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여러 공급업체와 공동개발에서의 협업전략과 제품개발 성과

홍 윤 숙[†]
울산대학교 경영대학 경영학부

Collaboration Management Strategies and Product Development Performance

Yunsook Hong

■ Abstract ■

In collaborative product development with multiple suppliers, buyers must manage the suppliers' activities. This empirical research investigates the performance impacts of three strategies that buyers use to manage suppliers who design interdependent components. These strategies are: Instructionism (giving clear instructions to suppliers), Teaming (forming an interactive development team with suppliers), and Delegation (transferring component development responsibilities to suppliers). Data were collected through a cross-industry web-based survey of buying firms in manufacturing industries whose products require multiple, interdependent components. A path analysis utilizing 318 survey responses indicates that Instructionism has a positive effect on design quality, and Teaming has a positive effect on design quality and component innovation. The use of Delegation is not related to any of the performance indicators.

The practical implication of this research for product development managers is that both Instructionism and Teaming can be effective strategies. For the purpose of assuring design quality, a buyer should give clear instructions in detailed specifications or work closely with suppliers in development teams. If competitive priority is product innovativeness, however, the buyer should work closely with its suppliers during component development processes using a Teaming strategy.

Keywords : Collaborative Product Development, Supplier Involvement, Collaboration with Multiple Suppliers, Design Quality, Product Innovation

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† 교신저자 yhong@ulsan.ac.kr

1. Introduction

In an effort to develop better products faster, and at a lower cost, manufacturers have shifted the responsibility for component design from their own organizations to those their suppliers. For example, suppliers-developed many of the 787 Dreamliner's components, a shift from the past when Boeing typically designed 70% of components [70]. Empirical studies report benefits from increasing suppliers' responsibilities for development, including faster development [26, 44], better designs [79], more innovation and higher quality [35], and overall project success [53, 55, 61]. However, increasing a supplier's role in development is not without risks as Toyota learned from its massive recall attributed in part to an accelerator produced by one its suppliers [24]. Collaborating with multiple suppliers in product development requires managing individual suppliers' involvement as well as coordinating component development processes across multiple suppliers. The buyer must ensure that each supplier's component meets the end product's requirements and that the components fit together and function as required in the component system. For example, when designing a car door, the auto assembler must consider the interface among the wiring harness, window, seal, and other mechanisms designed by suppliers [32].

From the information-processing theory perspective, product development is viewed as a transformation process in which market and technical information is turned into new products through a series of complex, non-linear, and interrelated decisions [20, 45]. As the responsibility of component development moves to suppliers, the complexity of the product development process increases [2]. Information-processing and decision-making must occur not only within the buyer's organization but also dyadically with the suppliers, furthermore across the suppliers to ensure the compatibility of the components into an assembled end product. The fact that many component development projects nowadays involve learning from suppliers, who tend to be more knowledgeable about component technology than a buyer is, makes the inter-organizational learning theory a relevant framework to apply. This paper uses the information-processing theory [16, 20, 21, 78] and inter-organizational learning theory [31, 74, 76] as theoretical framework for understanding collaborative product development with multiple suppliers.

Ultimately, it is the buyer's responsibility to manage these collaborative activities and decision-making across multiple organizations to ensure that product development goals are met. Hong, Pearson, and Carr explained various approaches buyers could take for managing the complex information-processing and decision-making processes in collaborative product development with multiple suppliers [30]. Some buyers give very specific instructions to suppliers to reduce further information-processing, while other buyers work very closely with suppliers in teams [38]. Some delegated the responsibility to ensure the component compatibility to first-tier suppliers [12]. Ro, Liker, and Fixon report how the U.S. Auto industry uses product modularity as a way to achieve supply chain coordination [64]. However, most empirical research studies on collaborative product development have been limited to crossfunctional integration within a firm [1, 28, 69] and to the buyer-supplier integration [32, 20, 38, 63, 82], with the exception of a few studies that looked at supplier–supplier interfaces [29, 81]. This research addresses this gap in the literature by empirically examining the effects on product development performance of different collaboration management strategies that buyers use to ensure coordination among first tier suppliers who develop interdependent components.

My research objective is to understand how various approaches for managing suppliers' interdependent product development activities affect product development performance. Independent variables are the collaboration management strategies buyers use in managing two interdependent suppliers. For the dependent variables, product development performance will be examined in multiple dimensions, in order to investigate possible trade–offs in choosing collaboration management strategies.

2. Management Strategies

This section defines and describes three strategies that buyers can use to manage the product development activities across suppliers : Instructionism, Teaming, and Delegation. Buyers may choose to use these approaches singularly or together. Applying the information–processing theory and interorganizational learning theory, hypotheses will be developed regarding the effects of the three strategies on product development performance outcomes, namely design quality of the developed products, innovation of the components, and development speed. The scope of this discussion is limited to managing collaboration with two different first tier suppliers who develop interdependent components. This unit of analysis was chosen so that operational definitions and empirical measures would not be affected by product types or the size of the supply base. End product level performance metrics such as time–to–market or market share are not included because of the focus on two interdependent components at the component level rather than the overall end–product level.

2.1 Instructionism

In the project management literature, Instructionism is defined as a project management approach in which actions and policies are determined *ex ante* [57]. Adapting this definition to the research scope of collaborative component development, Instructionism in this research is defined as a collaboration management strategy in which the buyer makes as many design decisions as possible to provide interdependent suppliers with an explicit set of comprehensive detailed specifications for each interrelated component [38, 49]. When describing a buyer's management of a single supplier this strategy has been called as a "white–box" approach [56] and detailed control parts [13, 20]. Careful pre–planning and centralized decision–making by the buyer reduces the need for direct communication and information sharing between the buyer and suppliers and among suppliers.

Instructionism allows the buyer to maintain tight control over a product's design [46]. A product's system–level quality is different from component–level quality [28]. Because buyers are closer to the customers than their suppliers are, they have a better understanding of the product's overall quality requirements. Thus, the buyer can design the components and their interface in a way that best meets the end consumer's quality requirements. Centralized decision-making and attention to a product's requirements during the planning stage should increase the design quality of the component system.

Development speed also is likely to be positively influenced by the use of Instructionism. Clark [14] attributed the Japanese lead-time advantage in new car development in part to supplier component design, which allowed design to be done concurrently by the buyer and its suppliers. Provided the buyer has the engineering expertise and technical understanding of the components, Instructionism is likely to be faster than coordinating design activities across multiple suppliers.

