Exploring the Design Cognition of Concept Design Reviews Using the FBS-based Protocol Analysis

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Abstract: *Concept design reviews and critiques are essential components in most design education programs. This paper explores this evaluative activity with a well-developed methodology that has previously been used to analyze the design cognition of designing, i.e., the FBS-based coding scheme used in protocol analysis. It studies two case studies of an industrial design critique and a mechanical engineering design review. These concept review conversations were segmented and coded into a sequence of design issues on the basis of FBS-based coding scheme. The frequencies of design issues, the ratio of problem-related issues to solution-related issues, and the cumulative occurrences of design issues along timelines were used as measurements for exploring the design cognition of concept design review activities. The results are discussed in terms of (1) inter-disciplinary differences of concept design review, and (2) comparisons between concept review sessions and designing activities.*

Keywords: design cognition, design concept review, FBS ontology, protocol analysis

1. Introduction

Concept design reviews and critiques are important elements in most design education curricula. During the review or critique sessions, instructors not only appraise students' design work and provide feedback and suggestions for improvements, but the conversations also implicitly pass professional expertise and values to help students becoming competent designers. Apart from their common features (e.g., instructor appraisals, two-way interactions between the instructor and students), there seem to be a variety of review and critique styles among different design disciplines. Cardella et al.'s (2014) paper describes two genres of design feedbacks, i.e., design review and design critique. Different disciplines seem to adopt different terminologies. Mechanical engineering design (ME) often defines "design review" as a specific type of engineering meeting, playing multiple roles of concept evaluation, process monitoring and control, as well as information sharing (Huet, Culleya, McMahon, & Fortin, 2007). Industrial design (ID) and architecture have a "studio" tradition (Schön, 1985), referring their appraisal sessions to "design critique" (often "crit" in short). Design critiques not only help young students to improve their specific design concepts, they also place more emphasize the role of socializing students into their discipline via a master-apprentice type of interactions. Christensen and Ball's (2014) analysis of critiquing cultures also indicates profound differences between ME review sessions and ID and architecture's critiques.

Design reviews and critiques, as specific forms of design activity, should share many features of design thinking through the design cognition behind the designing process. Some studies directly used the analysis of design reviews and critiques to explore the general form of design cognition. Schön (1991), for example, used an architecture critique case to illustrate designing as a form of reflective practice. The DTRS7 symposium "analyzing design meetings" also used design review meetings of a professional product team as a case for exploring common design cognition patterns (McDonnell & Lloyd, 2009). However, the differences between design reviews and designing processes have rarely been compared.

1.1 Interdisciplinary comparisons of design cognition

Design thinking is considered as one of the fundamental ways of thinking and knowing complementary to scientific thinking (Brown and Katz, 2009; Cross, 2008; Cross, 2011; Owen, 2006). This way of thinking is claimed to capture the essential aspects of the activities that designers perform across all design disciplines and domains (Brown & Katz, 2009; Lawson, 2006). Studying design cognition behind the designing processes and identifying the regularities in designing that transcend any specifics of designers or situation helps to elucidate the essence of design thinking.

One of the major challenges to studying this hypothesized regularity of designing is based on the notion that designing is not a singular form of human activity. A variety of activities are embraced under the umbrella of "designing", ranging from formalized engineering design to artistic design. Visser (2006; 2009) argued that designing is "one, but in different forms", i.e., there are both commonalities and differences in the design cognition of different disciplines and situations. Without a deep understanding of the differences due to specific disciplines and situations, our confidence in the regularity beyond those specifics of designing will be limited.

Inter-disciplinary differences of designing are relatively underexplored. A brief summary of some empirical studies into the disciplinary similarities and differences of design cognition is provided in Table 1. All of these published studies focused on designers' cognitive effort spent on the designing process that generates design solutions in response to the given requirements. Other forms of design activities, such as design review and critique, have not been adequately studied.

Table 1. Empirical studies reporting inter-disciplinary differences and similarities in design cognition

Publication	Research Focus	Design disciplines
Akin (2001, 2009)	Variants and invariants of design cognition (e.g., problem decomposition strategies)	Architecture vs Electronic Engineering vs Engineering design
Kokotovich and Purcell (2000)	Design representation's role in mental synthesis	Graphic Design vs Product Design
Purcell and Gero (1996)	Fixation effect	Industrial Design vs Mechanical Engineering Design
Kan and Gero (2011)	Designers' cognitive efforts	Architecture vs Software Design vs Mechanical Engineering
Jiang, Gero, and Yen (2014)	Cognitive emphasis on reasoning about design problem or design solution	Industrial Design vs Mechanical Engineering Design

Several studies in the DTRS 10 symposium focused on comparisons of design reviews between several design disciplines. Cardella et al. (2014) found that mechanical engineering and industrial design instructors provided different review environments. Purzer, Eila and Dick (2014) compared mechanical engineering, industrial design and choreography, and identified several interdisciplinary differences in terms of identity aspects. There is a paucity of comparing design review/critique and the designing processes.

