Human and Social Capital Explanations for R&D Outcomes

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***Abstract*—This paper assesses the extent to which human capital (education, work experience, and training) and social capital (level of interconnectedness, relationship, and shared expectations with others) impact on research and development outcomes. Controlling for gender and type of industry, logistic regression analyses indicate that an individual's education level has a positive impact on patents/copyrights obtained, articles published/presented, and product/process improvements. Hierarchical logistic regression analyses show that an individual's level of interconnectedness with others has incremental impact over one's human capital in projects completed, internal technical reports generated, product/process improvements made, and products commercialized. Explanations for the incremental value of social capital are made in terms of Nahapiet and Ghoshal's structural, relational, and cognitive dimensions of social capital.**

***Index Terms*—Human capital, research and development (R&D) outcomes, social capital.**

IN TODAY'S competitive environment, firms are under constant pressure to innovate to stay ahead of their competition [56]. One way to enhance a firm's level of innovation and research and development (R&D) outcomes is to ensure that organizational members continuously enlarge their learning activities [49], [59]. Individuals may do so through an insular learning process to add to their stock of human capital, or they may learn through a complex process of interacting with others to add to their social capital.

The personal knowledge of an individual that is accumulated through a lifetime of experience, experimentation, perceptual observation, and learning forms an important foundation for innovation [43]. However, this personal knowledge base that is contained within the head of an individual may not be sufficient for today's complex innovation process, which often requires a multidisciplinary approach [34]. Instead, an individual who is involved in a "community of practice" [12], [13] has access to the knowledge bases of others [44]. Working and interacting with others often represent knowledge creation through fusion, as a variety of views from different individuals help the person rethink his/her existing premises by looking at the problem from different perspectives [18]. This process of "creative abrasion" in which an individual combines his/her expert and tacit knowledge [61] with others facilitates knowledge creation [44], [49].

Therefore, in addition to the importance of an individual's personal and unique set of knowledge, skills, and abilities, drawing upon and/or combining the creative and intellectual skills of others when interacting together enhances the individual's R&D outcomes. Such R&D outcomes include the number of scientific papers and reports completed, patents obtained, products/process improvements made, or products commercialized [5], [23], [25]. Although Pelz and Andrews [57] and Farris [21] investigated the social-psychological factors that impact on the performance of scientists and engineers using correlational analyses, while Badawy [5] and Farris and Cordero [23] provided extensive reviews on suggestions to manage and lead R&D personnel, no empirical studies have contrasted an individual's personal knowledge base against his/her expertise obtained from working with others on R&D performance. This paper seeks to fill this gap by teasing out the separate effects of a person's human capital versus his/her social capital on R&D performance measures. Hence, in addition to assessing how and which aspects of an individual's human capital, namely, his/her level of education, work experience, and training impact on R&D outcomes, we also assess how and which aspects of an individual's social capital has incremental value beyond one's level of human capital in achieving R&D outcomes. The contribution of this study would be to provide firms and individuals with an understanding of the areas that knowledge workers need to develop their skills and capabilities on as well as to focus on ways to structure interactions with others so as to better integrate the expertise of others to enhance R&D performance.

I. Theoretical Framework

A. Human Capital Theory

The basis of human capital theory is the concept that individuals possess skills, experience, and knowledge that have an impact on their level of work productivity [8]. An individual who possesses more human capital in terms of having more education, work experience, or training acquires more relevant skills and knowledge necessary to be productive [8], [9]. Enhancing one's level of human capital is particularly critical for knowledge workers who are involved in R&D activities or among individuals who work in high-technology intensive industries because they face continuous technological advancements [56]. However, since the work of Pelz and Andrews [57], there have been few empirical studies that have investigated the impact of human capital on work performance despite constant assertions

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about the importance of human capital in R&D-intensive environments in order for firms to be competitive [11], [24]. Among the studies that have assessed the impact of human capital on work performance, the focus has been on the performance of management or non-R&D employees [30]. Hence, the following hypotheses seek to test the impact of human capital on the performance of R&D scientists and engineers to extend literature in this area.

Education is a key variable in human capital theory because it provides individuals with explicit knowledge necessary for task performance [8]. Accordingly, individuals with higher levels of education have higher levels of ability to solve problems and to learn the content of particular disciplines more effectively. As a result, Pelz and Andrews [57] found that the performance of Ph.D. scientists exceed those without Ph.D. degrees in terms of quality and quantity of R&D outputs. In a 2001 R&D salary survey conducted by R&D Magazine, the mean annual salary of researchers having Ph.D.s was $11 461 more than those with a Masters degree because of perceived and actual performance differences due to the difference in education level [63]. Hence, individuals with higher levels of education are hypothesized to be better able to achieve greater R&D outcomes compared to those with lower levels of education.

