Comparing Two Approaches to Studying Communications in Team Design

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This paper explores intragroup communication in team design using data collected from a protocol study. Two units of analysis are introduced, (1) at a coarse level: turn-taking of utterances during conversations, and (2) at a fine level: design issues on the basis of the FBS ontologically-based coding scheme. These basic elements of team design activities (i.e., conversational turns and design issues) are then interconnected using Goldschmidt's Linkography method. The proposed two methods are demonstrated and compared through a case study of product design meeting. Results indicate that, for the purpose of structure-based analysis, the measurements derived from the turn-taking model are able to largely resemble the measurements derived from the FBS-based model, though the former model could be achieved with much less labor than the latter model. However, content-based analysis could only be conducted by using the more sophisticated FBS-based method.

Introduction

To deal with the increasing complexity of contemporary design problems, the design professions have moved from mainly an individual activity towards predominantly a team-based activity. Studying team design activities, particularly verbal communications and interactions between designers as well as other stakeholders, therefore becomes one of the important emerging interests of design research. For example, the 7th Design Thinking Research Symposium (DTRS7) "analysing design meetings" [1] and

Design Computing and Cognition DCC'16. J.S. Gero (ed), pp. 301-319.

the 10th Design Thinking Research Symposium (DTRS10) "analysing design review conversations" [2] both focus on multidisciplinary design collaborations through conversation.

The shift from individual's work to teamwork introduces new dimensions beyond a simple increase of the number of participants. Olson et al. [3] found that in various small team design sessions only 40% of the time on average was spent on direct discussion of the design. Social issues, e.g., information sharing, collective learning and cognitive consensus, need to be explicitly considered when studying team design activities [4].

This paper focuses on detailed analyses of verbal communications of a small design team during one or a few design sessions. This is a typical situation for the use of the protocol analysis methodology. Many studies have adapted protocol analysis methods to explore shared mental models of the design team [5], multimodal communication channels [6], and some other team design issues. However, the majority of current cognitive studies into team design activities relied on the research paradigms developed from the cognitive studies of individual designers. They tended to consider the design team as a whole and primarily focused on the overall performance of the teams, rather than through the lens of communication between multiple participants. A more appropriate approach for modeling team design activities is required to facilitate a better exploration of the nature of team design.

This paper reviews several communication models and methods that attempt to elucidate the structure of communication during a team-based activity. It then synthesizes the merits of these methods and proposes two approaches to studying communications in team design. These two methods are then demonstrated and compared in a product design meeting case study using the DTRS7 common dataset.

Studying Communications in Team Design

Modeling communication as conversational turn-taking

Verbal communication provides a primary means for interpersonal information exchanges among team members [7]. To become a valid form of communication or team design activity, a necessary condition is the involvement of more than one participant. Turn-taking of conversations is a fundamental feature of interpersonal communication infrastructure [8, 9]. To a large extent, information is sequentially transmitted from one participant of communication to another with minimal time gaps or overlaps.

Sacks, Schegloff and Jefferson's classic turn-taking model [10] captured the structure of communication, rather than its contents. It was selected to form the basis for our initial approach to modeling team design communication. Irrespective of the content of utterances, conversational turns are then used as basic elements for a simple team communication model. We further encode conversational turns with the roles of designers, and explore the communication patterns from a social perspective.

Gero and Kan [11] demonstrated this turn-taking model in a case study of an engineering design meeting. They applied first-order Markov chain analysis to explore the interpersonal interactions between adjacent conversational turns. The transitional trend between turns revealed the formation of sub-teams during the team design activities.

Using Linkography to connect turns beyond adjacency

Gero and Kan's [11] turn-taking model is a syntactic model, based on the assumption that a successive design action has potential connection to its immediately preceding one. In reality, the conceptual dependency of a design action exists beyond adjacent ones [12]. A semantic modeling approach should construct the connection between two design actions on the basis of their semantic relationship, rather than the adjacency in terms of temporal relationship.