1.2 Educational contexts of engineering and industrial design

Design reviews and critiques can take place both in educational and in practice contexts. This chapter focuses on the former context, more specifically, exploring the design review and critique conversations in the context of tertiary design education curricula.

Several interdisciplinary differences have been discussed in the literature between engineering design programs and the studio approach (e.g., ID and architecture). Both ME and ID curricula value the learning-by-doing approach, in which guided design projects serve as a cornerstone component. Different pedagogical styles may be implemented in ME and ID courses (Jiang & Yen, 2013) including project-based and problem-based teaching (Prince & Felder, 2006; 2007). Some distinctions can be drawn with regard to the "structuredness"/"openness" of the problem, varying degrees of self-direction, as well as investigative or solution-driven nature of the approach.

Samsuddin (2008) compared architecture studios and engineering laboratory classes by surveying students taking dual degrees. The perceived differences between these two educational settings cover many dimensions, e.g., semantic versus episodic modes of knowledge. The interdisciplinary differences of ME and ID's educational programs imply there should be considerable differences between ME review and ID critique sessions.

The aim of the research presented in this chapter is to explore the interdisciplinary differences of design reviews and critiques and how these differences could be connected to the interdisciplinary differences identified in the designing processes. The chapter briefly introduces the protocol analysis methodology used in design research, followed by an introduction to the FBS-ontologically-based coding scheme and the quantitative measurements than can be made from the coded protocol. This is followed by a brief outline of the two case studies and detailed presentation of the results. The chapter concludes with a discussion of the results and their implications.

2. Analyzing design cognition using protocol analysis methodology

2.1 Protocol analysis in general

Protocol analysis is one the most commonly applied methodologies for studying design cognition (Cross, Christiaans, & Dorst, 1996; van Someren, Barnard, & Sandberg, 1994). It is a formal observational research method. A design protocol is a record of the time path of designers' activities during the design activity, often in the form of videoed recordings. Design protocols are a particular form of qualitative data. They have to be transcribed, parsed and/or categorized in some ways and it is the transformed protocols on which the analyses are performed (Purcell, Gero, Edwards, & McNeill, 1996). Development or adoption of a coding scheme is an essential step in the design protocol analysis process.

Though most design protocol studies have focused the cognitive processes behind the designing processes, there are several studies applied this methodology into the analysis of design review and critique conversations. Goldschmidt, Hochman, and Dafni (2010), for example, developed a specific coding scheme for analyzing one-on-one architectural design critique. Adams et al. (2014) and Christensen and Ball's (2014) coding scheme is also specifically developed for design evaluations. The ad-hoc nature of the development of coding schemes in traditional protocol studies, however, limits their use to the specific cases they have been developed for, and hinders the cross-comparisons and generalizations of the results from different analyses (Gero, 2010). To overcome this limitation and enable the comparison between design review and the relatively well-studied domain, i.e., the designing process, this paper adopts an ontologically-based approach that can be applied in different design situations independent of the specifics of design disciplines, tasks and number of designers (Gero, Kan, & Pourmohamadi, 2011). The domain and discipline-independency of this method enables the cross-comparisons with a variety of previous protocol studies, and makes it possible to discuss the findings of this study in the context of existing design cognition knowledge gained in the prior studies of designing processes.

Kan and Gero (2009) have successfully applied this methodology into analyzing the engineering review meeting. The comparison between design review and designing processes however has not been addressed.

2.2 The FBS-ontologically-based protocol analysis

This ontologically-based protocol analysis methodology is guided by a general design ontology, the Function-Behavior-Structure (FBS) ontology (Gero, 1990; Gero & Kannengiesser, 2004; Gero & Kannengiesser, 2014; Kruchten, 2005). This ontology claims to describe all designing and designed things in terms of three fundamental ontological constructs: function, behavior, and structure. The function (F) of a designed object is defined as its teleology; the behavior (B) of that object is either derived (Bs) or expected (Be) from the structure, where structure (S) represents the components of an object and their compositional relationships. These ontological constructs are augmented by requirements (R) that come from outside the designer and design description (D) that is the document of any aspect of designing, both R and D are expressible in F, B or S, Figure 1. These six ontological constructs are called "design issues".