Hypothesis 1a: Education will have a positive impact on R&D outcomes.

Past studies have measured the second component of human capital, namely, work experience, in terms of years on a job [51], [62], [73]. Length of time on a job has been found to be positively related to job performance because it takes time for an individual to develop the relevant job knowledge, skills, and competencies to do one's job effectively [66], [73]. Thus, individuals who have been with a company longer than other employees are often more productive because they have accumulated work routines that would enable them to succeed on the job and be valuable to the firm [52]. Hence, a positive relationship between work experience and career success often results [39]. Although some studies have found a curvilinear relationship between age and performance [31], [57], several meta-analyses that were conducted have consistently found positive relationships between work experience and performance that ranged from a correlation of 0.18 [32] to 0.43 [62]. Although few studies have specifically investigated the impact of work experience on R&D outcomes, we hypothesize that a positive relationship would result since McDaniel *et al.* [51] found a positive mean correlation of 0.32 across a number of occupations in their meta-analysis.

Hypothesis 1b: Work experience will have a positive impact on R&D outcomes.

Training, the third component of human capital, complements education because schooling alone does not completely prepare individuals for work [8]. Learning must also occur outside of schools to include job training so that employees can acquire skills that will directly improve their work productivity [8], [72]. In occupations such as engineering, where rapidly changing technologies mean that knowledge and skill sets continuously need to be updated [38], training becomes an important means to enhance one's human capital. Hence, Bartel and Sicherman [7] found that individuals who are employed in manufacturing industries that face higher rates of technological change are more likely to receive formal company training. Likewise, Badawy's [5] review reported that most scientists and engineers receive extensive training. Some of the training programs that research scientists and engineers (RSEs) undertake include project management training [6], [25], creativity training [76], practices on good manufacturing [6], as well as leadership training [6]. The impact of job training on productivity in general has been found to have positive [42]. For example, Bartel [6] found a positive and significant effect between training and the performance ratings of science, engineering, and information systems professionals. We extend existing literature by hypothesizing that training will have a positive impact on actual R&D outcomes.

Hypothesis 1c: Training will have a positive impact on R&D outcomes.

B. Social Capital Theory

Innovation is rarely an individual undertaking but often depends upon the collective expertise of others [44]. Although individual creativity is important, participating in the knowledge creation process with others transcends one's own limited perspective. Interactions with others is not only limited to one's work team, but often includes other individuals from within as well as external to the organization [10], [28]. Since R&D activities often involve nonrepetitive tasks that are inherently ambiguous and complex [34], working with others, particularly in cross-functional teams, allow the individual to draw upon the knowledge base of others and, hence, benefit from multiple viewpoints [1], [35], [75].

An individual who interacts with others over time develops social capital as the social interaction enables the person to gain access to other people's information and resources [17], [54]. The interaction facilitates the creation and exchange of knowledge and, therefore, the development of intellectual capital by providing the individual the opportunity to integrate and coordinate his/her tacit and explicit knowledge with others [15], [17]. Thus, the productivity of R&D scientists and engineers depends upon the access into appropriate networks of information flows [2], [19]. As innovation occurs through the interaction of different tacit knowledge and experiences among different individuals [48], [61], social capital theory provides the theoretical basis for explaining the incremental value to the knowledge development process beyond a person's own capabilities when he/she interacts with others.

Nahapiet and Ghoshal describe three dimensions of social capital, namely, structural, relational, and cognitive [54]. The structural dimension of social capital refers to the overall pattern of connections or interpersonal linkages that an individual has with others [2], [15]. It depicts how individuals interact with others on task allocation, responsibilities, and authority [29], [71], as well as describes the network ties between them [67]. Network ties provide individuals with access to other people's resources and serve to reduce the amount of time and effort one needs to gather information and resources [54]. The structure of network ties affects the accessibility and ease of information exchange by expanding the range of information that may be accessed [1], [75]. Performance is enhanced by the density of the network or the relative number of ties in the network that link individuals together [64], [70], [75]. The more relationships that link one individual to another, either upward, laterally, downward, internal, or external to the organization, the stronger the social capital and the more efficient the level of communication becomes [1], [26].

