**}$	$.59^{***}$
Potential of Technical Manpower	.14	-.08	$.28^{**}$	-.10	.11
Top Management Support	$.30^{**}$	$.45^{***}$	$.49^{***}$	$.46^{***}$	$.55^{***}$
Appropriateness of Technology Choice	$.22^{*}$	$.23^{*}$	$.47^{***}$	$.23^{*}$	$.48^{***}$
Intensive Technical Efforts	$.26^{*}$	.05	$.44^{***}$	.12	$.63^{***}$
Systemization of Technological Learning	.14	.05	$.42^{***}$	$.29^{**}$	$.46^{***}$
Stretched Goal Setting	$.37^{**}$	.15	$.54^{***}$	$.26^{*}$	$.74^{***}$

Note) Significance Level: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

aspect, while the other variables that could affect commercial performance directly (i.e., sales ability, financial capability, and organizational properties) are excluded. Hence, learning capabilities in Hypothesis 1 have higher correlations with technological performance than commercial performance.

The results that explicit technological efforts and learning motivation are important to technology development performance (commercial performance) enhance studies of technology development in developing countries, which have emphasized indigenous technological efforts (Dahlman and Westphal, 1981; Westphal, Rhee, and Pursell, 1981). It is predictable that learning motivation is important, especially in learning-by-doing type of countries, such as Korea. Further, learning motivation can explain the performance of innovative organizations, which is difficult to explain only with quantitative inputs. Table 6 shows that firms in the late internationalization stage have higher learning capabilities than firms in the initialization or early internalization stages.

Hypothesis 2 implies that the critical factors of technological learning performance change according to the technology development stage. As shown in Table 6, the analysis with Duncan's multiple range test provides the following results, leading to Hypothesis 2 being accepted.

Stock of technology, explicit technological efforts, and the formalization of a technological learning system are significantly different between the initialization, early internalization, and late internalization stages, and top management support, learning motivation, and the appropriateness of the technology choice are different between the initialization stage and early/late internationalization stages. For firms in the initialization stage, entering the early internalization stage is dependent on top management support and learning motivation. Firms in the early internalization stage to late internalization stage depend on explicit investment and technological efforts rather than the attitudinal as-

Table 6
Differences in Learning Capability Along the Stages of Technology Development

	Mean			F Value	Duncan Multiple Range Test		
	Initiation Stage	Early Internalization	Late Internalization		Initiation Stage	Early Internalization	Late Internalization
Stock of Technology	5.1	8.9	18.1	12.5***	L	L	H
Readiness to Learning	1.8	2.7	3.7	13.7***	L	H	H
Learning Motivation	3.2	4.0	4.5	10.1***	L	H	H
Potential of Technical Manpower	6.3	4.7	7.6	1.5	-	-	-
Top Management Support	2.5	3.7	4.2	9.0***	L	H	H
Appropriateness of Technology Choice	3.0	3.7	4.0	5.7***	L	H	H
Intensive Technical Efforts	0.8	1.5	3.0	12.5***	L	L	H
Systemization of Technological Learning	1.0	1.8	3.0	5.0***	L	L	H
Stretched Goal Setting	2.0	3.2	4.3	22.4***	L	M	H

Note) Significance Level: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

pect. Firms in the early internalization stage may be thought of as equipping this attitudinal capability (top management support and learning motivation) sufficiently.

Table 7 shows the relations between the level of technological learning and technology development stage, which supports Hypothesis 3. In addition, the differences between the level of technological learning in each technology development stage are statistically significant ($\chi^2 = 3.12$, $p < 0.1$; $\chi^2 = 5.71$, $p < 0.5$). The learning type of firms in the initialization stage is reactive learning (e.g., learning by imitating, changing, adapting/modifying), whereas in the internalization stage it is proactive learning (e.g., learning by designing, improved design, and self R&D). This result implies that the technology development process, which can be observed externally, is connected with the technological learning levels or processes within and without. This may be proof that the learning process is inherent in the development process, mean-

Table 7
Level of Technological Learning in Each Technology Development Stage

Learning Level \ Stage		Initiation Stage Early		Initiation Stage Late		χ^2	Internalization Stage Early		Internalization Stage Late		χ^2
Reactive Learning	Learning by Imitation	32 (82%)	39 (100%)	4 (10%)	36 (92%)	3.12*	0 (0%)	12 (40%)	0 (0%)	0 (0%)	5.71**
	Learning by Changing	6 (15%)		20 (51%)			0 (0%)		0 (0%)		
	Learning by Adapting/Modifying	1 (3%)		12 (31%)			12 (40%)		0 (0%)		
Proactive Learning	Learning by Designing	0 (0%)	0 (0%)	3 (8%)	3 (8%)		16 (53%)	18 (60%)	3 (30%)	10 (100%)	
	Learning by Improved Design	0 (0%)		0 (0%)			2 (7%)		6 (60%)		
	Learning by R&D	0 (0%)		0 (0%)			0 (0%)		1 (10%)		
Total		39(100%)		39(100%)			30(100%)		10(100%)		

Note) ① Significance Level: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.
② Numbers indicate the number of firms to be concerned.