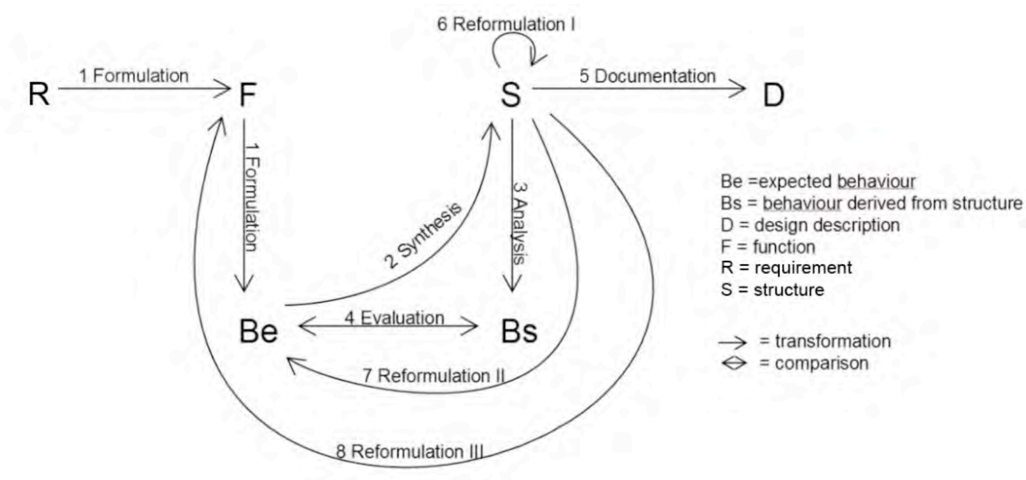

Figure 1. The FBS ontology with the resultants design processes delineated as transitions between the ontological constructs (after Gero & Kannengiesser, 2014)

To apply this ontology in protocol analysis, a discipline-independent coding scheme is developed with six categorical codes developed from the six design issues. The videoed design activities and their transcripts are segmented and coded using these six FBS design issues as codes. A FBS design issue is strictly assigned to only one segment. If an utterance is identified to contain more than one issue, it will be further segmented. Those utterances that do not fit in any of six the FBS categories are marked as others (O). All the O-segments are removed before a coded protocol is further analyzed.

It should be noted that there are two major views regarding what is a product/system's function, i.e., a product-centric view and an environment-centric view (Chandrasekaran & Josephson, 2000; Rosenman & Gero, 1994). Our definition of “function” belongs to the latter broader definition, referring to the teleology or purpose of a product. There is a body of literature, particularly engineering literature, that has adopted the former and narrower definition of function. “Function” code in Cardella et al.’s (2014) paper, for example, approximately matches “behavior” in the FBS coding scheme. Their two definitions of functions, “answers the question ‘will it work’” and “…could also be identified by calculations and feasibility”, could be coded as “expected behavior” and “behavior from structure” in the FBS coding scheme. These differences in the terminology should be noted when drawing comparisons between the FBS-based protocol analyses with other studies.

2.3 The FBS-based measurements and analysis methods

A number of measurements and analysis methods have been developed on the basis of FBS-based segmented and coded protocols (Pourmohamadi & Gero, 2011). This paper applies three FBS-based measurements: the frequencies of design issues (FBS codes), the problem-solution (P-S) index and cumulative occurrence of design issues. All the measures are independent of the length of the design session, as well as the number of participating designers. This allows the comparison of design protocols with different numbers of segments and participants. IBM SPSS v22 is used to calculate statistical results.

The frequencies of FBS design issues

The frequencies of design issues can be analyzed with the means of cross tabulations. The FBS codes consist of the rows of the cross tables, and other variables (e.g., discipline) form the columns of the table. Correspondence analysis is then applied to visualize and explore for latent patterns of the cross-tabular frequency data (Greenacre, 2007).

The problem-solution (P-S) index

The problem-solution (P-S) index is a meta-cognition concept and measures the cognitive focus on reasoning about either the design problem or the design solution (Jiang et al., 2014). It first categorizes the coded design issues into problem-related issues (requirement, function and expected behavior) and solution-related issues (behavior from structure and structure) based on a division of reasoning about the design problem and the design solution. The design description issue is not specified within the problem-solution division and is thus excluded in the analyses of P-S indexes.

The index is then calculated as the ratio of the summed frequency of problem-related issues over the summed frequency of solution-related issues, Equation (1). A P-S index value of greater than 1 indicates the designer expended more cognitive effort on reasoning about design problem than the design solution. A P-S index of less than 1 means the designer is relatively more focused on reasoning about design solutions than about the design problem.

$$\text{P-S index} = \frac{\sum(\text{Problem-related issues})}{\sum(\text{Solution-related issues})} = \frac{\sum(R,F,Be)}{\sum(Bs,S)} \qquad (1)$$

The cumulative occurrence of design issue

The cumulative occurrence of a design issue is formally defined in Equation (2). At a given segment *i*, the occurrence of the issue *x* (x_i) is counted as 1 if this segment is coded as *x*, or 0 otherwise. The cumulative occurrence of issue *x* is then calculated as a summed x_i from the beginning of a protocol to the current segment *n*, Figure 2. On the basis of this cumulative occurrence of design issues, two quantitative and two qualitative measurements and two quantitative measurements have been developed, Table 2.