As a result, Reagans and Zuckerman [64] found that R&D teams that have dense networks of interaction achieve a higher level of productivity, while Sethi and Nicholson [68] found that organizations that have structures that permit frequent contact between individuals across functional boundaries were more successful in the development of new products. Likewise, Pelz and Andrews [57] found that interactions with a variety of external or internal sources as well as the frequency with which an individual has contacts with these sources led to higher levels of scientific performance as these diverse contacts helped uncover problems, provided suggestions, or new approaches to solve problems. Farris [21] and Allen [2] also found that interactions with colleagues and increased communication have positive impacts on scientific output. Accordingly, network ties can be expected to have a positive influence on the development of intellectual capital beyond an individual's own capabilities when he/she has access to information and resources from others.

Hypothesis 2a: An individual's network ties will have a positive, incremental impact on R&D outcomes beyond the individual's level of education, work experience, and training.

The relational dimension of social capital describes the nature of relationships that an individual has developed with others, such as the quality and depth of interactions and the level of trust, friendship, and informality [53], [54]. Informal work-related communication or contact has been described as the prevailing mode of interaction in innovative companies [37], [58]. Since R&D tasks are integrative, complex, and require creativity, they are better handled through informal, decentralized structures [5]. This is because uncertainty in research outcomes often requires nonroutine problem solving and so spontaneous communication, casualness, interpersonal familiarity and an informal atmosphere of brainstorming or free association is more conducive for innovation, idea generation and creativity [14], [53], [74].

Informality also denotes friendship relations, interpersonal familiarity, social cohesion and trust [53], [69]. Where trust and friendship levels are high, people are more willing to engage in social exchange and cooperative interactions, such as confiding with another, asking for help, having spontaneous conversations and unstructured meetings, as well as sharing information, knowledge, and resources [10], [41], [54]. Harris and Lambert [29] and Van Aken and Weggeman [75] found that frequent, informal communications was positively related to R&D team effectiveness and the achievement of research outcomes. One reason is that in fast-paced research environments, informality facilitates the ease and frequent flow of communication, improves the sharing of information for decision making, enhances spontaneity, and the role of chance and serendipity necessary for knowledge creation [36]. Since informal communication networks enable individuals to work more flexibly, span more contacts and boundaries to collaborate more effectively, we hypothesize that an individual working in an informal relationship with others will have greater knowledge development outcomes beyond what he/she is capable of achieving on his/her own.

Hypothesis 2b: An individual's informal relationship with others will have a positive, incremental impact on R&D outcomes beyond the individuals' level of education, work experience, and training.

Past studies have found that setting specific goals facilitate overall performance [46]. However, McComb *et al.* [50] advanced the idea beyond goal setting to suggest that individuals involved in R&D activities need to have a shared understanding of the requirements in innovation activities so that they can have a common foundation or understanding upon which to act. For example, when individuals involved in R&D activities have a common or overlapping understanding of the organization's innovation objectives, their responsibilities toward these objectives, and the procedures they use to attain these objectives will be more coordinated as they share compatible knowledge. This shared mental framework [16] facilitates decision-making and coordination so that individuals can conduct their tasks without a continuous process of interpreting and reinterpreting the meanings and expectations of the innovation process [47]. Klimstra and Potts [40] reported that by aligning everyone's views toward a common framework based on shared expectations and agreement, higher levels of project success occurred.

The cognitive dimension of social capital refers to resources that are available to an individual from having shared expectations as team members interpret cues in a similar manner, make compatible decisions, and coordinate their actions [45], [54]. Since R&D work often involves novel tasks that are inherently ambiguous and complex [34], individuals who have a shared mental model with others can share ideas and information more efficiently and effectively [45]. As a result of having greater shared expectations and understanding, improved coordination, communication, and better R&D performance occurred [40], [55], [65]. Hence, we expect that an individual who has shared expectations with others on R&D projects will have higher levels of performance beyond what he/she can achieve on his/her own.

Hypothesis 2c: An individual's level of shared expectation with others will have a positive, incremental impact on R&D outcomes beyond the individuals' level of education, work experience, and training.

II. Methodology

A. Data Collection Process

The sampling frame was individual R&D professionals who were employed by R&D organizations in Singapore in 1997. Singapore was chosen as the research site because she is a technologically advanced country yet small enough to include every

R&D professional from every sector into the study. The National Science and Technology Board, the governing body on R&D activities in Singapore, provided us with 5605 names and designation of every R&D personnel in the country from the private sector, higher education sector, government sector, and public research institutes.