Table 8
Summarized Results of This Study

Aims	• Revealing relations between technological learning capabilities and technological performances • Identifying weather critical technological learning capabilities change according to the technological development stages or not • Investigating relations between technological learning levels/process and technology development stages
Samples	• 40 machine tool manufacturers in Korea
Methods	• In-depth interviews and survey with CEO or directors of technology development department
Measures	• Quantitative: commercial performance, technological performance, stock of technology, potential of technical manpower, top management support, systemization of technological learning, learning motivation, appropriateness of technology choice, stretched goal setting • Qualitative: intensive technical efforts, readiness to learning
Findings	• Technological learning capabilities are positively related to technological performance • Critical technological learning change according to the technological development stages • Technology development process is significantly connected with technological learning levels or process

ing that learning operates as an underlying principle. Table 8 represents summarized results of this study.

Ⅵ. *Towards a Post Catch-up Innovation*

Throughout the empirical analysis of the Korean machine tool industry, this study shows that the levels of technological learning capabilities vary along the technology development processes and that learning capabilities affect learning performance. Without the accumulation of certain capabilities, firms cannot proceed to the next stage of development. However, the Korean machine tool industry is in the catch-up era. Hence, the results of the empirical analysis are valid in the catching-up setting.

Recently, some innovative companies in Korea have accumulated technological capabilities and moved or have been trying to move toward global innovative leaders, thereby entering the post catch-up era. Choung, Hwang, and Song (2014) explained the transition process of innovation activities from the catch-up to the post catch-up modes. Good examples are selected firms in the semiconductor, automobile, steelmaking, and online game industries. They conducted a preliminary case study on new iron-making technology called FINEX, commercialized by POSCO. The shows that the following factors are promoting and facilitating successful transition from catch-up to post catch-up innovation, such as: a) strategic intent of founders and CEOs and corporate culture, b) leadership and change agents, c) design principles and routine, d) ecosystem including collaboration with partners, and e) committed resources and intensive R&D investment. Further studies are needed to elaborate the analyses and fact findings. Table 9 represents successful post catch-up innovations of FINEX by POSCO.

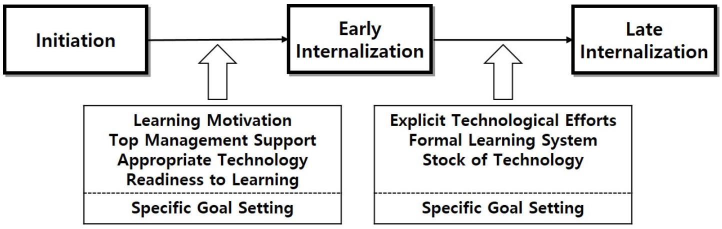
Ⅶ. *Conclusion*

This empirical study shows that the technological learning process and performance undergo a change depending on technological learning capabilities. The different learning capabilities (or influencing factors) cause the difference in technological performance among firms even though they are in the same environment and adopt the same technology. Learning capabilities are divided into nine factors: Stock of Technology, Potential of Technical Manpower, Explicit Technical Efforts, Readiness to Learning, Top Management Support, Formalization of Learning System, Learning Motivation, Appropriateness

Table 9
Successful Post Catch-up Innovation: FINEX by POSCO

Type of Innovation	• From follower to creative innovation leader • Disruptive process innovation • Cost-reduction and process-skipping
Characteristics of FINEX	• The most successful alternative iron-making process without coke and sinter • Simple, eco-friendly, and cost-competitive compared to the blast furnace
Development Period	• 1992～2004
Meaning of FINEX Development	• The first threshold crossing innovation in the history of iron making since blast furnace • The first major industrial process innovation of POSCO in 40 years of the company's history
Stages of Innovation Path	• ① Accumulated capability → ② New idea and long-term investment → ③ New competitive solutions
Key Success Factors	• Strategic intent of founders and CEOs, and corporate culture • Leadership and change agents • Design principles and routine • Ecosystem including collaboration with partners • Committed resources and intensive R&D investment.

Figure 3
Learning Capabilities as Enablers for Technology Development



of Technology Choice, and Specific Goal Setting. Pearson's correlations of these factors with technology development's commercial performance and technological performance were very high and significant. Among the factors used here, explicit technological efforts, readiness to learning, formalization of learning system, and appropriateness of technology choice are newly introduced. This learning theory points out that firms must have organizational technological learning and an accumulation system going over simple individual learning or human-embodied technology accumulation modes for learning high-level technologies more smoothly. Moreover, for successful technological learning, concrete goal setting, explicit technological efforts to reach that goal, and the construction of a technological learning system that is organized and integrated systematically that links the technological efforts to the goal, are critical.