Linkography, developed by Goldschmidt [13, 14], is an example of semantic modeling methods. It delineates the structure of the designing process in terms of a network of nodes and links. The basic element of Goldschmidt's Linkography is called "design moves", i.e., an incremental change of the design status [15]. The links among design moves are constructed on the basis of critical assessments of the semantic meaning contained in those moves [13, 14]. It enables constructing connections beyond adjacent moves and also allows one move to connect with more than one other move, or to have no connection at all (isolated or "orphan" move). Several measurements (e.g., critical moves, and link density) have been developed to analyze different properties of the designing process using this approach.

Though not developed for the purpose of analyzing team design activities, the idea of the designing process as a network of interconnected design actions is valuable for modeling team design activities. We thus integrate Goldschmidt's [13, 14] Linkography with Gero and Kan's [11] turn-taking model: on the basis of their semantic meaning, a conversational turn could be conceptually linked to another turn which has been taken either immediately preceding it or anywhere in the past.

FBS-ontologically-enhanced Linkography

The sequence of conversational turn-taking could be seen as a structure of communication that provides an environment for the acts of designing. A social-linguistic turn-taking model specifies that a turn may consist of many turn-constructional units (e.g., sentences or clauses) [10, 16]. A designer often generates more than one piece of design information in a conversational turn. Information items could thus be seen a unit of analysis nested in the conversational turn, Fig 1.

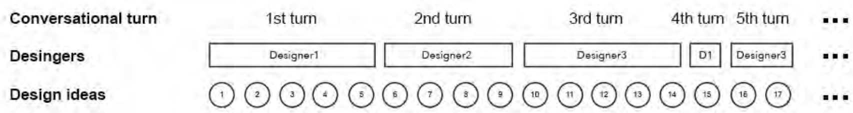

Fig 1. A sequence of conversational turns and design ideas in a team design process

The design information exchanged during team communication could be coded and examined in a variety of ways. The Function-Behavior-Structure (FBS) ontology [17, 18] and the corresponding coding scheme [19] provide a validated means to categorize design information, independent of specific contexts in which designing takes place. The FBS ontology describes the designing process in terms of function (F) of a designed object (its teleology); behavior (B) of that object (either derived [Bs] or expected [Be] from the structure), and structure (S) that represents the components of an object and their compositional relationships. These ontological classes are augmented by requirements (R) that come from outside the designer and description (D) that is the document of any aspect of designing, Fig 2.

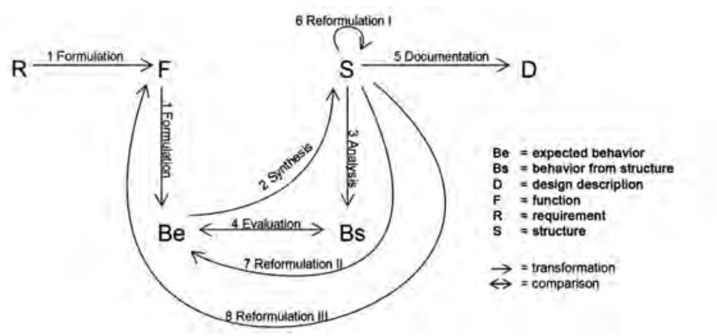

Fig 2. The FBS ontology with the resultants design processes delineated as transitions between the ontological constructs (after [18])

Kan and Gero [20] proposed a Linkography study based on the FBS-based coding scheme. The integration of Linkography method and categorization of design ideas should produce a richer understanding of design cognition. We consider conversational turns as a superimposed structure to design issues. The Linkography of design issues could also apply to examine relationships between designers.

Two Linkography-based Methods of Examining Communication in Team Design

Based on a simple turn-taking model, Linkography and the FBS-ontologically based coding scheme, we propose two approaches to studying communication in team design. They aim to cover major structure and content-based analyses. Both methods adopt Goldschmidt's Linkography to reveal the structure of designing process. The distinction is in the unit of analysis. The two methods respectively use conversational turns and design issues as basic building blocks. Fig 3 shows a graphical representations of communication in team design when applied with our methods.