Instructionism, however, may stifle innovation because of the low level of interaction among suppliers and the buyer's centralized decision-making [19, 75]. Suppliers have fewer chances to share their ideas [46] and the buyer misses opportunities to learn from suppliers. The supplier's production costs may increase because the buyer doesn't understand the supplier's processes. Clark and Fujimoto [14] confirmed that relative to their Japanese counterparts, U.S. automakers component costs were higher because of less supplier involvement in design.

Hypothesis H1a : Instructionism is positively associated with design quality of the two-component system.

Hypothesis H1b : Instructionism is negatively associated with component innovation.

Hypothesis H1c : Instructionism is positively associated with component development speed.

2.2 Teaming

In a Teaming strategy a buyer works with interdependent suppliers to jointly design components. Tasks are not specified in detail in advance, but are broadly specified and become more detailed as the development process progresses. A buyer using the Teaming strategy forms 'gray-box' arrangements with each of the suppliers [48, 35], and the buyer and its suppliers work together interactively. With Teaming, the buyer and suppliers communicate frequently increasing information-processing capabilities. Techniques for this strategy include using inter-organizational team meetings, guest engineers, co-location of suppliers' engineers, and early supplier involvement [35, 46, 48]. For example, Cadillac had supplier representatives on 75 percent of its development teams, and Boeing co-located suppliers in its manufacturing facilities [52]. Toyota interacts heavily with its suppliers of critical parts and designed critical components on Toyota's CAD system [40].

The Teaming strategy should have a positive impact on component system design quality and component innovation. Through close interaction, buyers and suppliers collaborate and work together. Guest engineers and inter-organizational teams facilitate effective problem solving and the integration of expertise that should enhance component quality and innovation [46]. Many studies show a significant positive relationship between innovation and intense communication [3, 4, 7, 11, 35, 54, 74].

Teaming is likely to have a negative influence on component development speed. If frequent reviews and reworks turn to excessive iterations between development stages, development time may increase as Ahmadi et al. [2] learned from their simulation study. Liker and Choi [40] reported that Team manufacturers like Toyota and Honda take time to teach suppliers their methods of doing business and to understand how suppliers work. These processes, though valuable, can take time.

Hypothesis H2a : Teaming is positively associated with design quality of the two-component system.

Hypothesis H2b : Teaming is positively associated with component innovation.

Hypothesis H2c : Teaming is negatively associated with component development speed.

2.3 Delegation

In the Delegation strategy the buyer delegates the coordination responsibility to capable suppliers who ensure that their components are compatible and fit with other suppliers' components. With the transition to modular systems, some suppliers take on the role of a systems integrator who coordinates the activities with the buyer and with of all of the suppliers involved in module design [12, 63].

The Delegation strategy increases the probability that the component system may not meet the quality requirements of the end product. Information used in technical problem solving is costly to acquire, transfer, and use in a new location [78]. Most technical failures of new products result from problems with sharing information and knowledge between organizations [59]. In addition, suppliers are likely to focus on optimizing their components rather than the end product. It is often necessary to accept suboptimal design at the component level in order to achieve product-level quality, for instance sacrificing durability to meet weight requirements. Even if suppliers try to consider all the technical influences to and from other components and component systems, those influences are often undetectable without putting together the final product [28].

At the component level, delegation allows suppliers to design their own components. Because they are more likely to be familiar with the technology for their components than the buyer is, the supplier is likely to be more innovative in design. In fact, suppliers are viewed as a source of innovation at the component level [46].

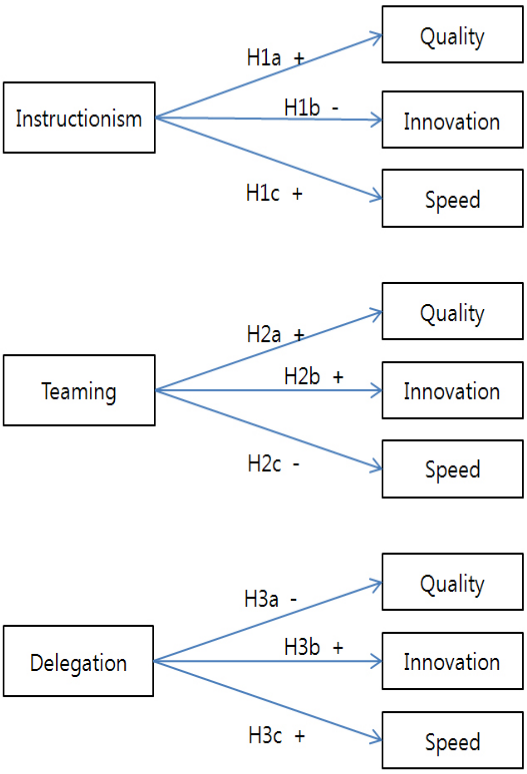
Delegation may improve component development speed because of suppliers' technical knowledge and expertise. Process development may start early, even concurrently with component development [72]. When suppliers have some autonomy from the buyer, the resulting component design will likely reflect the suppliers' production considerations [36] reducing problems during production ramp-up. While suppliers' engineers design components, buyers' engineers can focus on product design thus the overall development effort may be more efficient.

Hypothesis H3a : Delegation strategy is negatively associated with design quality of the two-component system.

Hypothesis H3b : Delegation is positively associated with component innovation.

Hypothesis H3c : Delegation is positively associated with component development speed.

The [Figure 1] summarizes the hypothesized paths.



[Figure 1] Conceptual Model with Research Hypotheses

2.4 Control Variables

To reduce error variances in the models, four component level control variables were used : Component modularity, Component technology newness, Suppliers' technical capabilities, and Suppliers' commitment to the buyer. Although outside of the scope of the research interest, these variables are expected to influence the dependent variables as explained below, thereby the need to control for them by using them as independent variables. Modular design reduces the need for coordination by standardizing the interface between components [64, 65], so delegation may be more effective when designs are modular. Suppliers' technical capabilities can affect design quality and development speed [13, 27, 32]. The newness of technology used for the component and its production can affect design quality and component innovation [9, 18, 34, 71]. The suppliers' cooperative attitude toward the buyer can affect on-time performance [33, 60].