A survey questionnaire was used to collect the data given the large sample size and the need to get information in the most efficient manner. The preliminary questionnaire was pretested on ten R&D professionals to ensure that the items were well-developed, and the terms and phrases used were understood. Although 1389 usable questionnaires were obtained, representing a response rate of 24.8%, only 1109 of these responses from RSEs were used for further analyses since they were most closely associated with R&D activities. The 280 R&D administrative and clerical staff who were not directly involved in R&D activities were not included for further analyses. The average age of the RSEs who participated in the study was 31.5 years old and 17.3% were female. A nonresponse bias check using the Kolmogorov–Smirnov Z-test found no statistical difference between respondents and nonrespondents on gender at $p < .05$.

B. Independent Variables

1) Human Capital: Human capital was measured by three variables, namely, education, work experience, and training. *Education* was coded as "2" if the highest level of education attained by the respondent was a doctorate degree, "1" if the highest level attained was a masters degree, and "0" if the highest level attained was a bachelor's degree or below. The higher the level of education attained, the higher is the individual's level of human capital [8].

Years of experience was measured by the logarithm transformation of the squared value of the number of years that an individual has worked. Although a greater level of work experience generally leads to a higher level of human capital due to a greater accumulation of tacit knowledge and work routines [51], however, when value of work experience is measured in terms of number of years, Pelz and Andrews [57] reported that productivity peaked for individuals in their late 30s and early 40s due to reduced motivation and risk taking. Due to the possibility of a curvilinear effect from years of work experience on performance, a squared value was calculated. Following that, a logarithm transformation of the squared value of the number of years was made because of the wide distribution in the number of years of work experience among the respondents $(\text{mean} = 9.39, \text{s.d.} = 7.40, \text{range} = 41,\ \text{and, skewness} = 1.31)$.

Training (*Number of Training Programs Undertaken*) was measured by the summation of the number of in-house and external short courses that the individual has undertaken in his/her field of technical expertise, as well as in other related technical fields. The more training the individual has undertaken, the higher his/her level of human capital [8].

2) Social Capital: Social capital was measured by three variables that were related to the structural, relational, and cognitive dimensions of social capital, respectively [54]. Since the structural dimension of social capital refers to the overall pattern of connections that the individual has with others [15], [54], we measured these connections on four separate dichotomous activities: *support from higher levels; coordinate activities with external groups; persuade others* within the organization *to support decisions*; and *keep others* within the organization *informed about activities*. Each item is coded as "1" if the individual is linked to others on that specific activity and "0," otherwise. The more an individual is linked with others, the stronger is the individual's network ties.

Since the relational dimension of social capital describes the nature of personal relationships that an individual has with others [54], we measured the individual's perception of the degree of informality he/she has with others (*informality*) on a five-point Likert-scale. An individual who perceives a higher the level of informality working with others on R&D projects is likely to experience more positive relational social capital.

Since the cognitive dimension of social capital refers to the individual's level of perceived shared understandings, representations, and interpretations of meanings [54], we measured this variable with four five-point Likert-type scaled variables on respondents': ability to define R&D goals; effectiveness in translating broad R&D goals into operational goals; clarity on who is responsible for various parts of the R&D work; and effectiveness in setting R&D priorities. These four items were factor analysis using principal components analysis and varimax rotation. Only one factor with an eigenvalue of over 1.0 was obtained ($\text{eigenvalue} = 2.58$), explaining 64.58% of the variance. Since the reliability among the four items was high (Cronbach's $\text{alpha} = .81$), the mean value of the four items was obtained and defined as *shared expectations*.

C. Dependent Variables

R&D outcomes were assessed in two ways. First, individuals were asked to assess their perceptions of their R&D achievements in past R&D projects, as well as current ongoing projects to capture their perceived R&D achievements over a longer time frame. This perception was assessed using five five-point Likert-type scaled items on the respondent's perceptions of his/her following achievements: contribution to scientific and technical knowledge; reputation as an outstanding professional; making significant scientific discovery; making significant inventions; technological innovations and breakthroughs; and finally, publishing results of significant research findings. These five items were factor analyzed using principle component analysis with varimax rotation. Only one factor with an eigenvalue of more than 1.0 was obtained ($\text{eigenvalue} = 3.08$), explaining 61.5% of the variance. Since the Cronbach's alpha for the five items is 0.84, indicating a high level of reliability for this perceptual scale, the mean value of these five items was obtained and named *perceived R&D achievements*.

