LEARNING TO COLLABORATE DURING TEAM DESIGNING: QUANTITATIVE MEASUREMENT

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Learning is difficult to study because of the paucity of data and the lack of adequate tools to measure it. In this paper we measure the learning by observing the behavior changes of members of a design team as they work together. The paper presents results from protocol analysis techniques used to quantify behavioral changes. It utilizes an ontological coding scheme for design issues; linkography that examines the interaction and individuals' design processes; and entropy measurement of linkographs that investigates contributions of individuals. The results show some correlations with changes in behavior.

Keywords: Team designing, measurement of learning, protocol analysis.

1. BACKGROUND

An earlier research [1] hypothesized that in order for a team to improve its performance, members need to adjust their actions and behavior through learning. The result, in that case study of brainstorming session of seven participants described in this paper, showed that by counting the words and the turn-taking, there were measurable behavioral changes. For example, the number of words remained constant but the number of turns varied with an increasing trend, Figure 1(a), and the formation of sub-teams, Figure 1(b).

This paper continues the study by examining both the syntactic structure and semantic content with design issues and considering those issues with idea links. We hypothesise that the interactions between team members increase toward the end, the interaction of the number of issues also increases which would be indicators they have learned to collaborate more.

1.1. The Data

Data was obtained from the protocol provided as part of Design Thinking Research Symposium 7 [2]. The team in the protocol consisted of a business consultant, who acted as the moderator (Allan), three mechanical engineers (Jack, Chad and Todd), an electronics business consultant (Tommy), an ergonomicist (Sandra), and an industrial design student (Rodney). They were all from the same company and the student, Rodney, was on internship with the company [1].

The brainstorming session lasted for one hour and thirty-five minutes. It can be divided into two episodes of fifty-five and forty-three minutes lengths respectively. In the first episode they focused on ideas to solve the problem of keeping the print head in contact and at the optimum angle to the media, despite wobbly arm moments. In the second episode, they dealt with ideas to protect the print head from abusive use and overheating.

1.2. FBS Design Issues Measurement as Indication of Learning

The communication of the participants was re-segmented based on the ontological issues of Function, Behavior and Structure (FBS) [3, 4], Figure 2. The transcript was segmented such that each segment

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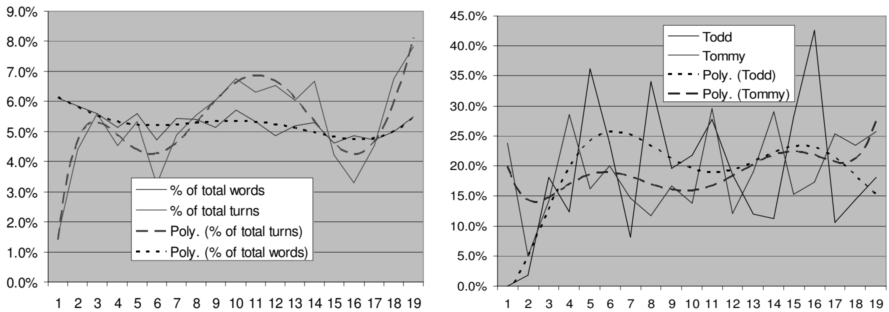


(a) (b)

Figure 1. **(a)** The percentages of total words and total turns in five minutes intervals for the entire team, "Poly" is the polynomial line of best fit. **(b)** The formation of cross-discipline sub-team [1].

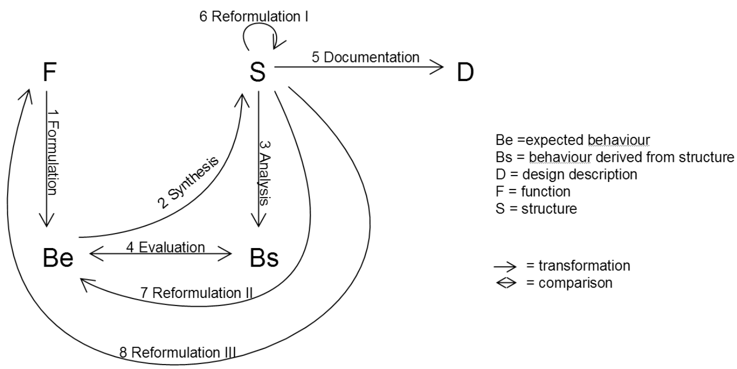


Figure 2. The FBS ontology of designing as a tool to measure learning.

contained only a single issue. We compared the number and the distribution of the FBS design issues of the two episodes with the hypothesis that there is a change of behavior. This will also gives us the rate of issues being dealt with, as a group and as individuals, in the two episodes of the session. We conjecture that this rate might give us some idea of individual learning concerning collaboration.