3. Research Method

3.1 Research Context and Unit of Analysis

The unit of analysis entails a situation where a buyer works with two different suppliers who provide interdependent components. For many products, key interdependences among components are limited to two suppliers, for example, a bottle and its closure, a piston and ring, value and cover, hose and bracket, and hood and grill. Using this unit of analysis, we avoided comparing situations in which the number of suppliers being coordinated differed greatly. The respondents were instructed to select two equally important components that have some level of interdependencies in terms of functionality, physical dimensions, material requirements, or thermodynamic influence. The respondents reported short descriptions of the two components they selected, and the researchers reviewed the components to make sure that the selected components met the interdependency and equal importance requirements. The respondents were in buyer organizations, and suppliers were not surveyed.

3.2 Operational Definitions and Measures

The independent variables in this research are the three strategies : Instructionism, Teaming, and Delegation. Measurement scales were developed based on the literature and existing scales were modified for this study. The sources of measurement items and the actual survey questions used are shown in appendix <Table A-1>. Some items were expected to differ for each of the components. For those items, respondents answered the same question for each component. Most items were measured using 7-point Likert scales. Item 15 was a quantitative measure, which helps supplement perceptive measures

The Instructionism is manifested by the extent of using physical specifications as opposed to performance specifications [38], giving explicitly defined tasks to suppliers, and maintaining decision-making authority for most of the design decisions [20]. Teaming is manifested by the extent of using joint design teams [1], using inter-organizational meetings [16, 23], frequently communicating [28], involving suppliers early [36], supplier engineers' working at manufacturer's facility (quantitative measure) [12], and frequently evaluating component compatibility [1]. Delegation is manifested by the extent of giving suppliers the responsibility to ensure component compatibility [12], and giving autonomy to suppliers to make design decisions.

Dependent variables in this study are design quality for the two-component system, component innovation, and component development speed. Appendix <Table A-2> shows the sources of the measures and the actual survey questions. Design quality was measured using a two-item scale asking respondents to compare the developed component system (the sub-assembly of two developed components) to competitor's products in terms of 1) conformance to system-level specifications and 2) performance quality, i.e, functional excellence [22]. Component innovation was captured using a two-item scale measuring the significant improvements achieved in the functionality of the component and in its production process [36, 54, 68]. Component development speed was measured with a three-item scale examining development time compared to expected, development leadtime compared to competitors, and the percent of on-time completion of suppliers' tasks (quantitative measure) [26].

A three-item scale measuring the ease of component replacement, the ease of specifying the interface between the two components, and the modularity of product architecture measured component modularity. Component technology newness was measured using a two-item scale that addressed how new the technologies were to the suppliers with respect to the components' features and functions (quantitative) and their manufacturing technologies. Supplier commitment to the buyer was measured using a two-item scale addressing uncooperative behaviors and the priority of the buyer to the supplier. Suppliers' technical capabilities were measured by asking the buyer if the suppliers were fully capable of designing the components to manufacturer's specifications.

To ensure content validity, seven researchers, two purchasing managers, and one engineer reviewed the survey instrument. They commented on the clarity and completeness of the survey questions. Based on their feedback, some wording and organization changes were made to the questionnaire.

3.3 Data Collection

Empirical data were collected, in U.S.A., through a cross-industry web-based survey of buying firms in manufacturing industries whose products require multiple, interdependent components. Targeted industries are those that typically practice supplier involvement for developing their assembly-type products. Included in the sample are : transportation equipment manufacturing (NAICS 336), machinery manufacturing (NAICS 333), computers and electronic product manufacturing (NAICS 334), electrical equipment, appliance, and component (NAICS 335), medical equipment and supplies manufacturing (NAICS 3391), furniture and related product manufacturing (NAICS 337), and fabricated metal product manufacturing (NAICS 332). I obtained email addresses of potentially qualified professionals from three professional associations (Product Development and Management Association (PDMA), the Council of Supply Chain Management Professionals (CSCMP), and the Society of Automotive Engineers (SAE) and two commercial list sellers' databases (Lead411.com, and Discount-list.com). To ensure that they were knowledgeable about their firms' supplier integration practices and product development project operations, the individuals targeted were in middle-to high-level management positions in their organizations. I screened by job titles to include supply chain manager, purchasing manager, project managers, senior engineers, directors, or vice presidents. However, it was not feasible to identify, in advance, those professionals who had recent experience in working with at least two suppliers for developing interdependent components. In fact, when people replied to the invitation email to indicate their decisions not to complete the questionnaire, the most frequently-mentioned reason was that their companies had not encountered a situation in which they worked with multiple suppliers for product development. Other reasons included a non-disclosure company policy; the requested information was outside of the person's expertise; and no time to complete the survey.

Potential respondents were invited to participate by email with a web-link to a survey. A reminder email was sent in two weeks, followed by a third email reminder. Invitation emails were sent to over ten thousand potential respondents. Of those who received the invitations, 1,428 clicked on survey link (7% clicks). Of those clicked on the survey after reading the study description and eligibility requirements, 328 individuals submitted completed responses (23%), and 318 responses were usable (22%). This response rate was not unusually low, given that only small percentage of the initial potential respondents may have been qualified to participate in the study, and that the questions asked for very extensive information on specific development project operation and actual development performance [17]. The final sample's characteristics are summarized in <Table 1> with respect to industries, respondents' job titles, and size of the firms. Approximately 50% of the respondents' firms have more than 1,000 employees, and approximately 50% have annual sales of over $1 billion.

〈Table 1〉 Sample Profile(N = 318)

Industry Description	Percent
Transportation Equipment Manufacturing	38.1%
Computer and Electronic Product Manufacturing	13.5%
Electrical Equipment, Appliance, and Component Manufacturing	12.3%
Machinery Manufacturing	9.4%
Fabricated Metal Product Manufacturing	6.0%
Medical Equipment and Supplies Manufacturing	6.0%
Aerospace Product and Parts Manufacturing	4.7%
Furniture and Related Product Manufacturing	1.6%
Semiconductor and Other Electronic Component Manufacturing	1.3%
Chemical Manufacturing	1.3%
Plastics and Rubber Products Manufacturing	0.6%
Job title	**Percent**
Senior Engineer	16%
Project Manager	15%
Vice President	14%
Engineer	11%
Director	11%
Executive	6%
Supply Chain Manager	5%
Purchasing Manager	5%
Product Manager	4%
Engineering Manager	2%
Senior Buyer	2%
Commodity Manager	2%
General Manager	2%
Other	3%

Number of Employees of Respondents' Companies	Percent
1~20	7%
21~100	11%
101~500	18%
501~1,000	10%
1,001~10,000	20%
10,001~100,000	23%
Over 100,000	6%
Missing	5%
Total	100%

All of the 318 usable responses were received within two months. We compared very early respondents (132 responses received within two days) and very late respondents (80 responses received after twenty days) on multiple demographic characteristics and all the variables used for the path analysis [6]. Two sample t-test procedures indicated that early responses and late responses were not statistically different with respect to respondents' knowledge level, product complexity, and ten variables used in the analysis. However, early respondents reported higher levels of revenue, number of employees, and Teaming than late respondents. This difference may reflect that larger organizations are more likely to work with suppliers and attempt to involve them in product development, therefore were more interested in the research topic.