Another set of R&D outcomes was assessed by six dichotomous measures of actual R&D outcomes that the respondents achieved in the last 12 months: *projects completed*; *internal technical reports* generated; *patents/copyrights obtained*; *articles published* in professional journals/*presented* at symposia and technical conferences; *product/process improvements* made; and *products commercialized*. Due to the strategic and sensitive nature on some of these R&D outcome measures and to encourage the respondents to participate in the study,

TABLE I
CORRELATION MATRIX

Variable	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Perceived R&D Achievements	3.79	.77														
2. Project Completed	.65	.48	.01													
3. Internal Technical Reports	.21	.41	.03	.27**												
4. Patents/Copyrights Obtained	.29	.46	.28**	.10*	.10**											
5. Articles Published/Presented	.41	.49	.46**	-.02	.10**	.46**										
6. Product/Process Improvements	.45	.50	.10*	.30**	.16**	.09*	-.17**									
7. Products Commercialized	.34	.47	.09*	.24**	.15**	.27**	.02	.36**								
8. Education	.64	.81	.34**	-.04	.04	.33**	.52**	-.17**	.06							
9. Years of Experience	3.82	1.73	.07*	.01	-.01	.12**	.14**	.02	.09*	.28**						
10. Number of Training Programs Undertaken	2.40	1.50	.04	.03	-.09*	-.10*	-.27**	.06	-.03	-.12**	-.04					
11. Support from Higher Levels	.59	.49	.10**	.16**	.17**	.08*	.11**	.10**	.18**	.13**	.11**	.06*				
12. Coordinate Activities with External Groups	.43	.49	.04	.08*	.03	.10**	.05	.15**	.14**	-.01	.08**	.06*	.34**			
13. Persuade Others to Support Decisions	.20	.40	.02	.11**	.15**	.02	.04	.17**	.19**	.05*	.10**	.03	.28**	.34**		
14. Keep Others Informed about Activities	.33	.47	.09**	.16**	.10*	.04	.07*	.13**	.18**	.02	.09**	.04	.39**	.42**	.44**	
15. Informality	2.77	1.09	.01	.08*	.09*	-.01	-.06	.10*	.08*	.01	.08**	.04	.04	.02	.05*	.04
16. Shared Expectations	3.71	.65	.25**	.02	.06	.08*	.07*	.07	.08*	.13**	.10**	.03	.14**	.13**	.14**	.17**
17. Gender	.83	.38	.05*	.04	.03	.13**	.03	.03	.10**	.10**	.06	-.05*	.03	.04	.04	.01
18. Industry	.54	.50	-.27**	.07	.01	-.24**	-.60**	.25**	.11**	-.40**	-.11**	.08**	-.07*	.01	.03	.03

	15	16	17
16. Shared Expectations	.14**		
17. Gender	.04	.08**	
18. Industry	.09**	-.13**	.03

** Correlation is significant at the 0.01 level (1-tail test)
* Correlation is significant at the 0.05 level (1-tail test)

respondents were not asked to provide the actual numbers to the above six categories of R&D outcomes. Instead, the respondents indicated a "1" or "0" for each of the six measures to indicate if they had or had not attained any such achievements in the last 12 months. The reason for having a perceptual as well as a set of actual measures of R&D performance is to allow respondents the opportunity to include their assessments of ongoing projects for which they have yet to attain any actual R&D outcomes.

D. Control Variables

Gender is included as a control variable because the research opportunities accorded to women in R&D facilities in Singapore have not been ascertained before and may be skewed due to their fewer numbers (17.3%). *Gender* is coded as "0" for females and "1" for males. The nature of the industry in which the individual works is also selected as a control variable because most of the manufacturing companies in Singapore are assembly plants of American, European, and Japanese origin, which may provide fewer opportunities for R&D activities compared with home-grown service-related companies. *Industry* is coded as "0" for service and "1" for manufacturing sectors.

E. Statistical Analyses

Controlling for gender and the type of industry, hierarchical multiple regression analysis was conducted to assess the extent to which human and social capital variables had differential impact on *perceived R&D achievements*. Similarly, hierarchical logistic regression analyses were conducted for the six dichotomous R&D outcomes.

III. RESULTS

Table I shows the means, standard deviations, and intercorrelations among the variables in the study. Due to the relatively mild relationships among the six dichotomous R&D outcome variables similar to the results found in Farris [22], these six measures of R&D performance were kept separate.