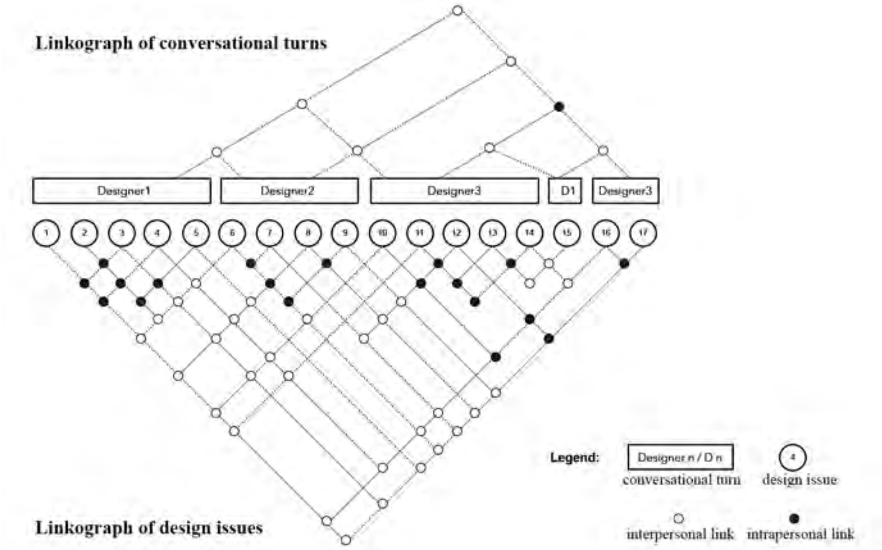

Fig 3. Linkograph of conversational turns and linkograph of design issues.

Linkography of conversational turns is a simpler method. Determining conversational turns from a transcript of team design is straightforward as the unit of analysis is the individual conversational utterance. The segmentation process can be untaken semi-automatically and inter-rater reliability of segmentation is sufficiently high for reliable results. As turn-taking is defined independent of utterances' semantic meaning, this unit of analysis is largely homogeneous in nature, except for the label of speakers.

The unit of analysis of FBS-based linkography is design issues. Empowered by the FBS-based coding scheme, both design issues and transitions between design issues are associated with ontologically-defined categories. A content-based analysis is thus possible using the linkograph of design issues. The benefits of Linkography of design issues come with a cost. The FBS-based segmentation and coding of designing process into design issues requires critical judgments about the scope of a design issue as well as the ontological category of individual issues. This process can be very time-consuming and labor-intensive. The Delphi method [21] is usually required to increase the coding reliability. A larger number of design issues, compared to the relatively smaller number of conversational turns in a same protocol, also demands more effort to construct the linkograph of design issues.

The main purpose of this paper is to examine to what extent the Linkography of conversational turns could resemble the characteristics of Linkography of design issues. If the differences between the measurements derived from these two methods are minimal, we could apply Linkography of conversational turns as a quick-and-dirty alternative to the more sophisticated Linkography model of design issues.

Case Study: Engineering Design Meeting from DTRS7

These two Linkography-based methods were performed on a seven-person team design session, using data from the DTRS7 dataset [1]. The source data was a video of design meetings taking place in a product design practice, Fig. 4. The meeting lasted approximately one and half hours. A multidisciplinary design team was asked to brainstorm ideas for solving technical issues in the design of a thermal printing pen. Fig. 5 illustrates what the thermal pen was intended to do.

The team consisted of a business consultant, who acted as the moderator (Allan), three mechanical engineers (Jack, Chad and Todd), an electronics business consultant (Tommy), an ergonomist (Sandra), and an industrial design student (Rodney). They were all professionals from the same company and the student, Rodney, was on an internship with the company. They knew each other well and were efficient at collaborating.

The details of the meeting setting can be found in McDonnell and Lloyd [1].

This dataset has been examined by a number of researchers, e.g., [11, 22, 23]. Previous findings are compared with current results.

Fig 4. Four camera digital recording of the design session.

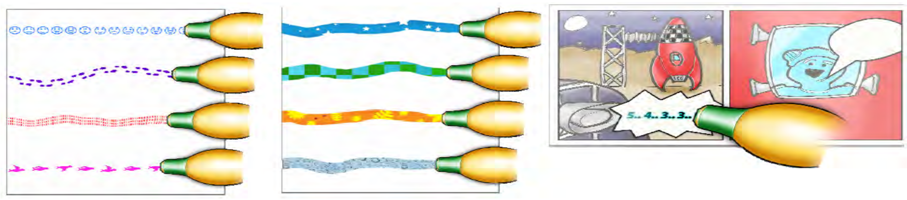

Fig 5. Illustrations used in the session showing the function and expected behavior of the thermal printing pen being designed.