1.3. Linkography, Intra — Inter-personal Design Processes as Indicators of Learning to Collaborate

Linkography [5] is a graphic representation of the semantic links between the protocol segments. The links are constructed by a human discerning if two segments should be connected based on their semantic connection.

Social interaction has long been associated with learning. However, we focus this study on design interactions, interactions that have direct impact on the designed artifact. In order to capture the interaction we need to know who initiated an issue and who responded to that issue. For example when one participant raised a functional issue and another participant responded with an expected behavior issue, the second participant was actually formulating the design problem since going from function to behavior is the process "formulation". We view that this kind of interpersonal design processes are essential for collaboration. We expect as an individual learns to collaborate within that team there is a decrease in intrapersonal design processes and an increase interpersonal design processes.

With a linkograph and the FBS coding scheme we can trace these two types of interactions that constitute the design processes of individuals. Figure 3 shows a linkograph connecting the design issues. Column 1 in this figure is the participant, column 2 is the segment number and column 3 is the

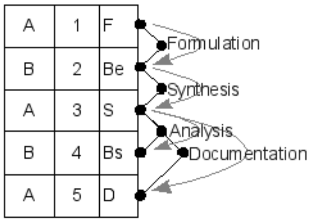


Figure 3. Exemplar case showing the production of the intra- and interpersonal design processes from the construction of the linkograph. Formulation, synthesis and analysis are all interpersonal processes and documentation is an intrapersonal process in this example.

design issue of the protocol. The dots represent the segments and the links and the gray arrow lines represent the derived design processes. The four links represent four design processes.

1.4. Entropy Variation and Learning

In information theory, entropy is used to measure the amount of information in terms of potential. Previous design research claims that the entropic measurement of linkographs indicates idea generation opportunities [6, 7]. It measures the saturation and distribution of the links of a linkograph. For example, zero entropy could mean two things: (1) the idea (or a segment) does not have any links due to it being not useful, too novel or crazy or (2) the segment is linked to all the segments indicating fixation and no novelty. It measures the goodness and contributions of ideas. We hypothesise that individuals' entropy variation over the session bear a relationship to learning.

2. CODING AND RESULTS

Two remotely-located independent coders segmented and coded the sessions separately. Both coders were familiar with the FBS ontology and they arbitrated through internet telephony to agree upon the final codes. The segments were discussed and agreed before coding. The inter-coder agreement was over 80% and each coder's agreement with the arbitrated set was over 88%. Table 3.1. shows examples of each code.

2.1. Design Issues

After arbitrating there were 1,280 segments that contained design issues. Table 4.1. summarizes the counts and percentages of each issue of the two episodes. The rates per minute of issues being raised are 12.77 and 14.33 for the first and second episode respectively.

If we assume that the rate of issues being raised is directly related to the design cognition rate, then the team had a 12% increase in design cognition rate in the second episode. This raise indicates

Table 1. Examples of coding.

Code	Example
F Function	"I mean it only moves in one axis that's the standard plain thermal paper err and then it can draw"
Be Expected Behavior	"so there needs to be this contact maintained"
Bs Behavior from Structure	" I mean it only moves in one axis "
S Structure	"a sledge or a snowboard a skis or snowboard"
D Design Description	(write: sledge)
Not Coded	"yeah, we'll come to that in a minute"

Table 2. Count and Percentage of Issues.

Issues	1st episode Count	1st Percentage	2nd episode Count	2nd Percentage
F	39	5.9	8	1.3
Be	151	22.7	124	20.1
Bs	172	25.9	197	32.0
S	251	37.8	261	42.4
D	51	7.7	26	4.2
Total	644	100	615	100

they were designing faster which supports our hypothesis that they learned to collaborate during the session.

2.2. Design Links

Again the links were established by two remotely-located independent researchers and the two sets of links were arbitrated through internet telephony. There are 5,194 links; 2,659 links were in the first episode and 2,535 links were in the second episode.

The rate per minute of design processes of the first and second episodes are 51.13 and 58.95 respectively. These translate to a 15% faster rate in the second episode than the first. Goldschmidt [8] used the term link index (number of links divide by number of segments) to benchmark design productivity. In this case the link index for the first and second episodes are 4.00 and 4.11 respectively, which converts to 2.8% productivity difference.