Since *perceived R&D achievements* is derived from five Likert-scaled items, the Harman 1-factor test [27], [60] was conducted to assess the degree of common method variance between this dependent variable with the four Likert-scaled items that measured the independent variable, *shared expectations*. The Harman 1-factor test uses the factor analysis method of principal components analysis with varimax rotation. If the items related to the independent variables are not loaded onto the items that are related to the dependent variable, this indicates that there is minimal common method variance. The results are shown in Table II. Two factors were found after rotation. The five items related to *perceived R&D achievements* were loaded onto one factor, while the four items related to *shared expectations*, were loaded onto the second factor. Hence, common method variance between *perceived R&D achievements* and *shared expectations* is minimal.

Controlling for *gender* and *industry*, hierarchical multiple regression analysis was conducted to assess the impact of the human capital variables on *perceived R&D achievements* to test the relationships stated in Hypotheses 1a–1c. The results are shown in Model 1 of Table III. None of the independent variables reported a VIF of over 2.0, indicating no serious multicollinearity among the independent variables. *education and number of training programs undertaken* have significant impacts on *perceived R&D achievements* at $p < .01$ and $p < .05$, respectively, giving support to Hypotheses 1a and 1c. *Years of experience* has a statistically negative impact on *perceived R&D achievements* and so Hypothesis 1b is not supported.

Where the six actual R&D outcomes are concerned, the results from the hierarchical logistic regression analyses in Table III show that none of the human capital variables has any statistical impact on *projects completed, internal technical reports*, and *products commercialized*. Among the human capital

TABLE II
HARMON 1-FACTOR TEST BETWEEN ITEMS RELATED TO PERCEIVED R&D ACHIEVEMENTS AND THE COGNITIVE DIMENSIONS OF SOCIAL CAPITAL

	Rotated Component Matrix	
Make significant scientific discovery	.87	
Publish results of significant research	.82	
Make significant inventions/technological innovation/breakthroughs	.80	
Contribution to scientific & technical knowledge	.75	
Establish a reputation as an outstanding professional	.62	
Effective in translating broad into operational R&D goals		.83
Effective in setting R&D priorities		.81
Able to define R&D goals		.80
Clear who is responsible for various parts of the R&D work		.75

TABLE III
LOGISTIC REGRESSION ANALYSES ON R&D OUTCOMES

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	Perceived R&D Achievements+	Projects Completed	Internal Technical Reports	Patents/ Copyrights Obtained	Articles Published/ Presented	Product/Process Improvements	Products Commercialized
Control Variables							
Gender	.03	.14	.06	.82*	-.26	.19	.64*
Industry	-.13**	.13	-.05	-.65**	-2.45**	.77**	.67**
R^2 Change	*7.4%***	*.4%*	*.1%*	*8.6%***	*31.7%***	*5.5%***	*2.3%***
Human Capital Variables (1-tail test)							
Education	.28**	-.10	-.04	.69**	.98**	.27*	.20
Years of Experience	-.05*	-.06	-.08	.01	-.02	.04	.07
Number of Training Programs Undertaken	.07*	.02	-.12	-.03	-.31**	.01	-.06
R^2 Change	*6.9%***	*.1%*	*.5%*	*5.2%***	*8.3%***	*.7%*	*2.1%*
Social Capital Variables (1-tail test)							
Support from Higher Levels	.02	.67**	.90**	.15	.10	.31	.55**
Coordinate Activities with External Groups	-.01	-.13	-.36	.46*	.20	.28	.06
Persuade Others to Support Decisions	-.06*	.06	.57*	-.03	.26	.44*	.39
Keep Others Informed about Activities	.07*	.61**	.13	-.12	.45	.10	.31
Informality	-.01	.12	.21*	.01	-.13	.12	.07
Shared Expectations	.20**	-.02	.11	.13	.25	.18	.14
R^2 Change	*4.4%***	*5.4%***	*5.4%***	*.9%*	*1.3%*	*4.0%***	*4.7%***
Total R^2	*17.8%***	*5.9%***	*6.0%***	*14.7%***	*41.3%***	*10.2%***	*9.1%***

+ hierarchical multiple regression analysis
* p<.05; **p<.01

variables, *education* has significant impact on *patents/copyrights obtained* and *articles published/presented* at $\text{p} < .01$ and *product/process improvements* at $\text{p} < .05$, giving partial support to Hypothesis 1a. *years of experience* has no significant impact on any of the six actual R&D outcomes at $\text{p} < .05$, while *number of training programs undertaken* has a statistically negative impact on *articles published/presented*, giving no support to Hypotheses 1b and 1c, respectively. Hence, taking perceptual and actual R&D outcomes as a whole, there is some support for Hypothesis 1a, no support for Hypothesis 1b, and mixed support for Hypothesis 1c.