Overall comparisons between two Linkography models

A simple and crude way to compare these two Linkography-based models is to visualize them in a graphic form, i.e., as a linkograph, and visually inspect the geometric patterns of these two linkographs. A linkograph can be generated by software such as LINKODER [24].

This is followed by overall comparison of Goldschmidt's [14] Linkograph metrics: (1) link density, the ratio of the number of links to the number of segments (turns or design issues); (2) forward link (a transition connecting a segment to a subsequent one) and backward link (a transition connecting a segment to a previous one).

Linguistic turn-taking models focus on transitions between an adjacent pair of turns [10, 25]. We then examined the proportions of adjacent turns/issues link.

Communication operates on both intrapersonal and interpersonal levels [7]. Fig 3 distinguishes two broad categories of interpersonal links and intrapersonal links. A high percentage of interpersonal links would indicate a high interchange of opinions among collaborative designers. A high percentage of intrapersonal links may indicate a less successful team efforts, as each designer tends to concentrate on their own ideas and considers other participants' contributions less.

A more detailed categorization was imposed onto the Linkography of design issues, Table 1. This coding scheme takes the relative positions of two issues into consideration. It distinguishes conceptual dependency between recent turns/issues and those between remote turns/issues. For the Linkography of conversational turns, *Intra 1* and *Intra 2* types are not applicable, and *Inter 1* and *Inter 2* links will collapse into a single sub-category.

Table 1. Coding scheme for links of Linkography of design issues

Category	Sub-category	Description
Intrapersonal link	Intra1 (immediate)	A design issue to its immediately preceding issue generated by the same participant
	Intra2 (same turn)	A design issue to an issue that is generated by the same participant in the same conversational turn, but not immediately adjacent
	Intra3 (cross turn)	A design issue to an issue that is generated by the same participant, but in a different conversational turn
Interpersonal link	Inter1 (immediate)	A design issue to its immediately preceding issue generated by a different participant
	Inter2 (adjacent turn)	A design issue to an issue that is not immediately preceding in the issue level, but is in the immediately preceding turn
	Inter3 (cross turn)	A design issue to an issue that is generated by a different participant, and beyond an adjacent conversational turn

Transitional analysis between designers

Dynamics between participants are key to communication. A more detailed comparison looked into the patterns of information exchange between designers, through examining transitions between designers. A transition between designers is unidirectional, from a designer with a forward link connecting to another with a backward link. We first examine whether some designers were more likely to initiate a transition and some others were more likely to follow team members' lead. This is done by a Pearson's Chi-square test of independence, comparing overall frequency distributions of designers before and after a transition.

Contingency tables were then generated for each Linkography model. Designers with a forward link are listed in rows, and the corresponding designers with a backward link in columns. The cells are frequency of transitions from designer with a forward link to designer with a backward link. Contingency tables help to reveal whether transitional relationship of designers are reciprocal, i.e. whether the probability of designer A transiting to designer B is statistically different from the probability of designer B to designer A. This can be done using the Bowker procedure [26, 27], a symmetry test of contingency table, which examines changes in the categorical responses before and after some treatment condition.

The similarity between contingency tables from the two Linkography models is then compared by a regression vector coefficient, R_V coefficient [28]. It is a generalization of the Pearson's product-moment correlation coefficient for two matrices.

$$\mathrm{RV}(W_i, W_j) = \frac{trace(W_i,W_j)}{\sqrt{trace(W_i,W_i)\cdot trace(W_j,W_j)}}$$

Where $trace(W_i, W_j)$, $trace(W_i, W_i)$ and $trace(W_j, W_j)$ are respectively generalized covariance coefficient between matrices W_i and W_j, and generalized variances for matrices W_i and W_j. The R_V coefficient takes values between 0 and +1. The closer R_V is to 1, the more similar are the two contingency tables. The significance test of R_V was conducted by Monte Carlo resampling (number of permutations = 5000). Statistical software XLSTAT (version 2015) was used for calculation.