$$c = \sum_{i=1}^{n} x_i \qquad (2)$$

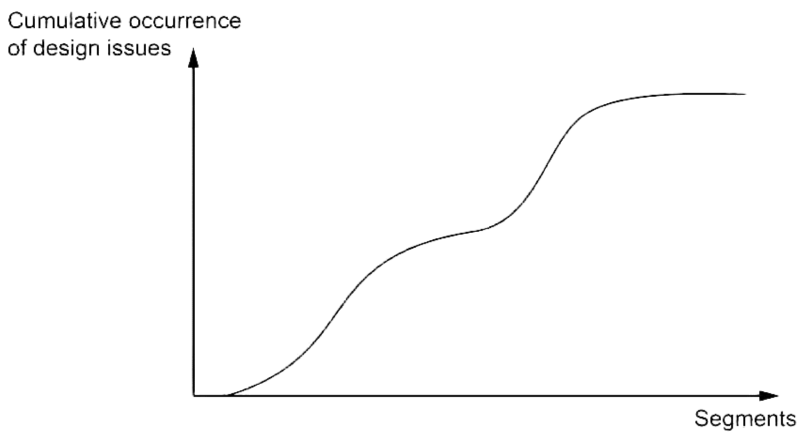

Figure 2. Graphical representation of cumulative occurrence of design issue in a design protocol (source: Gero, Kannengiesser, & Pourmohamadi, 2014)

Table 2. Measurements based on cumulative occurrence of design issues*

Measurement	Qualitative/quantitative	Explanation
Slope	Quantitative	Slope of the best-fit line, measuring the rate at which design issues are generated.
R^2	Quantitative	The graph of cumulative occurrence of an issue is linear when $R^2 \geq 0.950$
First occurrence at start	Qualitative	Whether this issue is considered from the start of the design session.
Continuity	Qualitative	Whether this issue is considered throughout designing or only up to a certain point.

* Source: Gero et al. (2014)

3. Two cases of design review conversations

This paper is based on two videoed datasets of concept review sessions of "Industrial Design (Graduate)" and concept design review (CDR) sessions of "Mechanical Engineering" available as part of the dataset of DTRS10 (Adams& Siddiqui, 2013). These review conversations were situated in two practice-intensive design courses, and more specifically half way through design projects. During these two review sessions, design students presented their early design works to their tutor and gained feedback in the form of concept design reviews or critiques.

Two design review conversations were chosen as case studies for this exploratory analysis, Figure 3. The selection criteria are mainly based on the duration of the review conversation and word counts of the transcript. The richness of verbalization and information exchange provide a sufficient quantity of data points (e.g., FBS codes) that enable stable results for quantitative analyses.

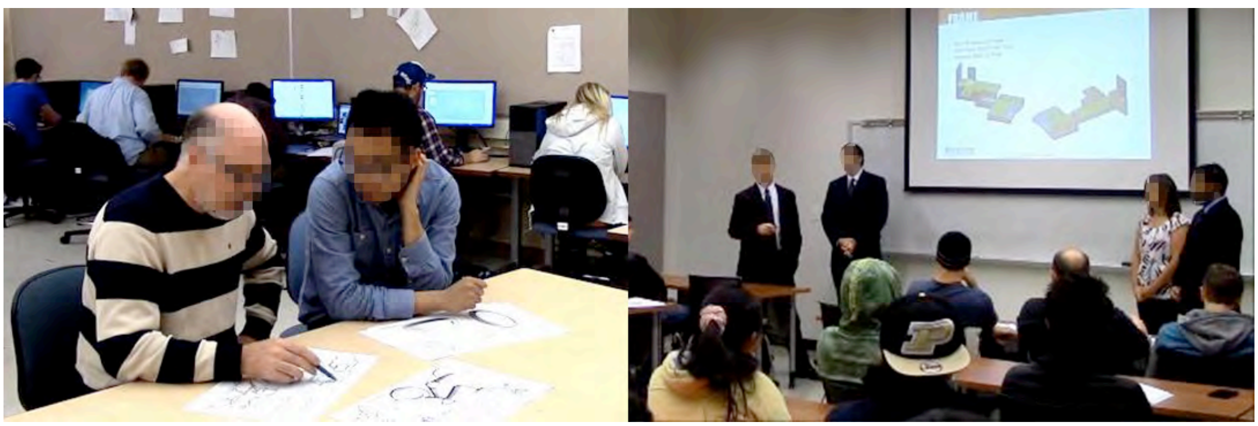

Figure 3. Screenshots of concept design review conversations (left: ID critique; right: ME review)

3.1 The case of ID critique

The ID critique occurred in the 4th week of an 8-week course project "Outside the laundry room". The requirements of this project are exploratory and open-ended. Students were asked to explore the laundry process from multiple perspectives and to look for design opportunities to enhance users' experience.

The chosen case took place after a two-week D-search (identifying design problems) and a two-week concept design. The critique session lasted about half an hour, a typical duration for a critique occurring in an ID studio. The instructor and student discussed design concepts individually. Design concepts were presented through the medium of design sketches. The instructor proactively assessed the student's design sketches, and the student clarified his ideas on the basis of the instructor's comments. A total of three concepts were reviewed sequentially.