Figure 4 shows the distribution of the design processes of the first and second episodes. There were less formulation and type III reformulation, which is related to function, in the second episode. Table 3 shows the counts and percentages of each design process of the two episodes. Not all the links were translated to design processes, for example we did not count Bs to Bs links, which usually are further analysis.

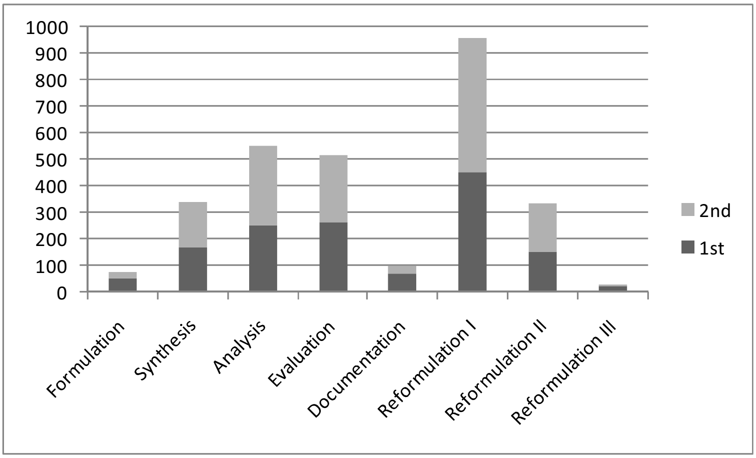


Figure 4. The distributions of design processes of the whole team.

Table 3. Count and Percentage of FBS processes.

Processes	1^{st} episode Count	1^{st} Percentage	2^{nd} episode Count	2^{nd} Percentage
Formulation	54	3.8%	20	1.4%
Synthesis	168	11.7%	170	11.6%
Analysis	253	17.6%	297	20.3%
Evaluation	263	18.3%	253	17.3%
Documentation	69	4.8%	31	2.1%
Reformulation I	453	31.6%	504	34.5%
Reformulation II	154	10.7%	178	12.2%
Reformulation III	20	1.4%	7	0.5%
Total	1434	100%	1460	100%

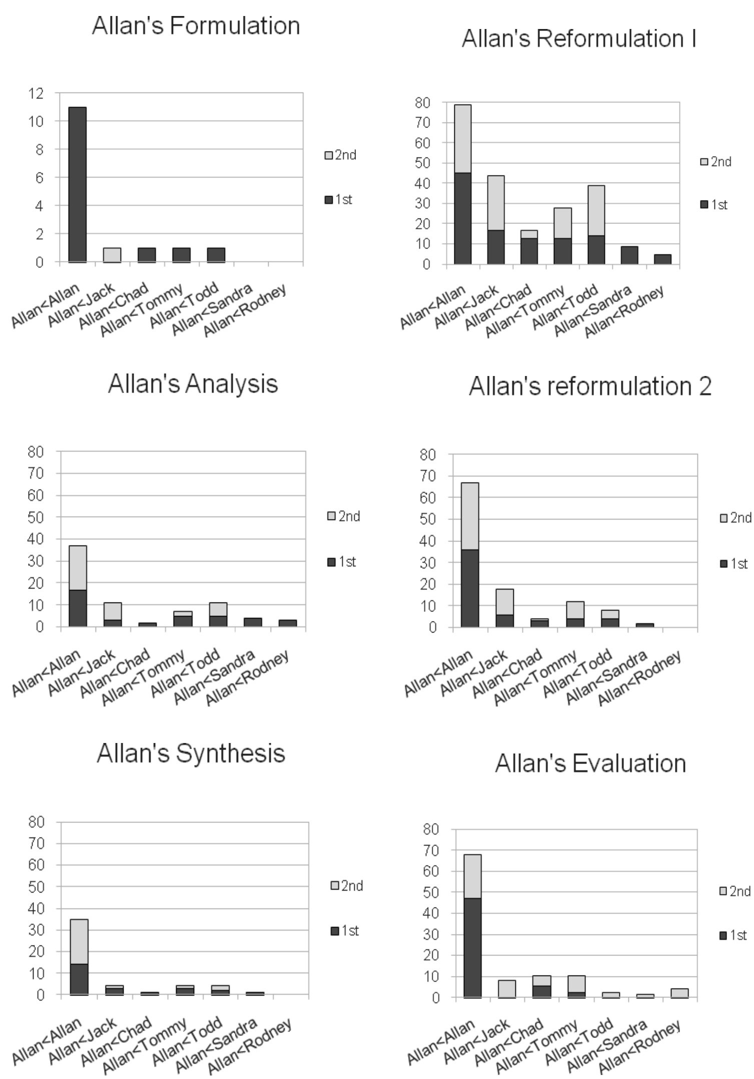


Figure 5. The processes and their team member sources between Allan and other members of the team.