If the above comparisons reveal these two models are similar, this will indicate that a model produced with significantly lower effort will suffice to reveal the structure of communication in team design. Should that be the case we will continue to examine any additional benefit when using Linkography of design issues, i.e., what benefits the labor-intensive FBS-coding will provide above the simpler turn-taking model.

Results and Discussions

Protocol segmentation and coding

Turn-taking model

The segmentation and coding of design protocols resulted in 1279 design issues and 563 conversational turns taken during this team design session. Table 2 shows the frequencies of conversational turns. Participants were not equally active in terms of how many times they addressed their options. Allan, the moderator of this meeting, contributed the most conversational turns, approximately one quarter of total turns. Todd (a mechanical engineer) and Tommy (an electronics business consultant) generated 21% and 19% of total turns respectively. The ergonomist (Sandra), and the student intern (Rodney) were relatively inactive during the conversations.

Table 2. Frequency distribution of conversational turns

Designer	Role	count	%
Allan	Moderator & business consultant	137	24.5
Chad	mechanical engineer	57	10.1
Jack	mechanical engineer	88	15.6
Todd	mechanical engineer	117	20.7
Rodney	industrial designer (intern)	27	4.8
Sandra	ergonomist	32	5.7
Tommy	electronics business consultant	105	18.6
Total	-	563	100.0

Design issue model

The frequencies of design issues, when applied with the FBS-based protocol segmentation and coding, are presented in Table 3. It shows that, for the categories of design issues, the structure issues were most discussed, representing 40% of total design issues. It is followed by two behavioral issues (expected behavior and behavior from structure), together representing approximately one half of total issues. Design description and function issues constitute the rest 10% of total issues. No requirement issue was identified in this session. It was thus removed from the following analyses.

Table 3. Frequency distribution of design issue

Design issue	count	%
Requirement	0	0.0

Function	47	3.7
Expected behavior	275	21.5
Behavior from structure	369	28.8
Structure	512	40.0
Description	76	6.0
Total	1279	100.0

Conversational turn can be seen as a superordinate unit of analysis to design issues. It is possible to calculate the frequencies of design issues embedded in the unit of analysis of designers. Table 4 shows that one conversational turn, on average (mean), contains 2.3 design issues (SD =2.5). The number of design issues per turn is highly left-skewed. Approximately three quarters of the turns contain only one or two issues. There are only 12 conversational turns containing more than 10 design issue per turn. The longest turn is generated by the engineer Jack when he was elaborating the structure in the late phase of the session. This turn contains 30 design issues (19 structure issues, 10 behavior from structure issues and 1 expected behavior issue). The second longest turn drops to 16 issues, when the moderator Allan addressed the beginning of the session (10 expected behavior issues, 3 structure issues, 2 behavior from structure issues and 1 function issue).

Table 4. Frequencies of design issue per designer

Designer	**Frequencies of design issues**		**Frequencies of design issues per designer**	
	count	**%**	**Mean**	**SD**
Allan	307	24.0	2.24	2.40
Chad	129	10.1	2.26	2.42
Jack	225	17.6	2.56	3.51
Todd	248	19.4	1.93	1.38
Rodney	52	4.1	1.56	1.19
Sandra	50	3.9	2.12	2.06
Tommy	268	21.0	2.55	2.64
Total	1279	100.0	2.27	2.51

Though designers varied their involvement in the group design activities (measured in the number of conversational turns and design issues), a Kruskal-Walis one-way ANOVA shows the median numbers of design issue per conversational turn were not statistically different among designers, χ^2 (6)=6.47, p=0.37.

Comparison of the overall distributions of designers

Pearson's Chi-square test for independence was performed to compare the overall frequency distributions of designers between the Linkography of conversational turns and Linkography of design issues. Results indicate the distribution differences between two models were not statistically significant, χ^2 (6)=5.56, p=0.47, Cramer's V=0.055. We could use the measurement of either model to indicate designers' relative involvement during the team design communication.