3.2 The case of ME review

The ME review session took placed in the 8th week of a 16-week capstone engineering design course. It followed 2 weeks of problem definition and 3 weeks of design conceptualization. The course project required students undertaking a thorough designing procedure included modeling, approximation techniques, optimization, prototyping and testing.

The chosen case is about a group of senior engineering students (identified as the Purdue Prop Pullers [PPP] team) designing a portable, self-propelled tow bar that could pull light aircraft short distances over the ground. In this ME review session, the PPP team presented their design using a slideshow presentation in front of the instructor and an external jury. The audience, mainly the instructor, intercepted questions, asked for clarifications and proposed comments from time to time.

4. Results

4.1 Frequency of design issues

After the transcripts of the videos were segmented and coded, these two cases of concept design review conversations resulted in two sequences of design issues containing 342 segments (ID critique) and 307 segments (ME review) respectively. The frequency distributions of design issues are shown in Figure 4 and Table 3. The total occurrence of requirement issue in each session is less than 10 issues in terms of absolute frequency and less than 3% of total issues in terms of relative frequency. Thus, the requirement issue is excluded from the correspondence analysis and the analyses of cumulative occurrence of design issues, due to the small number of data points.

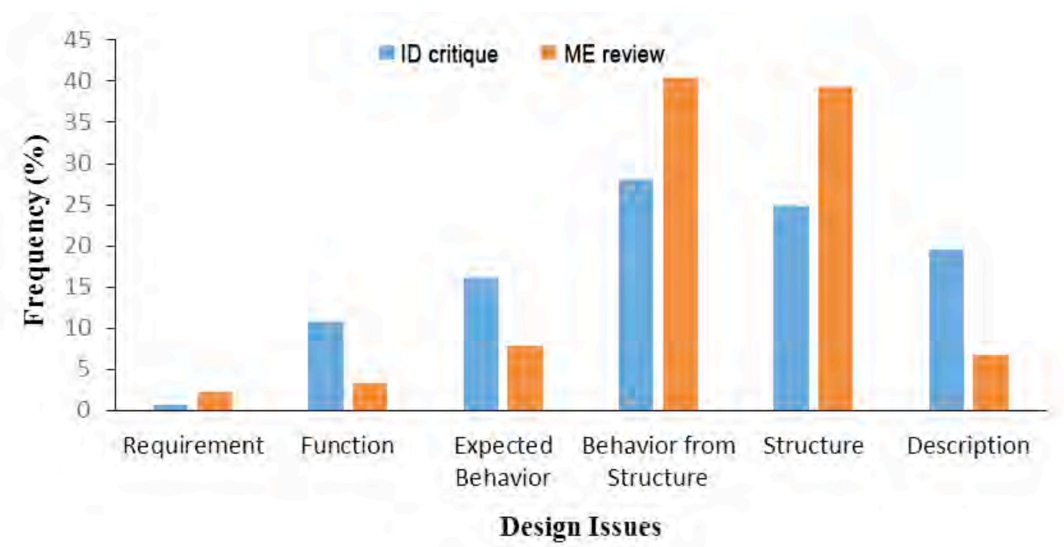

Figure 4. Frequency distribution of design issues

Table 3. Frequency distribution of design issues (% by column)

Design issue	ID critique			ME review			Total
	Overall	Student	Instructor	Overall	Student	Instructor	
Requirement	0.6	1.1	0.4	2.3	2.5	0.0	1.4
Function	12.8	22.0	9.4	3.3	2.9	6.3	8.2
Expected behavior	22.3	19.8	23.3	7.8	5.1	31.3	15.4
Behavior from structure	20.5	18.7	21.2	40.4	43.3	15.6	30.0
Structure	22.6	17.6	24.5	39.4	38.5	46.9	30.6
Description	21.1	20.9	21.2	6.8	7.6	0.0	14.3
(Total)	100	100	100	100	100	100	100

Between the two sessions, the design issue distributions are significantly different, $\chi^2(4)=98.41$, $p<0.001$, Cramer's V=0.394. The ID critique session focused more on function, expected behavior and description issues, while the ME review session focused more on behavior from structure and structure issues.

In order to further explore latent patterns underlying these two sessions, we introduced two additional variables into considerations. One is the role of participants, whether the instructor and student have different focuses during the review and critique conversations. The other is a coarse-grained temporal indicator. We divided the whole protocol into three chunks with equal number of design issues, to roughly represent the beginning, middle and the later stages of the review and critique conversations. A multiple correspondence analysis (MCA) is applied. This multivariate technique is conceptually similar to principal component analysis that uses categories of each variable as data points. It can transform a large set of categorical data into perceptual mapping, a two-dimensional graph, to illustrate the associations of specific categories between different variables. If two category points of different variables are close in distance and located in the same direction from the origin point (0, 0), then there should be associations between these two category points.