Model 1 in Table III shows that social capital had a significant incremental impact over human capital on *perceived R&D achievements* $(\Delta R^2 = 4.4\%, \text{p} < .01)$. Specifically, the respondents perceived that the cognitive dimension of social capital in having *shared expectations* has positive and significant impact on *perceived R&D achievements* at $\text{p} < .01$, providing support for Hypothesis 2c. However, the relational dimension of social capital, *informality*, has no statistical impact on *perceived R&D achievements* at $\text{p} < .05$, providing no support for Hypothesis 2b. There was mixed support for Hypothesis 2a regarding the impact of the structural social capital variables on *perceived R&D achievements*.

Where actual R&D outcomes are concerned, Table III shows that an individual's social capital has statistically significant incremental impact over one's human capital on *projects completed* $(\Delta R^2 = 5.4\%)$, *internal technical reports* $(\Delta R^2 = 5.4\%)$, *product/process improvements* $(\Delta R^2 = 4.0\%)$, and *products commercialized* $(\Delta R^2 = 4.7\%)$ at $\text{p} < .01$. An individual's social capital has no statistically significant incremental impact over his/her human capital on *patents/copyrights obtained* and *articles published/presented* at $\text{p} < .05$. Table III indicates some support for Hypothesis 2a for the actual R&D measures as the structural dimension of social capital, *support from higher levels* has significant impact on *projects completed*, *internal technical reports*, and *products* *commercialized* at $p < .01$. The ability to *coordinate activities with external groups* has significant impact on *patents/copyrights obtained* at $p < .05$, while the ability to *persuade others to support decisions* has significant impact on *internal technical reports* and *product/process improvements* at $p < .05$. Finally, to *keep others informed about activities* has significant impact on *projects completed* at $p < .01$. The relational dimension of social capital, *informality*, has significant impact only on *internal technical reports* at $p < .05$, providing marginal support for Hypothesis 2b for actual R&D outcomes. Finally, the cognitive dimension of social capital, *shared expectations*, has no significant impact on any of the six R&D outcomes at $p < .05$, providing no support for Hypothesis 2c for the actual R&D measures.

In general, the impact of human capital and social capital have opposite effects on actual R&D outcomes, i.e., where human capital has significant impact on *patents/copyrights obtained* and *articles published/presented*, social capital has no significant incremental impact over human capital on these R&D outcomes. Conversely, where human capital has no significant impact on *projects completed*, *internal technical reports*, *product/process improvements*, and *products commercialized*, social capital has significant incremental impact on these R&D outcomes.

IV. Discussion and Implications

The results indicate that among the human capital variables, education has the greatest positive impact on R&D performance. This result is consistent with Pelz and Andrews's [57] report on the positive impact of education on scientific performance. Where complex and nonroutine knowledge work such as R&D activities are concerned, education provides the foundation for individuals to add on new knowledge and integrate other fields of knowledge to their existing knowledge base as technological requirements change.

The number of years of work experience did not have a positive impact on any measure of R&D performance. Even after transforming the value of work experience to account for possible curvilinear effects from a peak in productivity due to age [57], the results suggest that the value of years on the job diminishes quickly for knowledge workers. With rapidly changing technologies, time-based measures of work experience did not provide value to an individual doing complex research activities. Respondents perceived that the number of years of work experience had a negative impact on R&D achievements, indicating that an individual who does similar activities over a long period may find it more difficult to look at research problems from new angles, thus limiting his/her opportunities to achieve scientific breakthroughs. The reliance on past work routines and the entrenchment of past work behaviors may stifle an individual's level of creativity in R&D activities. Future research should consider defining work experience in terms of variety, depth and breadth of tasks and responsibilities, and also consider the effects of job-specific, firm-specific, occupational-specific, and general work experience on innovation outcomes [62], [73].

Although the respondents perceived that the number of training programs that they have undertaken contributed to their R&D achievements, the logistic regression analyses on actual R&D outcomes found the opposite effect. Undergoing many training programs may give knowledge workers a sense of confidence and security that they would be better able to cope with technological changes when such events happen. Hence, they feel positive about attending training programs. However, the results indicate that attending training programs had a negative impact on actual R&D performance. Perhaps by taking time away from R&D activities to attend project management and other nontechnical management training programs to manage the innovation process [5], [23] interfere with their research work. Hence, future research should measure the impact of different types of training programs on R&D performance.

