4 LEARNING TO COLLABORATE DURING TEAM DESIGNING: SOME PRELIMINARY RESULTS FROM MEASUREMENT-BASED TOOLS

John S Gero* **and Jeff WT Kan**†

**Krasnow Institute for Advanced Study, USA and University of Technology, Sydney, Australia*
E-mail: john@johngero.com
†*Faculty of Architecture, Design and Planning, The University of Sydney, Australia,*
E-mail: kan.jeff@gmail.com

This paper reports on preliminary results of an explorative study of a protocol analysis of team learning while designing using in-situ data. Two measurement-based frameworks are proposed. One framework is based on a sequential analysis of communication utterances and the other on codes using the Function-Behavior-Structure ontology and linked using Linkography. Only the former is reported in this paper. Results indicate that team learning occurs and can be discerned from an analysis of the utterances only but only at a high level of granularity.

Keywords: Team Learning, Design Collaboration, Protocol Analysis, Research Method.

1. BACKGROUND

New design ideas and products are increasingly the result of teamwork. Often a team is put together for a single project and the members of the team need to learn to collaborate. Is collaboration an innate quality of humans or do they have to learn to collaborate? We hypothesise that in order for a team to increase performance, members need to adjust their actions and behaviour through learning. Learning is difficult to study because of the paucity of data and the lack of adequate tools. Most data comes from laboratory (in-vitro) experiments with little coming from in-situ sources. Much in-situ sourced data is too noisy and unstructured for current analysis tools. This study uses in-situ data of a team of cross-disciplinary professional designers collaborating on a novel product design.

1.1. Learning Research

Depending on the field of study, for example education or organization behaviour, the focus of exploring team learning engages with a different set of issues. Bransford *et al.*[1] summarized the development of learning research as "from speculation to science". Initially, behaviourists conceptualised learning as a process of connecting stimuli and responses. They assumed the motivation to learn is determined primarily by drives, such as hunger, and the availability of external forces, such as rewards and punishments. This view is rather restrictive in studying phenomena such as understanding, reasoning, and thinking. Cognitive science, which emerged in the late 1950s, provides new tools and methods to examine learning in a scientific manner (e.g. Ref. 2–4). Meanwhile rigorous qualitative research methodologies have provided perspectives on learning that complement and enrich experimental research (e.g. Ref. 5 and Ref. 6).

The new science of learning stresses learning with understanding which leads to the focus on the processes of knowing (e.g.Ref. 7, and Ref. 8). Barab[9] considered the core of traditional pedagogy is a polarization of the learner and the learning context that he called the "Cartesian paradigm" and he proposed an "ecological paradigm". The Cartesian model separates the individual (knower) from the environment (known) while the ecological model situates the learner within the learning context. Lifelong learning[10–12] is an example of situated learning Refs. 13 and 14 and is difficult to study because of the paucity of data and the lack of adequate tools. A recent analysis of tools[15] found that:

> "discussion of 15 instruments results in a number of critical conclusions. There are questions about the coherence between the theoretical base and the operational translation of the theory in the instruments. Instruments are hardly compared or contrasted with one another. As a consequence the empirical base of the validity of the instruments is limited. The analysis is rather critical when it comes to the issue of reliability."[15]

Most data comes from laboratory experiments with little coming from in-situ sources. Much in-situ sourced data is too noisy for many of the direct statistical tools to be used successfully and requires filtering.

1.2. Learning to Design Collaboratively

In the area of design learning, there are studies Refs. 16 and 17 that explore cognitive style and design learning. There are also studies that showed the differences between novice and experts designers in terms of knowledge, problem solving behaviour, and cognitive activities Refs. 18 and 19 — this difference may be attributable to learning. These studies focus on individual designers learning designing.

Team interaction remains one of the most important elements in developing ideas.[20] Systematic studies of designers started in the 1970s.[21] Compared to individual designing, studies of teams[22–25] have shown that there is a multiplicity of factors that contribute to or affect team designing. Some of these factors are role and relationship, trust, social skills, common ground, organisational context and socio-technical conditions. How team members learn these issues has not been well studied.