Figure 5 is the perceptual mapping visualizing the associations among design issues and other considerations. Dimensions 1 and 2 explain 56.3% and 36.7% of variance. The interdisciplinary differences are mainly distinguished by Dimension 1. Two problem-related issues, function and expected behavior, are located in the positive side and the two solution-related issues, structure and behavior from the structure, are located in the negative side. The results in Figure 5 indicate that the ID critique expended relatively more cognitive efforts on reasoning about the problem, while the ME review was more focused on design solutions. All three points of the temporal variable are close to zero in Dimension 1. This implies that the relative focuses on problem or solution do not vary over time. The meaning of Dimension 2 is not obvious on the basis of current data.

The date points of ID instructor, ID critique and description issue are close to each other. This corresponds to the qualitative analysis of the video that the ID instructor led the critique session, and his appraisal was mainly based on design sketches. Meanwhile, ME students played a more proactive role in the ME review session. This is reflected in Figure 5, in which the data points of ME review and ME student are close to each other.

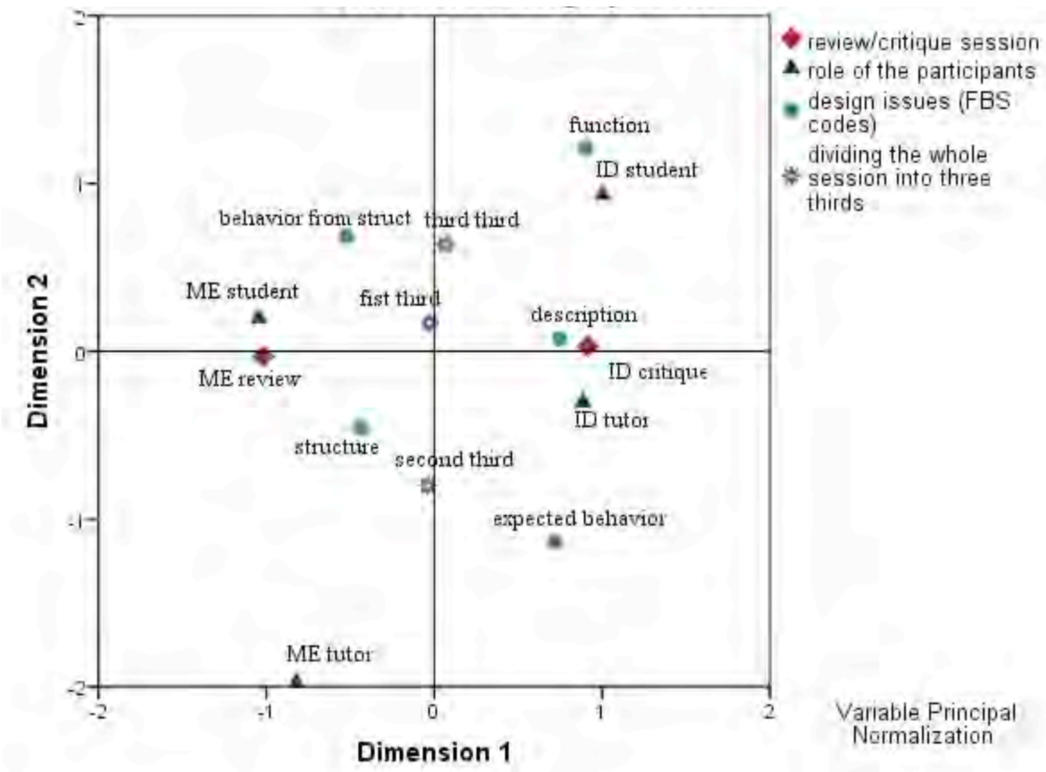

Figure 5. Joint plot of category points (multiple correspondence)

The cluster of ID student and function issue visualizes the much higher percentage of function issues generated by ID student, 22% compared to 8.2% on average (Table 3). The qualitative assessment of video data shows that when the ID student clarified his ideas, he referred to the purpose of design often. This also provide some evidence that the ID project is more exploratory in nature and tends to guide the student "to dive deeper" in design problems rather than articulate the solutions. The location of ME student data point shows that solutions are much more their concerns. In particular, ME students' verbalizations contained 43% of behavior from structure issues, significantly higher than the other counterparts (15%~20%).

4.2 Results on the basis of problem-solution index

The P-S index values of the whole concept design review/critique session as well as of the first and second halves of the review session are shown in Table 4. In general, these two design review sessions are solution-focused, indicated by the P-S Indexes being less than 1. The inter-disciplinary differences of these two review sessions are revealed by inter-row comparisons in Table 4. It shows that, for each column, the value of ID review session's P-S index is almost triple that of the ME session.

The trend that design cognition develops through each review session is illustrated by the comparison between the first half and second half of the critique sessions (third and fourth columns of Table 4). It indicates that, for both concept design review conversations, there are no differences between the first half and second half of the session.