Because independent variables and dependent variables were measured in the same questionnaire Harman's one-factor test was performed to check for the existence of common method variance [58]. All independent and dependent variables were analyzed in an exploratory factor analysis to examine if there is a substantial amount of method variance was present across constructs. Only 11.24% of variance was accounted for by the first factor, suggesting a negligible threat of common methods bias.

4. Data Analysis And Results

4.1 Data Treatment

A review of the data for normality revealed that a few variables were skewed, thus variables were transformed to the closest normality possible out of the original distribution [80] using the 'normal scores' function provided by PRELIS 2.72. Then, missing data were imputed to obtain a complete data set. Only 1.48% of the values in the data set were missing, and they were replaced using a single imputation method, Expectation Maximization (EM) algorithm, using LISREL 8.72. After normalization and treatment for missing data, the data set was standardized to make the quantitative variables and Likert scale variables comparable and to center all variables.

The underlying factor structure for Instructionism, Teaming and Delegation were examined using exploratory factor analysis (EFA). Four items were dropped from the Teaming scale (two questions, each answered for component A and component B) and one item was dropped from the Delegation scale, because they cross-loaded on more than one construct. Composite scores for each of the strategies are the average of the standardized values of the indicators that loaded on each factor shown in <Table 2>. The scales for performance constructs were refined through a series of confirmative factor analysis, which resulted in dropping one item from Innovation and another item from Development Speed. The scales for control variables also were refined through a series of confirmatory factor analysis.

〈Table 2〉 EFA Results for Collaboration Management Strategy Scales

Indicator	Factor1	Factor2	Factor3
INST1A	.086	**.548**	-.037
INST1B	.095	**.510**	-.144
INST6A	.265	**.699**	.134
INST6B	.307	**.645**	.098
INST16	.239	**.598**	-.075
INST2A	-.155	**.624**	-.151
INST2B	-.153	**.628**	-.143
INST7A	-.293	**.550**	-.104
INST7B	-.323	**.497**	-.124
TEAM3A	**.607**	.087	.088
TEAM3B	**.641**	.041	-.011
TEAM4A	**.672**	.018	-.025
TEAM4B	**.682**	-.003	-.113
TEAM8A	**.641**	.204	.024
TEAM8B	**.638**	.183	-.093
TEAM10A	**.650**	-.067	.053
TEAM10B	**.705**	-.006	.014
TEAM15A	**.600**	-.213	.147
TEAM15B	**.592**	-.188	.048
TEAM18	**.567**	.144	.088
DELEG5A	.320	.013	**.533**
DELEG5B	.297	-.014	**.511**
DELEG12A	.022	-.139	**.718**
DELEG12B	.014	-.149	**.697**
DELEG13A	-.184	-.082	**.770**
DELEG13B	-.193	-.096	**.763**

4.2 Unidimensionality, Discriminant Validity, and Reliability

Unidimensionality was examined for the performance measures and for the control variables by doing an exploratory factor analysis for all 11-performance measurement items and for all 10 measurement items for the control variables [51]. The results showed that each set of indicators is associated with only its underlying latent factor. Discriminant validity was assessed by examining the correlations between the latent variables, which should be statistically different from one. For a pair of latent variables, the first confirmatory factor analysis allowed two constructs to correlate freely, then a second confirmatory factor analysis set the correlation between the two constructs to one and a chi-square test was conducted for the two models [25]. All the chi-square differences are significant at the 0.001 confidence level supporting discriminant validity for all of the constructs.

Cronbach's alpha coefficient and composite reliability were used to assess the internal consistency of the items comprising each scale as shown in <Table 3>. The Cronbach's alphas for the constructs in the study are all over .70, as recommended by Nunnally [50] for a purified scale, except for the Component Modularity (alpha = .63). Because the respondents reported on two different components, it is possible that the underlying items were not homogeneous [62], thus I also examined composite reliability scores. The composite reliability scores for three of the scales, Instructionism (.71), Delegation (.66), and Component Innovation (.66) are slightly lower than Cronbach's alpha.

〈Table 3〉 Finalized Scales for the Constructs

Construct	Cronbach's Alpha	Composite Reliability	Measurement Scales
Instructionism	.78	.71	1. Our firm made as many design decisions as possible in order to provide the supplier with comprehensive specifications/drawings. 6. Tasks for the supplier were explicitly defined when they were given to the supplier. 16. Our firm took extra time to make the specifications for the suppliers as detailed as possible.* 2. The supplier was not expected to make critical design decisions on its own. 7. The component specifications passed to the supplier were mostly physical specifications (e.g., specific dimensions, tolerances, material hardness ratings) rather than performance specifications (e.g., response time, stopping distance).
Teaming	.86	.86	3. Joint design teams were used, where our engineers and the supplier's engineers jointly worked on component design. 4. Our company organized inter-organizational meetings with the supplier. 8. Exchange of information with the supplier took place frequently. 10. Engineers from the supplier participated early-on in component development phases. 15. What percentage of the time were the supplier's engineers working at your facility during the project? 18. Several reviews regarding design compatibility of the two components were conducted during the development process rather than at the end of the design cycle.*
Delegation	.77	.66	5. Our firm gave the supplier full responsibility to ensure the compatibility of the component with other components. 13. When a problem arose, the supplier was expected to take care of it without referring to our firm. 12. When a decision had to be made for which no guidelines or rules existed, the supplier had authority to make the decision.
Design Quality	.79	.78	12. Conformance quality (i.e., adherence to system-level specifications)* 13. Performance quality (i.e., functional excellence)*
Component Innovation	.72	.66	2. Significant improvements were made to the functionality of the component during the development process. 3. The supplier made improvements in process technology (i.e., technical aspects of the production process) during the development process.
Development Speed	.74	.74	4. The development of this component took longer than is usually expected for a component of this type. 5. What percentage of the supplier's tasks were completed by due dates (approximately)? 14. Development lead time (from idea to production start-up)*
Component Modularity	.63	.64	16. Replacing one component design was relatively easy without the need for making substantial adjustments to other component.* 17. The interfaces between the two components could be easily specified.* 18. The product architecture was highly modular.*
Supplier Technical Capabilities	.74	.75	4. The supplier was fully capable of detail designing the component to our specifications.
Technology Newness	.73	.73	9. What percentage of the component's features and functions involved the technologies that were new to the supplier? 14. How new were the manufacturing technologies that were employed to produce each component?
Supplier Commitment	.71	.76	5. The progress of this project was hampered by the uncooperative behavior of the supplier. (Reverse coded) 1. The supplier considered other customers to be a higher priority than we were. (Reverse coded)