This study supports existing research that insists on indigenous technological efforts being important to developing countries (Dahlman and Westphal, 1981), and offers another meaningful finding that learning capabilities have dynamic characteristics. The critical factors change as the development process goes on. In the early stage of technological development, top management support, learning motivation, and appropriateness of technology choice are critical influencing factors. In the late development stage, explicit technological efforts and an organizational technological learning system are more important. Conclusively, technological development in firms is guided by the technological learning process. Hence, to accomplish the development process successfully, learning capabilities are necessary for all organizations. The change in technological learning capabilities can be simplified as shown in Figure 3.

This study identifies the different roles of technological learning capabilities in promoting innovation and creativity to move along the stages of technological and economic development. Furthermore, it confirms that technological learning can be understood as an intrinsic principle of the technology development process. Proactive learning is mainly performed by firms in the late stage, while reactive learning prevails by firms in the early stage.

This study suggests a technological learning theory based on the review of related literature and preliminary case studies and analyzes the proposed theory empirically. Although it tries to identify the factors influencing the performance of technological learning, technological learning is an underlying process and is not easily observed. Therefore, more in-depth studies are required to explore the nature of technological learning. Further studies are also need to extend to a generalized theory, with a more deliberate operationalization of the variables and cross-cultural comparative studies.

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기술학습역량 강화를 통한 추격 및 탈추격 혁신 촉진*

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기술 학습, 기업가정신, 혁신, 창의성에 대한 동기 및 관련 활동은 아시아 국가들의 경제 발전의 원동력이었다. 기술 발전의 초기에는 기술 학습과 기업가정신이 선진국들을 효과적으로 따라잡을 수 있는 방안으로 작용하였다. 왜냐하면 이를 통하여 기업들은 상대적으로 낮은 리스크를 가지고 기술과 지식을 빠르게 축적할 수 있었기 때문이다. 그러나 기술 발전의 후기에는 혁신과 창의성이 보다 중요하게 작용하였다. 본 연구의 목적은 1) 기술 학습 성과에 영향을 미치는 요소들(학습 역량)과 2) 창의적인 조직 및 경제 환경 구축을 위한 혁신 역량 강화에 필요한 과제들을 규명하는 것이다.

본 연구의 핵심 내용은 탈추격 시대에서의 학습 역량과 연관되어 있다. 문헌 연구 및 한국의 경제발전 사례를 바탕으로 본 연구에서는 기술 학습에 영향을 미치는 다양한 요소들로 구성된 기술 학습 모형을 제시하였다. 이와 관련하여 세 가지 가설을 설정하였고, 한국의 공작기계 제조업체들로부터 데이터를 수집하였다. 또한 해당 업체들의 CEO들과 R&D 책임자들을 대상으로 구조화된 설문을 수행하였다. 이를 바탕으로 상관 분석과 ANOVA를 수행하여 가설을 검증하였다. 추가로 사례 분석과 정책 분석을 수행하여 혁신 활성인자와 방해인자들을 규명하였고, 이를 근거로 혁신 역량 강화를 위한 방안을 제시하였다.

실증 분석 결과를 기반으로 1) 기술 축적정도 2) 기술인력들의 잠재력 3) 확고한 기술적 노력 4) 학습에 대한 의지 5) 최고 경영층의 지원 6) 공식적인 기술 학습 시스템 7) 높은 학습 동기 8) 적절한 기술 선택 9) 명백한 목표 설정과 같은 기업의 학습 잠재력과 활동(학습 역량)을 규명하였다. 이와 같은 학습 역량은 경제 발전 초기 기업의 학습 성과를 결정하였다. 또한 기술발전 단계별로 기술학습을 위해 필요한 핵심 요소들이 상이하였다.

통계 및 정책 분석을 통하여 기술학습은 기술발전 과정의 본질적인 원칙으로 이해될 수 있음을 입증하였다. 선제적이고 창의적인 학습은 후기에, 대응적이고 모방적인 학습은 초기에 활성화 되었다.

추가로 본 연구에서는 탈추격 시대에서의 혁신역량 및 혁신활동 강화의 원동력 또는 촉진 요소를 탐색하였다. 예비 사례분석 결과는 1) CEO의 전략적 의지와 기업 문화 2) 리더십과 변화 주도 챔피언의 존재 3) 디자인 원칙과 방식 4) 에코시스템과 협력체계, 5) 지속적 R&D 투자가 혁신역량 및 혁신활동 강화의 촉진 요소로 작용함을 보여주었다.

주제어 : 기술학습, 혁신, 학습 역량, 혁신 장애물, 기업가정신

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