The results on social capital show that an individual who was more integrated with others at the upper echelons or within the organization has significantly greater incremental R&D achievements. The ability to coordinate activities with external groups did not lead to any significant impact on actual R&D outcomes, contrary to Bouty's [10] findings. Only network ties and interactions within the organization have positive impacts on R&D outcomes. Since innovation projects and activities are very firm- and assignment-specific, interactions and network ties with other professionals outside of one's organization for the purpose of sharing expertise appears to have limited incremental value in R&D outcomes required by the organization. Future research should investigate the differential impacts between internal and external networks on R&D outcomes.

Informal relationship with others has very marginal impact on actual R&D outcomes, contradicting reports from past studies [29], [36], [75]. Having an informal personal relationship with others may give individuals some leeway in extending deadlines for or receiving help in completing internal technical reports. However, the individuals in this study did not find that having informal personal relationships significantly stimulated innovation through the informal learning process. This finding is similar to Andrews's [3] study in which he found that communication had little or no effects on innovative outputs. Future research should evaluate other dimensions of personal relationships that is conducive to R&D performance.

The results on the cognitive dimension of social capital found that individuals who have shared expectations with others perceived the sharing of research objectives and understandings to have a positive impact toward achieving greater R&D performance. However, the logistic regression results on actual R&D outcomes did not find any significant impact, contradicting past findings [45], [47], [50], [65]. The results suggest that a positive bias in evaluating one's work performance occurs when a person has a higher degree of agreement with others. Individuals tend to report more positive performance outcomes in self-report measures due to a perceived supportive and positive environment [20]. The lack of an incremental impact from having shared expectations on actual R&D outcomes is in line with Ayers *et al.*'s [4] findings. They found that having shared expectations led R&D teams to seek concurrence at the expense of new product success, falling into the trap of groupthink [33] as teams minimize argument, conform to majority views, and shield team members from adverse information.

The positive and significant incremental impact of social capital on projects completed, internal technical reports generated, product/process improvements, and products commercialized suggest that working with and through others help individuals perform better in attaining R&D outcomes that are within the control of the individual. Individuals can be kept up-to-date on emerging opportunities, as well as provide each other with expertise that one lacks. The ability of individuals to leverage their own capabilities depends in some part on how well, to whom, and from whom they exchange information with. Since obtaining patents/copyrights and publishing/presenting articles are outside the control of the individual's immediate contacts, social capital plays no significant part in attaining such outcomes. The contribution made by this paper is to clearly show that social capital is the contextual complement of human capital, an area that was not tested previously.

Since the data was collected from a sample of RSEs in Singapore, the study needs to be replicated with samples from other subpopulations to test for generalizability. A second limitation of this study is the way in which the actual R&D outcome was measured as a dichotomous variable. Future studies should assess the actual number of R&D outcomes that the individual has achieved for each category of R&D activity. In addition, since the respondents returned the questionnaire anonymously, we were not able to check on the reliability of the data on actual R&D achievements provided by the respondents. A fourth limitation of the study is the single-item measure for the relational dimension of social capital. Future studies should include other personal relationship items related to the level of trust, friendship, and identification that the respondents have toward those they work with. A fifth limitation is the inability to conclude on the direction of causality for the relationship between human and social capital and R&D achievements because of the cross-sectional nature of the study. In doing a longitudinal study, Farris [21] found that R&D performance led to greater levels of contact with others and other social-psychological factors. Hence, it is likely that individuals who have greater levels of R&D performance would have more opportunities to add to their future stock of human and social capital. Finally, the overall variance explained in this study, though statistically significant, is relatively small. One possible reason is due to the crude way in which the R&D measure was obtained as a dichotomous variable. However, we argue that in real dollar terms, an improvement of 4%–6% for each category of actual R&D outcome may translate into millions of dollars for technology-intensive firms, which would represent a real and significant impact for the firm.

This study shows that education has the greatest impact on R&D outcomes as the human capital variable, while the structure in which one interacts with others has the greatest impact on R&D outcomes as the social capital variable. In attempting to tease out the human and social capital effects on R&D performance, we showed that human and social capital complement each other as each have unique and distinct impacts on R&D outcomes, providing a contribution to existing literature.

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