*All items were asked for Component A and Component B except these which were only asked once.

4.3 Hypotheses Testing

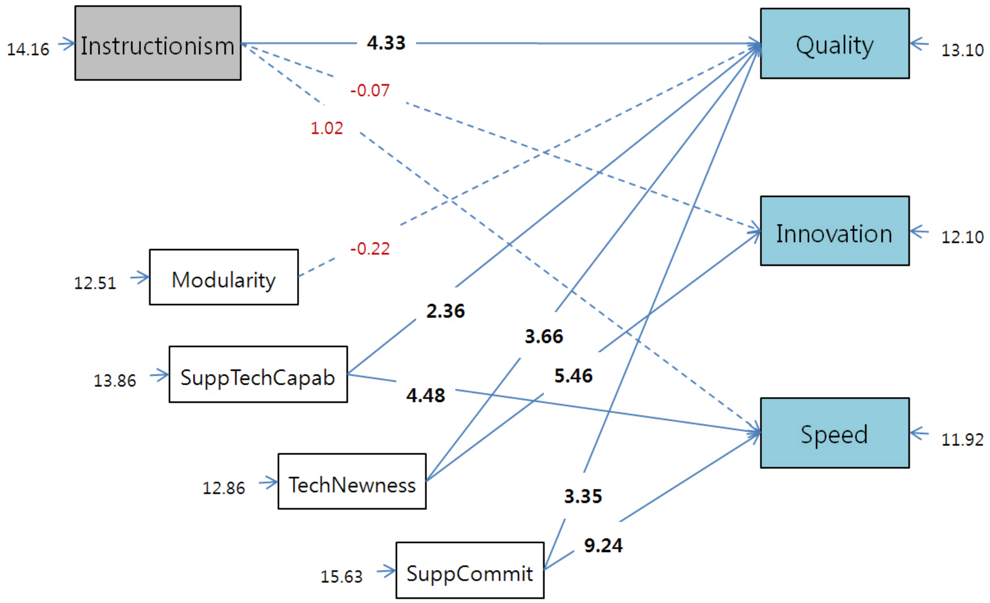
Path analysis was used to test the hypotheses because it is an extension of multiple regressions and allows examining effects of a strategy on multiple dependent variables simultaneously. A path model was developed for each of the three strategies separately [Figures 2~4], because correlation analysis revealed that the three collaboration management strategies are not likely to be used together simultaneously. There is no significant correlation between Instructionism and Teaming or Teaming and Delegation suggesting that these strategies are not used together by the buyers in this study <Table 4>. Instructionism and Delegation are negatively correlated (Pearson correlation = −.210) at $p < .01$ suggesting that buyers are less likely to use these strategies simultaneously.

The variables used for the path models were the composites calculated from the refined scales of multiple indicators shown in <Table 3>. The Robust Maximum Likelihood estimation method was used for model estimations [15]. To assess model fit, chi−square statistics and root mean square error approximation (RMSEA) were examined, along with multiple fit indices, namely Bollen's Incremental Fit Index (IFI; Bollen, 1989), the Comparative Fit Index (CFI; Bentler, 1990), and the Goodness of Fit Index (GFI; Hu and Bentler, 1999). The path model for Instructionism [Figure 2] indicates a good fit (Weighted Least Squares χ^2 =18.60, χ^2 corrected for non−normality = 19.63, df = 8, χ^2/df =2.45, p = .012, RMSEA = .059, IFI = .97, CFI = .96, GFI = .99). The path model for Teaming [Figure 3] also shows a good fit (Weighted Least Squares χ^2 =13.01, χ^2 corrected for non−normality = 12.99, df = 8, χ^2/df = 1.62, p = .11, RMSEA = .040, IFI = .99, CFI = .99, GFI = .99). The Delegation model [Figure 4] has an acceptable fit (Weighted Least Squares χ^2 = 18.58, χ^2 corrected for non−normality = 20.07, df = 8, χ^2/df = 2.51, p = .010, RMSEA = .060, IFI = .97, CFI = .96, GFI = .99). The χ^2/df is below 3.0, the three fit indices are well over 0.90, and the root mean square of approximation (RMSEA) is lower than 0.06, indicating a good fit (Bollen, 1989). The t−values for the paths that are greater than 1.96 are statistically significant at the 0.05 level.