> "Dewey[26] described learning as an iterative process of designing, carrying out, reflecting upon, and modifying actions, in contrast to what he saw as the human tendency to rely excessively on habitual or automatic behaviour".[27]

Edmondson[28] treated learning in a team as a process that attempts to articulate the behaviours through which such outcomes were considered as: adaptation to change, greater understanding, or improved performance in teams. We assume team members need to learn: 1) to acquire skills (social and communicational); 2) to establish their role and trust; and 3) to gain knowledge of common ground for collaboration, all with the result of producing performance as a team that is more than the sum of the performances of the individuals. We propose, initially, to study this kind of learning by examining their communication patterns to see if these patterns exhibit behavioural changes — both as individuals and as a group. Then, we further propose to investigate the semantics of the communication — verbal, written words and drawings — by coding and linking the communication content.

2. THE DATA

Data was obtained from the 7th Design Thinking Research Symposium.[28] The source data was a video of design meetings taking place in a product design practice. The data is made up of a 4-camera video recording, Figure 1, and the transcripts of the voice communication. 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 ergonomicist (Sandra), and an industrial design student (Rodney). They were all from the same company and the student, Rodney, was on an internship with the company.

In this brainstorming session,[29] the team was asked to provide ideas for solving technical issues of a working demonstrator of a thermal printing pen, Figure 2. Two main issues were: 1) keeping the print head in contact and optimum angle with the media despite wobbly arm moment; and 2) protecting the print head from abusive use and overheating. Observing the protocol, it can be divided into two episodes corresponding to these two issues.

Figure 1. A frame from the 4-camera video recording of a team of 7 designers collaborating.

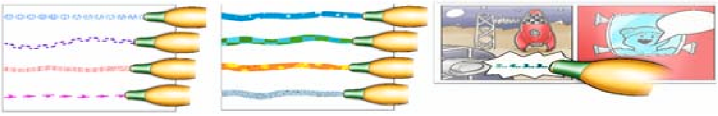


Figure 2. Illustrations of the function and behaviour of the design object: thermal printing pen.

Table 1. Measuring change of participations as a behaviour change of individuals that indicates learning.

		Observations	
Change in participation	Superficial behaviour	Number of words Number of turn-taking	Pure quantitative measures
	Underlying contributions that change performance of team	FBS contributions Number of ideas Strength of ideas (no. links) Spread of ideas (link distance)	Quantitative measures via coding and linking segments

3. PROPOSED STUDY FRAMEWORK

The units of analysis of this study will be the individual and the team. Learning is treated as a process that results in the improvement of the performance of the team. The performance is measured by the number of ideas and their impact within a specified timeframe. Behaviour is measured by a number of factors: contribution according to turn-taking; contribution according to word utterances; contribution according to semantic content in terms of quantity, strength or importance (number of links), inference or spread (link distance) of ideas, and the reformulation processes of the Function-Behavior-Structure ontology.[30] The transcript was segmented based on ideas and turn taking. Segments form the basis of a linkograph of the protocol.[31] A linkograph is constructed by linking the semantic contents of related segments. The framework is shown in Table 1. This paper only examines and measures the number of words and turn-taking. Markov analysis is used to examine the pattern of turn-taking.

4. RESULTS

4.1. Word Count

A participant was deemed to dominate a time interval if the word count of that individual was over 30% in that interval. Active participation can be observed when turn taking was over 15%, the average participation percentage for 7 participants. Table 2 presents the total number of words and turns in five

Table 2. Total number of words and turns in a five minutes interval.

Interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Total no. words	907	863	828	761	830	700	804	800	758	845	786	717	766	782	684	717	700	738	810
Total no. turns	21	61	78	63	74	45	68	77	84	94	88	91	84	93	59	46	63	94	109

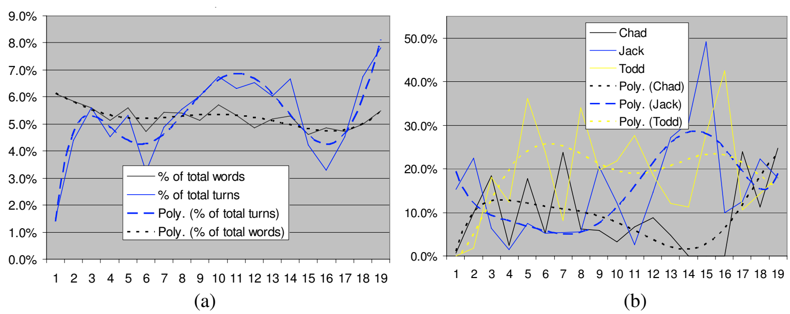


Figure 3. (a) The percentages of total words and total turns in a five minutes interval, and (b) the percentages of word count of the three mechanical engineers. "Poly" is the polynomial line of best fit.

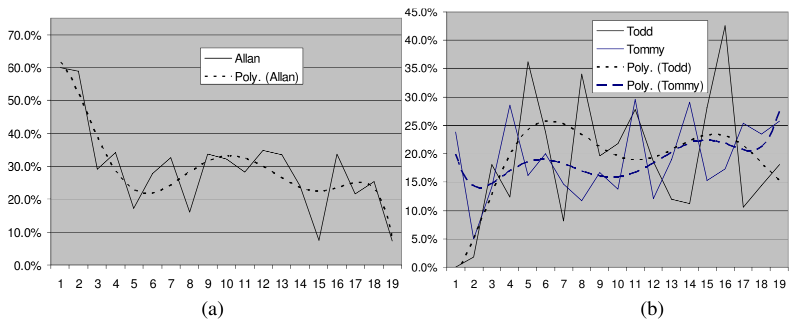
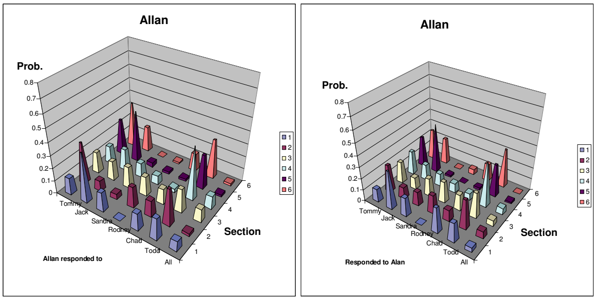


Figure 4. (a) Allan's word count, and (b). the percentages of word count of Todd and Tommy. "Poly" is the polynomial line of best fit.

minutes intervals across the session. Figure 3(a) is the corresponding normalized trends of word count and turns.

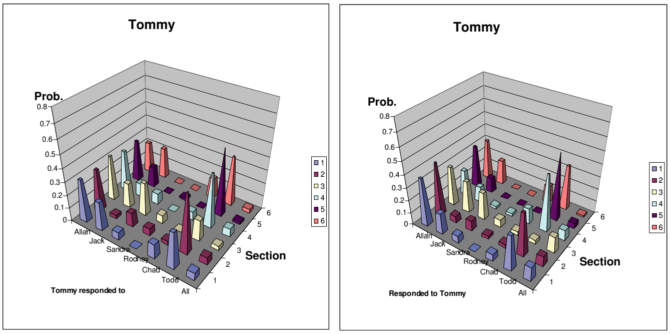
The group of mechanical engineers was the biggest group with the same background. Since they are of the same design profession, one may expect they share similar mental models, hence their conversation may display a common pattern. However, looking at the curves in Figure 3(b) did not suggest any obvious correlating patterns. Allan, the moderator, controlled the meeting at the beginning. His word contribution decreased after 15 minutes and stayed fairly consistent until the last 10 minutes, Figure 4(a). He dominated over 40% of the time during this session. Todd was the most active participant in this group according to word count and he dominated about 15% of the time. Figure 4(b) shows that the curves of Todd and Tommy are of similar shape from the 2nd interval until the 17th interval; they formed a cross-discipline sub-team which is confirmed in the Markov transition table, Table 3 in the next section.

Our hypothesis is that an individual will exhibit behavioural changes when s/he learns to collaborate with others. Looking at the team as a whole their percentages of interactions increased but their number



(a) (b)

Figure 5. (a) Probability of Allan responding to other members; (b) probability of other member's intermediate response to Allan.