Construction of Linkography

When applying the Linkography technique to interrelating segmented conversational turns and design issues, it generates 1879 links for the linkograph of conversational turns (Fig 6), and 5088 links for the linkograph of design issues (Fig 7). By presenting these two graphs to match their lengths and then overlapping them, the geometric features of these two graphs were visually similar.

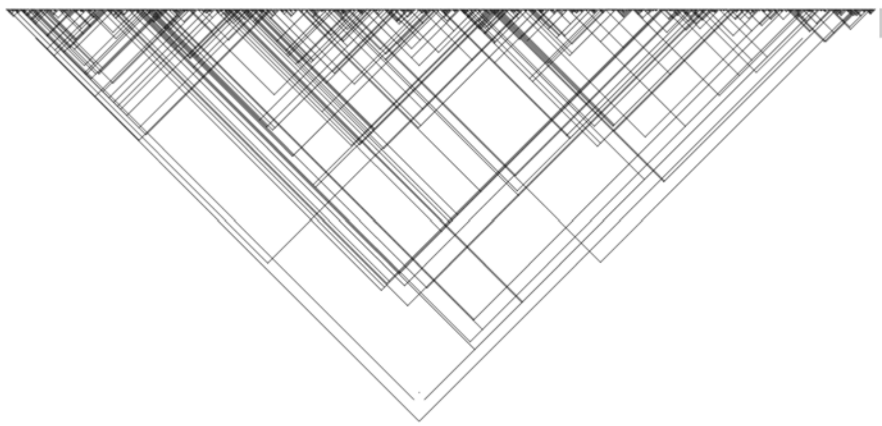

Fig 6. Linkograph of conversational turns (generated by LINKODER)

Using Goldschmidt [14] Linkography metrics, it was found that though total numbers of links varied, the link densities of two models were close, 3.34 and 3.98 respectively, Table 5. The distance between the two linked segments (link span) varied. A link may connect two immediately occurring segments, or connect a segment located nearer the beginning of the session and the other nearer the end of the session. The latter case happens when the team wrapped up the discussion and corresponded to the agendas set in the beginning of team design session. In general, the distributions of link spans were highly right skewed. The medians of link span were 4 for both linkograph of conversational turns and linkograph of design issues.

Table 5. Summary of Linkography

Link measurement	Linkograph of conversational turns	Linkograph of design issues
Number of links	1879	5088
Link density	3.34	3.98
Link span (range)	1~514	1~1178
Link span (median)	4	4

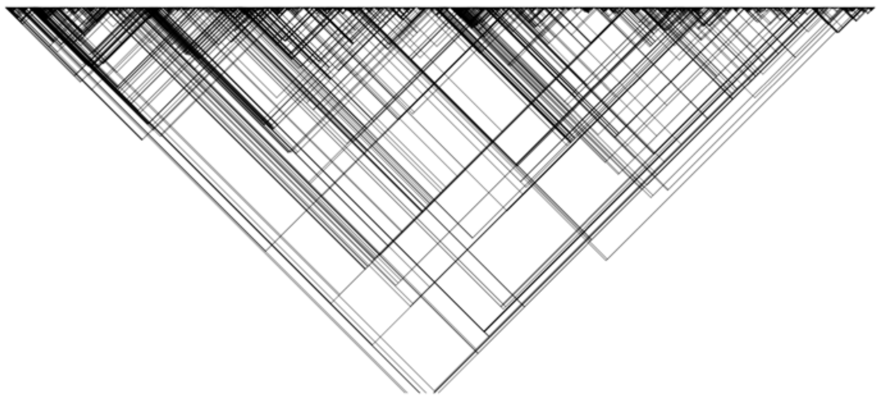

Fig 7. Linkograph of design issues (generated by LINKODER)

Directionality of links

Each node (a conversational turn or design issue) of a linkograph may be associated with a forward link (a link connecting to a consequential node), a backward link (a link connecting with a preceding node), or both. **Error! Reference source not found.** shows that the majority of nodes contain both forward and backward links, 92.4% for the linkograph of conversational turns and 91.5% for the linkograph of design issues. The frequency distributions of these three link types were not statistically different between two models, χ^2 (2)=3.00, p=0.23, Cramer's V=0.040.