〈Table 4〉 Correlation Matrix and Shared Variances

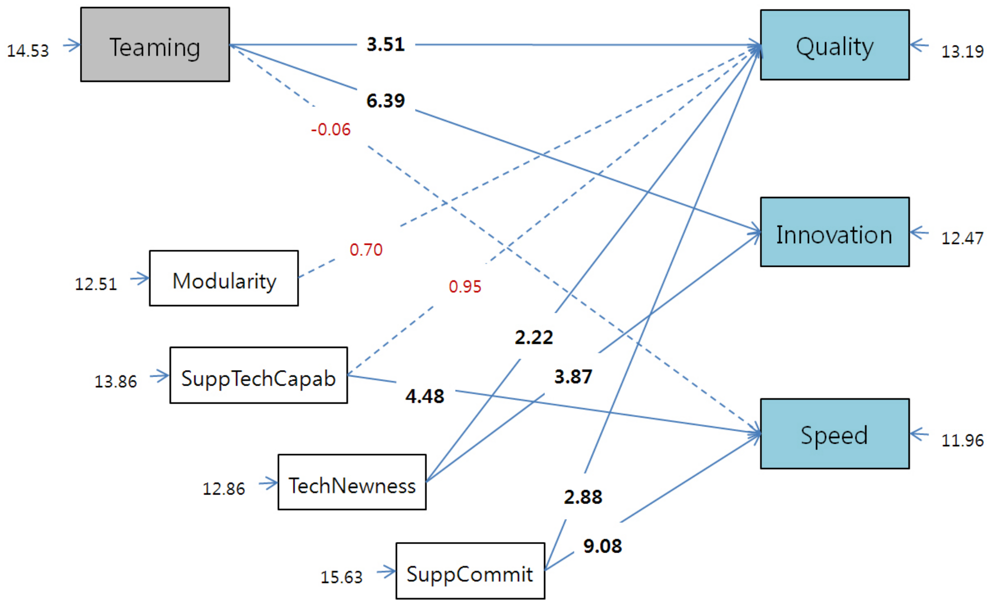
	1	2	3	4	5	6	7	8	9	10
1. Instructionism	-	.002	.044	.052	.000	.004	.023	.033	.003	.012
2. Teaming	.046	-	.008	.000	.177	.013	.001	.011	.095	.042
3. Delegation	-.210	.089	-	.069	.004	.000	.028	.075	.014	.019
4. Design Quality	.228	.263	-.007	-	.040	.027	.005	.008	.028	.047
5. Component Innovation	-.021	.421	.061	.199	-	.006	.002	.000	.108	.006
6. Development Speed	.059	.113	.016	.165	-.078	-	.029	.064	.007	.220
7. Component Modularity	.153	.031	.168	.073	.047	.170	-	.087	.011	.023
8. Supplier Tech Cap.	-.181	.106	.273	.090	.020	.252	.295	-	.003	.006
9. Technology Newness	-.053	.308	.118	.166	.329	-.085	-.107	-.051	-	.002
10. Supplier Commitment	.108	.206	-.139	.217	.079	.469	.151	.079	-.042	-

Note : Correlations are included below the diagonal and shared variances are included above the diagonal. All correlations ≥ .10 are statistically significant at the $p < .05$ level.



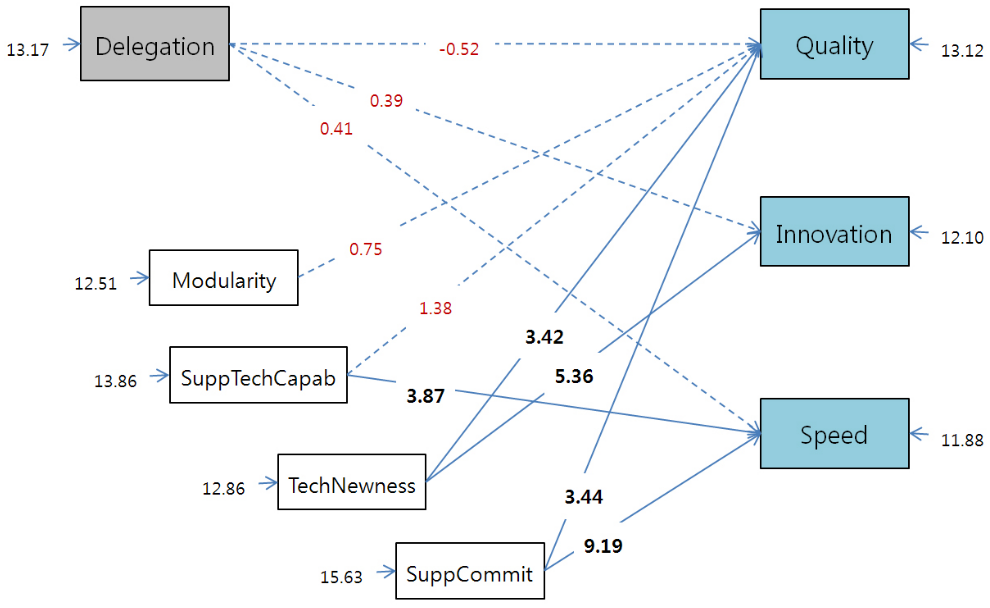
Chi-Square=16.73, df=8, P-value=0.03299, RMSEA=0.059

[Figure 2] Path analysis for Instructionism : t-values shown



Chi-Square=12.01, df=8, P-value=0.15066, RMSEA=0.04

[Figure 3] Path analysis for Teaming : t-values shown



[Figure 4] Path analysis for Delegation : t-values shown

<Table 5> summarizes the results in comparison to the hypotheses. Hypothesis 1a, 2a and 2b are supported at the 0.0001 significance level. Instructionism is positively associated with the design quality of the component system, supporting Hypothesis 1a. Teaming is positively associated with design quality of the component system and component innovation, supporting Hypotheses 2a and 2b. Hypotheses 1b (a negative association of Instructionism with component innovation), 1c (a positive association of Instructionism with component development speed), 2c (a negative association of Teaming with component development speed), 3a (a negative association of Delegation with design quality), 3b (a positive association of Delegation with component innovation), and 3c (a positive associate of Delegation with component development speed) are not supported.

〈Table 5〉 Summary of Hypothesis Testing Results

Strategy	Performance Measure	Hyp.	Hypothesized Sign	Stand Reg Coefficient	S.E.	t-values	Sig	Supported
Instructionism	Quality	H1a	+	0.24	0.019	4.33	**	Yes
Instructionism	Innovation	H1b	-	-0.00	0.027	-0.069		No
Instructionism	Speed	H1c	+	0.05	0.033	1.02		No
Teaming	Quality	H2a	+	0.18	0.013	3.51	**	Yes
Teaming	Innovation	H2b	+	0.35	0.022	6.39	**	Yes
Teaming	Speed	H2c	-	-0.00	0.025	-0.06		No
Delegation	Quality	H3a	-	-0.03	0.024	-0.52		No
Delegation	Innovation	H3b	+	0.02	0.040	0.39		No
Delegation	Speed	H3c	+	0.02	0.045	0.41		No

**Significant at the 0.0001 level.

Of the control variables, technology newness and supplier commitment are consistently related to the expected performance constructs in all three models. Modularity is not related to design quality of the component system in any of the models. Supplier technical capabilities are related to component development speed in all three models and to design quality in the model with Instructionism.