(a) (b)

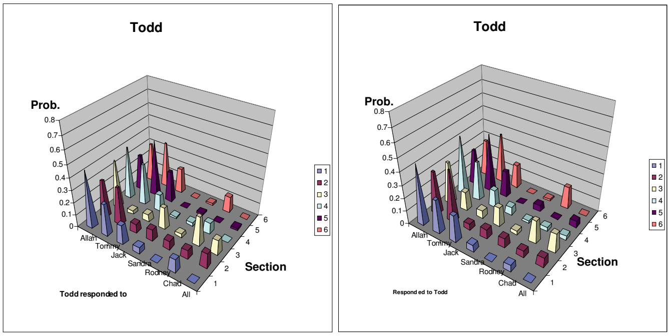
Figure 6. (a) Probability of Tommy responding to other members; (b) probability of other member's intermediate response to Tommy.

of words remained fairly constant. This may indicate they have learned by producing a shared mental model, which is implied by the increased interaction with each interaction requiring fewer words to communicate.

4.2. Turn Taking: First Order Markov Chain

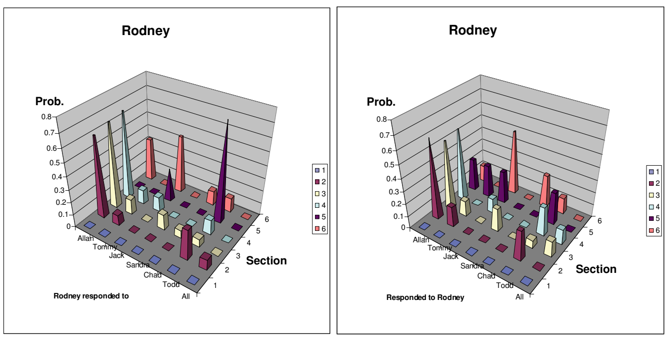
In order to investigate the transition trends between turns we modelled the turn taking behaviour in term of first order Markov chains. The session was re-divided into six sections (15 minutes each), with the last section being 19 minutes. These longer durations provides a larger set on which to base the transitions. Sandra left during the fifth section. Figure 5 shows the transition probabilities of response to/from Allan, the leader, in the six sections. Tommy, Jack, and Todd were engaged with Allan throughout all the six sections but Sandra and Rodney were less engaged in the beginning and the end of the session. In the first section Allan received responses from the entire group except for Rodney, and he interacted with Jack most frequently. In the second section Allan formed a partnership with Todd and Tommy. In the third section Allan's responses (to and from) were mostly evenly distributed. In the fourth section his partnership with Todd's surfaced and this sub-team was joined by Tommy and Jack until the end.

Figures 6 and 7 present the transition probabilities of Tommy and Todd respectively. Indicated by the tallest columns in the figures, we can observe their partnership was strong except for the third section; the probability of their interactions was closer to or over 30 percent. Allan, the moderator, also interacts frequently with this sub-team.



(a) (b)

Figure 7. (a) Probability of Todd responding to other members; (b) probability of other member's intermediate response to Todd.



(a) (b)

Figure 8. (a) Probability of Rodney responding to other members; (b) probability of other member's intermediate response to Rodney.

Table 3. Transition table showing the probability of transition from one member to another.

	Allan	Tommy	Jack	Sandra	Rodney	Chad	Todd	All
Allan	0.00	0.21	0.21	0.09	0.08	0.11	0.27	0.03
Tommy	0.31	0.00	0.15	0.04	0.01	0.07	0.35	0.06
Jack	0.40	0.20	0.00	0.06	0.03	0.04	0.22	0.07
Sandra	0.37	0.21	0.16	0.00	0.02	0.09	0.15	0.00
Rodney	0.47	0.10	0.12	0.06	0.00	0.04	0.16	0.06
Chad	0.29	0.16	0.16	0.02	0.02	0.00	0.26	0.10
Todd	0.33	0.33	0.14	0.04	0.03	0.08	0.00	0.04
All	0.29	0.14	0.19	0.09	0.01	0.14	0.14	0.00

In the first section Rodney did not interact with anyone and in the second section he began to join the conversation of the dominant sub-team (Tommy, Todd and Allan), Figure 8. Allan took notice of him and actively responded to him in the second, third and fourth sections. There is an increase interaction between Jack and Rodney in the last three sections.