Table 4. Summary of problem-solution index

Protocol	Problem-solution index		
	Whole session	1st half of the session	2nd half of the session
ID critique	0.52	0.51	0.53
ME review	0.17	0.17	0.17

We then divided the whole session into deciles for a more detailed examination of the change in the P-S index as the review session progresses. A simple linear regression model was used to model the decile P-S indexes. The slopes of the regression line (the line of best fit) is used to depict the increasing or decreasing trend of designers' cognitive focus on reasoning about design problem. Table 5 shows that, for both sessions, the slope of the sequential P-S indexes' best-fit lines is not significantly different from 0. Although P-S indexes fluctuate, there is no increasing or decreasing trend identified throughout the review session.

Table 5. Sequential P-S index calculated on the basis of 10 deciles of the protocol

Protocol	*t* statistic	*p* value	95% CI for the slope
ID critique	0.408	0.694	-0.064 ~ 0.091.
ME review	-0.646	0.536	-0.054 ~ 0.030.

4.3 Results on the basis of cumulative occurrence of design issue

Gero et al. (2014) used cumulative occurrence of design issues to generalize common patterns of design cognition. Their focus is linearity of the cumulative occurrences of design issues on the basis of determination coefficient R^2. A further examination of the tabulated data of each issue's cumulative occurrence measurements in Gero et al. (2014) indicates that the slope value could be used to examine inter-disciplinary difference between two design review sessions. A larger slope value indicates this issue occurs more frequently during the design session. Figure 6 shows that the industrial design review session has a higher slope value for the problem-related issues of function and expected behaviors. While the ME review session showed higher slope values for the solution-related issues of structure and behavior from structure issues.

5. Discussion

5.1 Comparisons between ID design critique and ME design review

The findings from the locations of category points in Dimension 1 of correspondence analysis' perceptual mapping (Figure 5), differences of P-S index (Table 4) between ID critique and ME review sessions, and different slopes of cumulative occurrence of design issues (Figure 6) are congruent with each other. They all indicates that overall the ID critique expended more cognitive resources on reasoning about the design problem than ME review sessions.

The results also converge into a similarity between ID critique and ME design review sessions: the cognitive focus on the design problem or solutions does not show any increasing or decreasing trend throughout the time. This conclusion is support by the evidences that Dimension 1 of Figure 5 is not able to discriminate the three temporal category points; no significant differences are found between the first and second halves of the P-S index (Table 4), and the slopes of sequential P-S index are not statistically significantly different (Table 5).

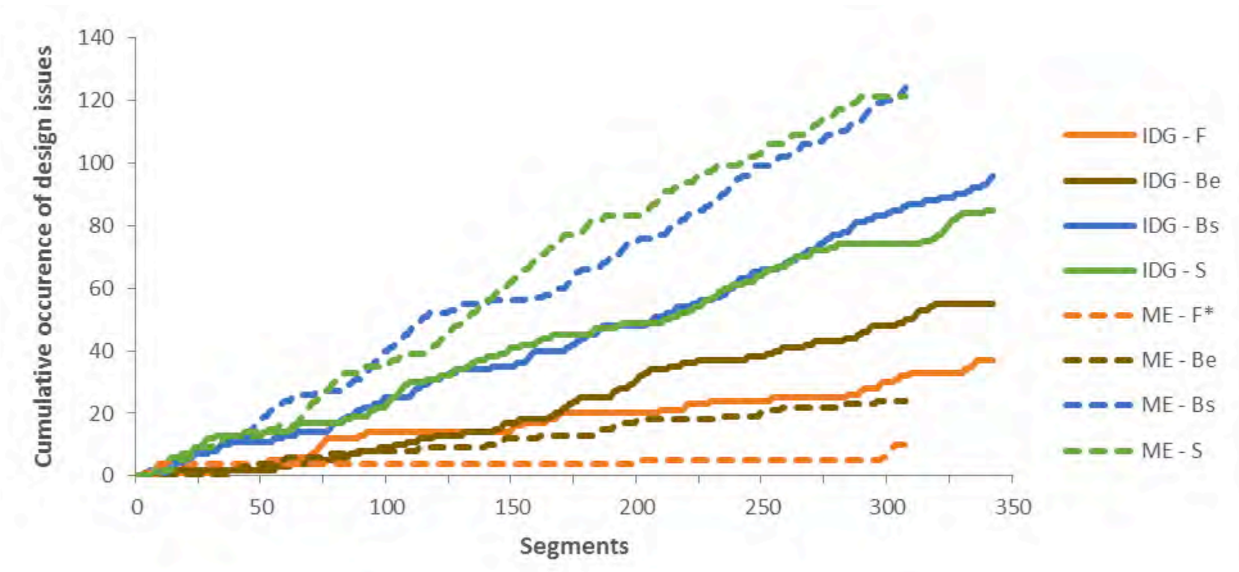

Figure 6. Cumulative occurrence of design issues in the observed concept design review conversations. IDG = industrial designers, ME = mechanical engineers.

* Non-linear

5.2 Comparisons between design review/critique and designing processes

The main purpose of applying the ontologically-based coding scheme rather than ad-hoc ones is to enable comparing design cognition of review and critique conversations with the design cognition behind designing processes.