5. Discussion

The results show that two of the three strategies, Instructionism and Teaming are related to product development performance. As hypothesized (H1a), Instructionism has significant positive effect on design quality for the component system. It is consistent with decision-making theory [67] and information-processing theory [21]. Centralized decision-making in Instructionism allows the buyer to maintain control on design quality at the component system as decision-making theory prescribes. Detailed specifications and explicitly defined tasks reduce the need to share and process information with suppliers.

The hypothesized negative relationship between Instructionism and component innovation (H1b) and the positive relationship between Instructionism and component speed (H1c) were not supported. The H1b hypothesized that the low level of interaction and communication between the buyer and suppliers during product design is expected to negatively impact innovation because of less information sharing and fewer opportunities for learning. The reason that H1b were not supported may be that the buyer's technical capabilities and expertise, which were not measured, compensated for low interaction. The lack of support of H1c suggests that the buyer's capability of system-level design may not necessarily lead to fast development of components, which is similar to what was observed by Clark [14] in the automotive industry. Instructionism's sequential nature of the design process, with the buyer doing the design and then handing it off to the suppliers, might have resulted in a slowdown in the hand-off phase or the production-launch phase.

The finding that Teaming is positively related to design quality for the system (H2a) and component innovation (H2b) is consistent with several empirical studies [3, 54, 61, 74]. As suggested by information processing theory [5, 21, 47, 73], frequent and timely interaction with interdependent suppliers allows quality problems to be identified and solved. Teaming promotes interpretations from diverse perspectives and this diversity facilitates organizational learning by increasing the repertoire of possible actions [31]. I had hypothesized that the Teaming strategy would have a negative impact on component design speed but this was not supported by the results. Although with Teaming more time may be spent in meetings and communicating, delays in reworking designs or changing production processes are likely reduced.

None of the hypotheses with respect to use of a Delegation strategy are supported. Studies have shown that shifting component design responsibility to first tier suppliers reduces development time if the suppliers are technically capable [13, 27]. However, Boeing found that its suppliers did not have the capabilities to accommodate its plan to transfer product development responsibilities [42, 43]. Many Boeing suppliers had not been expected to design large modules or complete subsystems until the 1990s [8]. Further, Clark [13] suggests that to be effective, increased design responsibility should be accompanied by integration methods such as guest engineers and co-operative supplier relationships. Similarly, Petersen et al. [56] suggest that involving suppliers in setting technical objectives is essential when suppliers assume responsibility for design. It is possible that the benefits of delegation are limited to specific industries such as the automotive, electronics, and computer industries. In addition, the benefits of Delegation may be conditional if suppliers are technically capable or not (moderation effect of supplier technical capability as opposed to the direct effect that the model supposed). Future research should examine delegation further to identify situations where it may be effective.

6. Conclusion And Limitations

This research extends the collaborative product development literature beyond dyadic buyer-supplier integration to managing interdependencies at the supplier-supplier level. I described three strategies for managing collaborative product development, and empirically investigated the performance implications. Consistent with the information-processing theory and inter-organizational learning theory, we found that Instructionism and Teaming strategies are effective, although via different mechanisms. The result is also consistent with findings from empirical studies [10, 39, 66, 82] that report positive performance effect of collaboration in supply chains

From a practical standpoint, collaboration management with multiple suppliers has gained practical importance due to the recent trend of design outsourcing and system integration [48]. A major implication for product development managers is that both Instructionism and Teaming can be effective. If the buyer is trying to compete in terms of component innovativeness, the buyer should work closely with its suppliers during component development processes using a Teaming strategy. Useful approaches could include inter-organizational joint development teams, co-location of suppliers engineers, early supplier involvement, frequent communications with suppliers, and iteration of feedback and rework (e.g., [27, 37, 41, 77]). If a buyer is trying to compete in terms of design quality of the system, either an Instructionism or a Teaming strategy can be used. However, if pursuing both design quality and innovation then, Teaming is the clear choice.

This research has several limitations. The study is only from the buyer's perspective and gathering suppliers' perspectives might have provided different results. This research used self-reported and subjective measures. In addition, the buyer self-selected the two interdependent components A and B on which to report. The level of interdependency among the A and B components was not explicitly measured thus there may be differences across the sample. Because the survey responses were anonymous, the measures could not be supplemented with secondary data. The research focused only on three dimensions of product development performance. Although, design quality of the component system, component innovativeness, and component development speed are primary measures of component development success, other performance dimensions such as development cost and financial or market success might have provided additional interesting perspectives. Product characteristics such as complexity and use of project management techniques that may moderate the relationship of collaboration strategy and performance were not measured in the study.

There are ample opportunities for future research. Future research should examine if the findings hold true if a great number of suppliers are involved and how extensively the strategies are used in different industries, in different countries, or in situations with different levels of overall product complexity. How the buyer-supplier's prior relationship affects the success of the collaboration with suppliers in new product development would be an interesting research topic as well. The use of specific project management techniques as moderating factors should be explored. Investigating how the fit between these strategies and the competitive business strategies leads to market successes is another possibility. Finally, a decision model for choosing an appropriate collaboration strategy given a set of factors such as buyers' competitive strategies, product modularity, relationship with supplier base, and technological uncertainty could be developed.

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〈Table A-1〉 Sources of Items Used to Measure Coordination Constructs (Before Scale Refinement)