Table 3 shows the transition probabilities from one member to another of the whole session. Figure 9 is a graphical representation of Table 3, the x and y-axis are the team members and the z-axis represents the transition probability from a member in the y-axis to a member in the x-axis. The rows in the y-axis add up to one; and the rows in the x-axis present the absolute quantity of participation. As can

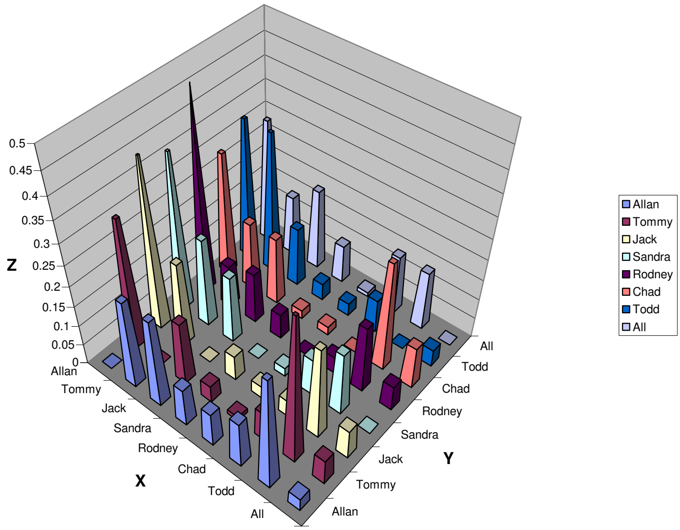


Figure 9. 3D representation of the transition probability matrix — the Markov chain.

be observed from this chart Allan, Tommy, Todd, and Jack were the most active persons picking up conversations (tall columns) whereas Robert, Sarah, and Chad were the quietest (short columns).

5. FINDINGS AND DISCUSSION

In this preliminary study, by simply counting the words and the turn-taking we were able to discern some behaviour patterns changes that indicate the formation of sub-team. The number of words remained fairly constant (the trend was slightly decreasing) throughout the session but the number of turns varied with an increasing trend. This indicates they used fewer words to communicate for each interaction as the team depended more on tacit knowing as they learned to collaborate with each other. First order Markov analysis allowed us to study the relationship of members in terms of intermediate transitions of utterances. This helped us to confirm the formation of sub-teams and examine individual interaction patterns. These preliminary results indicate that this group of individuals exhibited behaviour associated with learning to collaborate.

The next step is to study the content with the FBS contributions and idea links – linkography.[31] With the same design problem within a design session, the FBS contribution pattern of an expert is different from a novice. Therefore, we propose to measure the FBS contributions as an indicator of performance changes and learning. Kan *et al*.[32] introduced the use of Shannon entropy[33] as a potential measure of the progress of a protocol through measuring the entropy changes in a linkograph. Shannon entropy measures the information carried by a message or symbol and, here, can be related to the amount of collaboration and hence to learning to collaborate. The rate of change of entropy across sequential segments will be explored to determine whether it matches the learning rate.

ACKNOWLEDGEMENTS

This research is supported by a grant from the US National Science Foundation, grant no. SBE-0750853

REFERENCES

[1] Bransford, J. D. Brown., A. L., R. R. and Cocking, (1999). How People Learn: Brain, Mind, Experience, and School, Developments in the Science of Learning, National Research Council, National Academy Press, Washington, DC.
[2] Anderson, J. R. (1982) Acquisition of cognitive skill, Psychological Review, **89**, 369–406.