2.2.1. Intra — and Interpersonal Processes

We examined the interactions between team members during design processes since each link in the linkograph has an individual at both ends as indicated in Figure 3. Figure 5 shows Allan's intrapersonal and interpersonal design processes.

The preliminary results shown in Figure 5 indicate that self is the primary source of design processes. This is an unexpected result as many believe that brainstorming or group process is one of the important sources for ideas. In comparing the number of design processes of the first episode and second episode, the result for Allan is mixed. For the Evaluation process, inputs from others become more dominant in the second episode. However, for the other design processes, there is not enough evidences to support

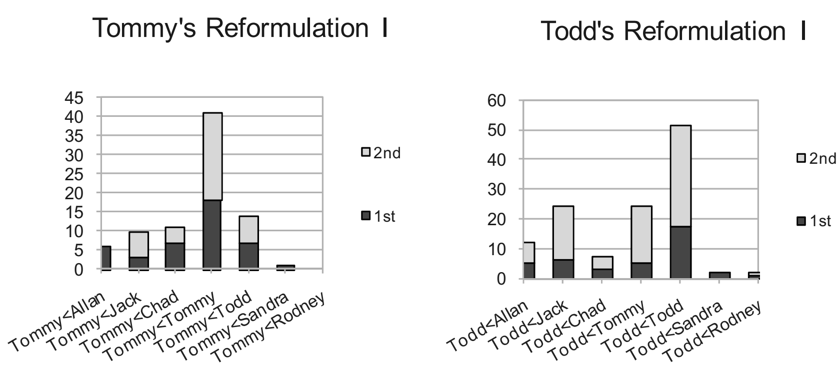


Figure 6. Chars showing Tommy and Todd's intra- and inter-personal reformulation I.

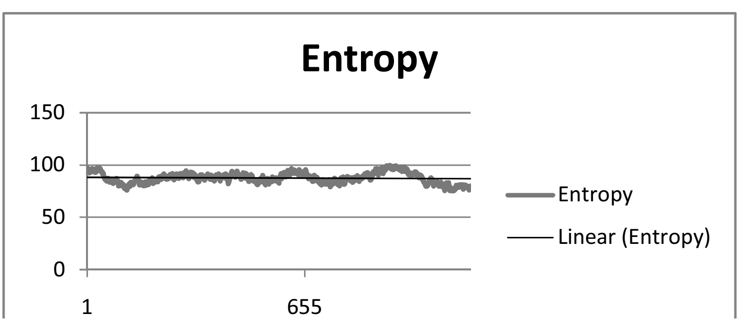
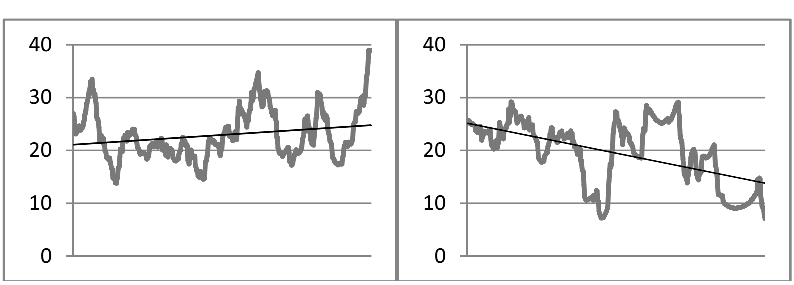


Figure 7. Entropy variation of the session, segment 655 marks the start of the second episode.



(a) **(b)**

Figure 8. **(a)** Allan's entropy of the first episode (segment 1 to 526). **(b)** Allan's entropy of the second episode (segment 655 to 1152).

our conjecture that he learned to collaborate. We assessed the intra –and interpersonal design process of the other members of the team but did not find an obvious trend. Further investigation is required to study this dynamic relationship between intra –and interpersonal processes. Figure 6 shows the type I reformulation of Todd and Tommy, both intra and interpersonal.