Table 6. Forward and backward links associate to the segments

Type of link	Linkograph of turns		Linkograph of design issues	
	count	%	count	%
Bi-direction	1182	92.4	515	91.5

Forward only	30	2.3	9	1.6
Backward only	67	5.2	39	6.9
Total	1279	100	653	100

Adjacent links

Syntactic models, which only consider the transition between adjacent pairs, are widely used in studies into designing processes, e.g., [23, 29]. Here 480 transitions between adjacent turns and 1100 transitions between adjacent design issues were identified. Applying the syntactic modeling approach, there are 562 links for the turn-taking model and 1278 links for the design issue model. Even though these syntactic links were constructed unrelated to the semantic meaning in the segments, the majority of these links were valid in the semantic modeling, 85.4% and 86.1%, **Table 7**. The proportion of adjacent turn links in the total number of semantic links was slightly higher than the proportion of adjacent issue links, 25.6% vs 21.6%. It shows the Linkography of design issues may enable more elaborate analysis of conceptual dependency beyond adjacent design issues.

Table 7. Transition between adjacent pairs of turns/ design issues

	Linkography of conversational turns	Linkography of design issues
No. of adjacent links	480	1100
No. of syntactic links	562	1278
Adjacent link / syntactic links (%)	85.4	86.1
Adjacent link / total semantic link (%)	25.6	21.6

Intrapersonal and interpersonal links

The Linkography of conversational turns compresses intrapersonal links within a turn, the intrapersonal percentage therefore would be lower than its counterpart of Linkography of design issues. A correction should be made by only considering cross-turn links when comparing the relative frequency of intrapersonal links. There are seven participants in this team design session. If the transitional probabilities from one person to another are equal, the percentage of intrapersonal links is approximately 14.3% (1/7) of cross-turn links. The actual intrapersonal link percentage is 28.6%, almost twice of the hypothetically evenly distributed probability. This implies that, when designers refer to their previously generated design ideas, they are more likely to revisit their own ideas rather than their partners'.

For the Linkography of design issues, the frequency of intrapersonal links was 44.9% of total links, more than triple of this hypothetically evenly distributed probability (14.3%). It shows designers not only revisit their own ideas more often in terms of conversational turns, they also elaborate more of their own ideas than other participants' ideas.

Transitional analysis between designers

A Pearson's Chi-square test of independence of the distribution comparison of forward links and backward links was conducted, Table 8. There was no statistical difference found in the Linkography of conversational turns, $p= 0.58$. The test was statistically significant for the Linkography of design issues, $p<0.01$, but the small Cramer's V value (<0.1) indicated the difference was trivial.

Table 8. Comparison of nodes with forward and backward links

Statistic method		Linkography of conversational turns	Linkography of design issues
Pearson's Chi-square test of independence	$\chi 2$	4.72	19.35
	df	6	6
	p	0.580	0.004
	Cramer's V	0.035	0.044
Bowker procedure	B	17.50	59.10
	df	21	21
	p	0.680	0.000

The Bowker procedure showed that transitions in the Linkography of conversational turns were reciprocal, $p=0.68$. A significant result was found in the Linkography of design issues, $p<0.001$. But post hoc tests [26] failed to detect specific discrepancies. We thus argue that transitions in the Linkography of design issues were essentially reciprocal.

The similarity of transitions between the two Linkography-based models was then quantitatively assessed using the R_V coefficient. Results confirmed that two transition matrices were strongly similar, $R_V = 0.85$, $p<0.001$.

Comparing Linkography of conversational turns and Linkography of design issues

On the basis of the above comparisons, the characteristics of the Linkography of conversational turns, to a large extent, were similar to the

Linkography of design issues in terms of the structure-based analysis. This implies that we could apply the Linkography of conversational turns as a relatively economic tool to explore structural patterns of communication in team design, e.g., relationships between designers.

On the other hand, the hierarchical feature of the Linkography of design issues enable us to explore the team communication beyond the turn-taking structure, and tap into semantic information exchanged during communication. For example, a richer categorization of links (Table 9) can be applied to explore the nuanced dynamics of team design communication. The transition between design issues can be automatically coded as eight ontologically design processes (Fig 2), providing access to semantic aspects of concept developments. The following example illustrates a content-based analysis that can only be obtained using the more labor-intensive FBS-based method.