Constructs	Manifest variables	Source of items	Survey questions used
Instructionism (Operational definition: a collaboration management strategy in which a buyer makes as many design decisions for the two interdependent components as possible to provide the suppliers with comprehensive instructions for component development)	Use of physical specifications as opposed to performance specifications	Product specifications passed to the supplier focused on performance - output or results such as response time, stopping distances. Primarily physical specifications were passed to the supplier - specific dimensions, tolerances and material harness ratings (Laseter and Ramdas '02)	7. The component specifications passed to the supplier were mostly physical specifications (e.g., specific dimensions, tolerances, material hardness ratings) rather than performance specifications (e.g., response time, stopping distance). (INST7A; INST7B)
	Giving explicitly defined tasks to suppliers	Management clearly outlined those areas for which I was responsible. I did not know my role in the organization (reverse-scored) (Ayers, Dahlstrom and Skinner '97)	16. Our firm took extra time to make the specifications for the suppliers as detailed as possible. (INST16) 6. Tasks for the supplier were explicitly defined when they were given to the supplier. (INST6A; INST6B)
	Maintaining decision-making authority for most of the design decisions	% of detail-controlled parts: The proportion of design characteristics detailed by assemblers measured by fraction of part numbers (Fujimoto '98)	1. Our firm made as many design decisions as possible in order to provide the supplier with comprehensive specifications/drawings. (INST1A; INST1B) 2. The supplier was not expected to make critical design decisions on its own. (INST2A; INST2B)
Teaming (Operational definition : a collaboration management strategy in which a buyer closely works with two suppliers by involving them in an interactive team-like design process)	Joint-development of components with suppliers	'Team' coordination mechanism : Joint product/process design teams used in product and process design phase; Transition teams used in manufacturing phase (Adler '95)	3. Joint design teams were used, where our engineers and the supplier's engineers jointly worked on component design. (TEAM3A; TEAM3B)
	Using inter-organizational meetings	The number of disciplines that were regularly represented in patient rounds (Gittell '02)	4. Our company organized inter-organizational meetings with the supplier. (TEAM4A; TEAM4B)
	Frequent and timely communication with supplier engineers	There was frequent communication within our team. There was intensive communication within our team. The team members were happy with the timeliness in which they received information from other team members. The team members were happy with the accuracy of the information received from other team members. (Hoegl et al., '04)	8. Exchange of information with the supplier took place frequently. (TEAM8A; TEAM8B) 9. Our firm communicated with the supplier in a timely way about relevant project information. (TEAM9A; TEAM9B)*
	Integrating suppliers early-on	Our suppliers are involved in the early stages of product development We ask our suppliers for their input on the design of component parts. (Koufteros et al., '05)	10. Engineers from the supplier participated early on in component development phases. (TEAM10A; TEAM10B)
	Co-locating suppliers engineers at manufacturer's site	How much of the time during the project were supplier technical personnel working at your facility? (Hartley, dissertation)	15. What percentage of the time were the supplier's engineers working at your facility during the project? (TEAM15A; TEAM15B)
	Frequently evaluating component compatibility	Multiple design reviews during design-cycle instead of at the end of the design cycle : "[case companies] found that they needed to have several design reviews rather than incorporating the review into the sign-off procedure." (Adler '95)	18. Several reviews regarding design compatibility of the two components were conducted during the development process rather than at the end of the design cycle.(TEAM18) 11. There were many iterations of feedback and rework with the supplier regarding component design. (TEAM11A; TEAM11B)*
Delegation (Operational definition : a collaboration management strategy in which a manufacturer delegates the coordination responsibility to capable suppliers)	Giving suppliers the responsibility to ensure component compatibility	A first-tier supplier carried the responsibility of coordinating the design activities with second-tier suppliers (Choi and Hong '02)	5. Our firm gave the supplier full responsibility to ensure the compatibility of the component with other components. (DELEG5A; DELEG5B) 20. Our firm requested that the suppliers coordinate with each other. (DELEG20)*
	Giving autonomy to suppliers to make design decisions	Please indicate how the following decisions are usually made at your lab : Making significant changes to existing products; Modifying the production process of the lab; Restructuring the lab; Setting project priorities for the lab (Persaud et al., '02) When a product related problem arose, I had to refer the problem to someone higher up in the organization for the answer. Even small matters had to be referred to someone higher up for a final answer. (Ayers, Dahlstrom and Skinner., '97) (reverse)	13. When a problem arose, the supplier was expected to take care of it without referring to our firm. (DELEG13A; DELEG13B) 12. When a decision had to be made for which no guidelines or rules existed, the supplier had authority to make the decision. (DELEG12A; DELEG12B)

*dropped during scale refinement

[Disagree 1-2-3-4-5-6-7 Agree] for most questions; [Never 1-2-3-4-5-6-7 Extensively] for questions 3, 4, and 10; [_%] for question 15.

〈Table A-2〉 Sources of Items Used to Measure Performance Constructs (Before Scale Refinement)

Constructs	Manifest variables	Source of items	Survey questions used
Design quality	Conformance quality	Conformance: meeting pre-established standards (Garvin '84)	Please compare your system (i.e., the sub-assembly of components A and B) with your competitors'. 12. Conformance quality (i.e., adherence to system-level specifications) (PCONQ12)
	Performance quality	Performance : a product's primary operating characteristics (Garvin '84)	Please compare your system (i.e., the sub-assembly of components A and B) with your competitors'. 13. Performance quality (i.e., functional excellence) (PPERQ13)
Innovation	Improvement made to functionality of the component	Component innovation : Our capability of developing unique features; Our capability of developing new product and features (Koufteros et al., '02)	2. Significant improvements were made to the functionality of the component during the development process. (PINNV2A; PINNV2B)
	Improvement made to process technology	Improvements in the technical aspects of the production process (Persaud et al., '02)	3. The supplier made improvements in process technology (i.e., technical aspects of the production process) during the development process. (PINNV3A; PINNV3B)
	Innovativeness	Product's newness relative to the firm and newness relative to the outside world (Song and Montoya-Weiss, '98)	Please compare your system (i.e., the sub-assembly of components A and B) with your competitors'. 11. Innovativeness of the system (PINNV11)*
Development speed	Project speed	This project was completed in significantly less time than similar projects undertaken by this organization This project took longer than the usual amount of time for a project like this, in this organization (R) This was one of the fastest projects ever undertaken by this organization (Primo and Amundson '02)	4. The development of this component took longer than is usually expected for a component of this type. (PTIME4AR; PTIME4BR) (reverse-coded)
	Development leadtime	How long did this project take from funding to production start-up or termination (months)? (Hartley, dissertation)	10. How long did the overall project take from funding (earlier of components A and B) to production start-up (later of components A and B)? (PTIME10R) (reverse-coded)* Please compare your system (i.e., the sub-assembly of components A and B) with your competitors'. 14. Development lead time (from idea to production start-up) (PTIME14)
	On-time completion of suppliers' tasks	Approximately, how many of the supplier's activities were completed by the due date during the project? (Hartley, dissertation)	5. What percentage of the supplier's tasks were completed by due dates (approximately)? (PTIME5A; PTIME5B)

* dropped during scale refinement

[Disagree 1-2-3-4-5-6-7 Agree] for questions 2, 3, 4 and 5; [Inferior 1-2-3-4 Average-5-6-7 Superior] for questions 11, 12 and 13; [Shorter1-2-3-4 Average-5-6-7 Longer] for question 14; [_months] for question 10; [_%] for question 5.