2.3. Entropy Variations

The entropy measurement is sensitive for different number of segments. In order to compare here we specify a 128 segment window as the basic unit for the entropy calculation. We measure the forelink and backlink entropy only. Figure 7 is the entropy variation of the group with this 128 segment window sliding across the whole session in one segment increments. The entropy remains fairly constant with a slight drop at the end of the session. This indicates the team's ideas generation opportunity remains fairly constant.

2.3.1. Individual Entropy Variations

Figure 8 plots the entropy variation of Allan, the moderator. In the first episode, Figure 8(a), his entropy average value was 23.6, and climbed to nearly 40.0 at the end of the episode. There was an increasing trend in this episode. However, in the second episode, Figure 8(b), his average entropy was 19.5 and had a decreasing trend.

The group's total entropy remained fairly constant in both episodes, both average at 87.54. However, Allan's entropy dropped; this could indicate that Allan learned to be a better moderator because he was better at enhancing others to contribute ideas in the second episode.

Figures 9 and 10 show the entropy variation and trend line of the sub-team Tommy and Todd respectively. Tommy's average entropy for the first and second episodes is 16.7 and 19.1 respectively;

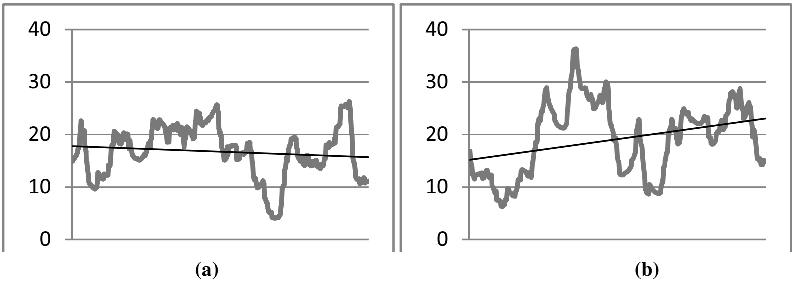


Figure 9. **(a)** Tommy's entropy of the first episode (segment 1 to 526). **(b)** Tommy's entropy of the second episode (segment 655 to 1152).

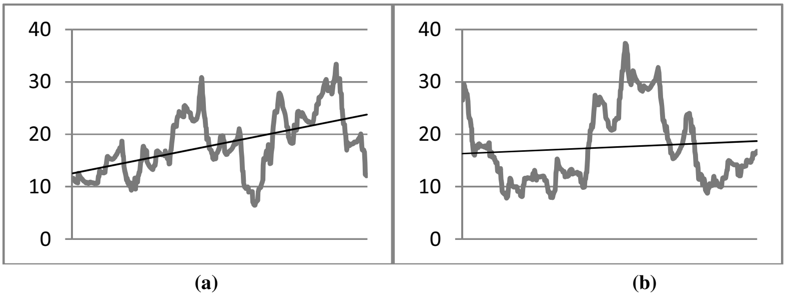


Figure 10. **(a)** Todd's entropy of the first episode (segment 1 to 526). **(b)** Todd's entropy of the second episode (segment 655 to 1152).

and Todd's average entropy for the first and second episodes is 18.3 and 18.6 respectively. Both of them were contributing more in the second episodes.

3. CONCLUSION AND DISCUSSION

In this paper we presented the results of using quantitative tools to study behavior changes so as to measure if participants learned to collaborate. We separated an in-situ brainstorming session into two parts and compared them.

A previous study showed that, in terms of communication, there is an increase in turn-taking with the word count remaining constant. In this paper we took into account the design semantics of the communication. Instead of using turn-taking, the protocol was segmented and coded according to design issues. The results showed the second part had a faster rate of both dealing with design issues and design processes. This indicates they were more effective in the second part of the brainstorming in terms of processing issues.

We also examined the interaction of issues among individuals by linking related segments. The notion of intra- and interpersonal design processes was introduced. We hypothesised that there would be more interpersonal processes in the second part of the session so as to confirm they all learned to collaborate. However, the results were mixed and in this case study the hypothesis could not be confirmed. The results showed that self is a primary source of design processes. Further investigation is required to generate more conclusions from this data.

Entropy is a measurement that abstracts the semantic links into a value that was hypothesised to correlate with idea generation opportunities. The entropy of the session remained fairly constant while individuals' contributions varied. We showed that the moderator appeared to have learned to perform better as a moderator by this measurement.

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