Table 9. Comparing two Linkography-based methods

	Linkography of conversational turns	**Linkography of design issues**
Unit of analysis	Conversational turns	Design issues
Nature of unit of analysis	Homogeneous in nature	Six ontological categories, e.g., function, expected behaviors (Fig 2)
Segmentation and coding	• Straightforward and fast (semi-automatic) • Reliable (single coder is sufficient)	• Labor-intensive and time-consuming • Require Delphi method [21] to increase reliability (in this case, agreement between individal codings and final arbitrated code is approximately 84~87%)
Construction of links	Manually construct (relatively less labor-intensive, due to smaller number of turns than design issues)	Manually construct (labor-intensive, inter-ratter agreement is 80+% in this case)
Nature of link	homogeneous in nature	• Eight ontological categories, e.g., formulation, synthesis (Fig 2) • Possible to categorize higher-order transitions
Intra- vs. inter-personal links	No intrapersonal links within a turn	Richer categories (Table 1)

Scope of application	Structure-based analysis only	Structure-based analysis Content-based analysis

Exemplary content-based analysis using Linkography of design issues

Design issues are considered to be nested in the structure of conversational turns. We cross-tabulated the frequencies of design issues against designers, Table 10. Pearson's Chi-square test of independence shows that the frequency distribution of design issues was statistically associated with designers, χ^2 (24)=83.80, p<0.001, Cramer's V=0.128.

Table 10. Design issue frequencies for each designer

Designer	Design issues (%)					Problem-Solution index
	F	Be	Bs	S	D	
Allan	5.2	29.6	18.2	34.5	12.4	0.54
Chad	3.1	14.7	34.1	42.6	5.4	0.22
Jack	3.6	17.8	27.6	46.2	4.9	0.27
Todd	3.6	17.7	31.0	41.5	6.0	0.27
Rodney	0.0	15.7	45.1	39.2	0.0	0.19
Sandra	6.0	22.0	38.0	34.0	0.0	0.39
Tommy	2.6	23.1	32.8	39.6	1.9	0.35
Total	3.7	21.5	28.9	40.0	6.0	0.34

A closer examination indicates the differences are related to the role of participants, using a battery of Z tests (adjust p value by Bonferroni method). The differences were mainly exhibited by the moderator Allan. He had a significantly higher percentage of expected behavior issue (29.6%) than the three mechanical engineers (14.7~17.8%), and a lower percentage of behavior from structure issue of 18.2% than the rest of participants (32.2% in average). It seems that Allan was more focused on the design problems, and less evaluative. The problem-solution (P-S) index [30] also shows Allan had a higher value of 0.54 than the other participants (0.30 in average). The role of the moderator may require him pulling back the discussion, from time to time, and aligning it with the set agendas. Allan also generated approximately a half of total description issues.

It is interesting to note that, there are no statistically significant differences among three mechanical engineers, Chad, Jack and Todd, χ^2(8)=2.75, p=0.95. They are generally more focused on structure and behavior from structure issues. Using the FBS-based method is possible to detect how the participants perform the roles they are assigned through examining the FBS-coded communication contents as well as transitions between design issues.

Linkography of design issues, based on coding with the FBS ontology, should help to elucidate how design concepts are synthesized and evolve during communication in team design.

Conclusion

This paper proposed two Linkography-based methods of examining team design communication at two different levels of analysis units. The Linkography of conversational turns is an economic tool in term of the labor required to produce results. The relative objectivity of determining turn-taking of conversations make it much less labor-intensive than the Linkography of design issues, which requires critical assessment of the scope of a design issue and its ontological category. A series of model comparisons in a case study showed the characteristics of the Linkography of conversational turns to be similar to those of the Linkography of design issues if researchers are mainly concerned with structural patterns of communication in team design. Linkography of conversational turns should be sufficient for this structure-based analysis. But the Linkography of design issues should be selected if researchers want to extend their interests into content-based analysis. The more labor-intensive Linkography of design issues can provide deeper insights to team design communication. The hierarchical feature of model building blocks enables us to investigate both structure and content of team design communication. The selection of model should be based on the purposes of investigation and available resources.

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