Previous findings: Commonalities and differences across designing

Previous FBS ontologically-based protocol analyses have produced empirical evidence of some commonalities and inter-disciplinary differences of design cognition across different design domains.

Commonalities across designing

- While designing progresses, a design session's P-S index decreases independent of design disciplines and situations (Gero, Jiang, & Williams, 2013; Jiang et al., 2014);
- The timeline graphs of cumulative occurrence of structure, behavior from structure,

expected behavior and description demonstrate a linearity while the graphs of requirement and function do not exhibit linearity (Gero et al., 2014).

Disciplinary differences between industrial design and mechanical engineering design

- Using the P-S index as the measure, industrial designers generally spend more cognitive effort on reasoning about the design problem than ME designers do (Jiang et al., 2014);
- Derived from Gero et al. (2014), the ID sessions' timeline graphs of cumulative occurrence of problem-related issues (function and expected behavior) generally contain a higher slope for the line of best fit, while the ME design sessions have a higher slope for the best-fit line of cumulative solution-related issues (structure and behavior from structure).

Comparing case studies with previous findings

Gero et al. (2014) analyzed the designing activities for various disciplines. It provides a reference for comparing design critique/review activities with designing processes. The critique/review case studies' cumulative occurrence of design issues are tabulated in Table 6. The shadowed rows show the reference values constructed from studies of the same discipline reported in Gero et al. (2014). Most measurements of cumulative occurrences of design issues in concept design review conversations are consistent with their counterparts observed in the designing sessions. In particular, the linearity of cumulative expected behavior issues, behavior from structure issues and structure issues are the same as these commonalities while designing. This indicates that, similar to the situation in designing sessions, these design issues were also focused on at a nearly constant rate throughout the whole review conversation, Figure 6.

Table 5. Quantitative and qualitative measurements related to the cumulative occurrence of design issues for case study and previous studies

Protocol		Slope	R^2	First occurrence at start	Continuity	Shape
ID critique	Function	0.099	0.966	Yes	Yes	Linear
		0.064 ~ 0.271	0.745 ~ 0.884	Yes	No	Non-Linear*
	Expected Behavior	0.181	0.978	Yes	Yes	Linear
		0.150 ~ 0.530	0.930 ~ 0.993	Yes	Yes*	Linear*
	Behavior from Structure	0.279	0.991	Yes	Yes	Linear
		0.079 ~ 0.254	0.928 ~ 0.992	No*	Yes	Linear*
	Structure	0.247	0.992	Yes	Yes	Linear
		0.287 ~ 0.336	0.990 ~ 0.993	Yes	Yes	Linear

ME critique	Function	0.008	0.439	Yes	No	Non-Linear
		0.019 ~ 0.034	0.830 ~ 0.960	Yes	No*	Non-Linear
	Expected Behavior	0.084	0.987	No	Yes	Linear
		0.056 ~ 0.110	0.929 ~ 0.984	Yes*	No*	Linear*
	Behavior from Structure	0.398	0.993	Yes	Yes	Linear
		0.179 ~ 0.352	0.982 ~ 0.997	Yes*	Yes	Linear
	Structure	0.435	0.993	Yes	Yes	Linear
		0.417 ~ 0.476	0.998 ~ 0.999	Yes	Yes	Linear

Shadowed rows: reference value calculated from Gero et al. (2014)
* for the majority of relevant protocols

Based on these preliminary findings, it seems that industrial designers tend to be more problem-focused than mechanical engineering designers in both critique/review activities and designing processes. The linearity of cumulative occurrences of structure and behavior issues are observed in both critique/review activities and designing processes.
However, the other commonality of designing, i.e., the trend of a decreasing focus on the design problem is not supported by these two case studies of review and critique conversations. Both the ID critique and the ME review cases show that the cognitive focus on design problems or solutions does not show any increasing or decreasing trend across time. This finding contradicts the trend found in multiple previous studies into designing, in which the P-S index value of the second half of the session was significantly lower than the P-S index of the first half of the session (Gero et al., 2013; Jiang et al., 2014). This is a significant difference between these review/critiques and designing generally.

6. Conclusion

This paper extends the exploration of commonalities and differences of design cognition into the field of concept design review and critique conversations, by comparing two cases of ID critique and ME design review sessions. Based on these preliminary findings, the inter-disciplinary differences of design review sessions are mainly consistent with the patterns found in prior studies of commonalities and differences between industrial designers and mechanical engineers while designing. Industrial designers are generally more problem-focused than mechanical engineering designers in both designing and review sessions.
Some commonalities of designing are also found to occur in the design review and critique scenarios, such as the cognitive effort expended on the structure issue and the behavior from structure issue has a constant rate throughout the whole session. However, the cognitive shift from reasoning about the design problem to an increased focus on design solutions in designing

is not found in these two design review cases. The concept design review sessions seem to be more solution-focused than designing sessions. This finding is not unexpected given that design critiques are mainly conducted around the assessment of design solutions.

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