[3] Anderson, J. R. (1987). Skill acquisition: Compilation of weak-method problem solutions, Psychological Review, **94**, 192–210.
[4] De Groot, A. D. (1965). Thought and Choice in Chess, The Hague, the Netherlands: Mouton.
[5] Erickson, F. (1986). Qualitative methods in research on teaching in Handbook of Research on Teaching, New York, Macmillan, 119–161.
[6] Hammersly, M, and Atkinson, P. (1983). Ethnography: Principles and Practices, London: Travistock.
[7] Piaget, J. (1952). The Origins of Intelligence in Children, M.Cook, trans. New York: International Universities Press.
[8] Vygotsky, L. S. Thought and Language. Cambridge, MA, MIT Press.
[9] Barab, S, A. (2001). Ecological Paradigm: seeking a new model of learning, http://inkido.indiana.edu/research/theory.html.
[10] Hargreaves, D. H. (2004). Learning for Life, The Foundations of Lifelong Learning, Policy Press.
[11] Field, J. (2006). Lifelong Learning and the New Educational Order, Trentham Books.
[12] Rowden, R. W. (2006). Workplace Learning: Principles and Practice, Routledge.
[13] Lave, J. and Wenger, E. (1991). Situated Learning: Legitimate Peripheral Participation, Cambridge University Press.
[14] Wenger, E. (1998). Communities of Practice, Cambridge University Press.
[15] De Wever, B, Schellens, T, Valcke, M and Van Keer, H. (2006). Content analysis schemes to analyze transcripts of online asynchronous discussion groups: A review, Computers and Education, **46**, 6–28.
[16] Cross, N. and Nathenson, M. (1981). Design methods and learning methods, in J. Powell and R. Jacques (eds), Design Science: Method, Guildford, Westbury House, 281–296.
[17] Yukhina, E. (2007). Cognitive Abilities & Learning Styles in Design Processes and Judgements of Architecture Students, PhD thesis, University of Sydney, Sydney.
[18] Kavakli, M. and Gero, J. S. (2003). Strategic Knowledge Differences between an expert and a novice designer, in U Lindemann *et al* (eds), Human Behaviour in Design, Springer, 42–51.
[19] Dorst, K. (2004). On the problem of design problems-problem solving and design expertise, The Journal of Design Research, 4.
[20] Salter, A. and Gann., D. (2002). Sources of ideas for innovation in engineering design, Research Policy, **32**, 1309–1324.
[21] Eastman, C. (1969). On the analysis of intuitive design processes, in G.T. Moore (ed), Emerging Methods in Environmental Design and Planning, 21–37.
[22] Cross, N. and Cross, A.C. (1995). Observations of teamwork and social processes in design, Design Studies, **16**, 143–170.
[23] Gabriel, G. C. (2000). Computer Mediated Collaborative Design in Architecture: The Effects of Communication Channels in Collaborative Design Communication [i.e. Communication], PhD thesis, University of Sydney, Sydney.
[24] Olson, G. M. and Olson, J. S. (2000). Distance matters, Human -Computer Interaction, **15**, 130–178.
[25] Zolin, R. Hinds, P. J. Fruchter, R., and Levitt, R. E. (2004). Interpersonal trust in cross-functional, geographically distributed work: a longitudinal study, Information and Organization, **14**, 1–26.
[26] Dewey, J. (1922). Human Nature and Conduct, New York, Holt.
[27] Edmondson, A. (1999). Psychological Safety and Learning Behavior in Work Teams, Administrative Science Quarterly, **44**, 350–383.
[28] McDonnell, J.and Lloyd, P. (eds) (2007). DTRS7 Design Meeting Protocols: workshop proceedings.
[29] Osborn, A. (1953). Applied Imagination: principles and procedures of creative thinking, Scribner, New York.
[30] Gero, J. S. (1990). Design Prototypes: a knowledge representation schema for designAI Magazine, **11**(4), 26–36.
[31] Goldschmidt, G. (1990). Linkography: assessing design productivity, Cyberbetics and System '90, R. Trappl, ed., World Scientific, Singapore, 291–298.
[32] Kan, J. W. T., Bilda, Z. and Gero, J. S. (2007). "Comparing entropy measure of idea links in design protocols, AIEDAM, **21**(4), 367–377.
[33] Shannon, C. E. (1948). A mathematical theory of communication, The Bell System Technical Journal **27**, 397–423.