Question asking in design reviews: how does inquiry facilitate the learning interaction?

Carlos Cardoso
Ozgur Eris
Petra Badke-Schaub

Faculty of Industrial Design Engineering,
Delft University of Technology, Delft, The Netherlands
c.m.cardoso, o.eris, p.g.badke-schaub@tudelft.nl

Marco Aurisicchio

Faculty of Engineering, Imperial College London,
London, United Kingdom
m.aurisicchio@imperial.ac.uk

Abstract:
Design reviews are common educational practice in design disciplines, where students meet with instructors and other stakeholders to discuss the progress of a project they are engaged in. Such reviews are tightly coupled with project-based learning approaches in the design studio. A number of research studies have looked into various characteristics of instructor-student interactions during design reviews. In this study, we investigated the question-asking behavior of instructors, students and clients. We paid particular attention to high-level questions that relate to causal and generative reasoning. We analyzed 22 reviews involving six undergraduate industrial designers, who undertook design projects individually. We observed that the instructors and clients were not effective in modeling question asking behavior for the students during the reviews. We also observed that the structure of the reviews did not facilitate the desired behavior either. Consequently, we present a theoretical framework that proposes a more explicit structure for design reviews, deliberately addressing particular aspects of the design process. Ultimately, we suggest that instructors should be inquisitive about the students' design approach, and that the students should take responsibility for reflectively articulating their design thinking and actions during design reviews.

Keywords: Question asking, design learning, design review.

1. Introduction

1.1 Design reviews

Design reviews, also called design *crits* (from *critique*), are a common pedagogical practice in design disciplines, such as architecture, engineering design, industrial design and graphic design (Goldschmidt, Hochman & Dafni, 2010). In such reviews, students meet, individually or in groups, often in a studio setting with an instructor to discuss the progress of a given design project. In general, design reviews take place on a regular basis for a determined period of time. The level of discussion in design reviews can range from informal conversations to more formal presentations. Design reviews can involve stakeholders such as real or simulated clients, suppliers and potential users in addition to design students and instructors. A design review typically starts with students bringing the instructors and other stakeholders up to speed on the status of the project (Goldschmidt *et al.*, 2010). Instructors might ask questions to the students to clarify aspects of the project, and provide advice on what to focus on and how to proceed. Students might ask questions to the instructors and

other stakeholders on missing pieces of information that they might possess and actively seek process or content related advice. In many respects, the design review paradigm is a derivative of the centuries old mentor-apprenticeship model of working and learning (Atman, Eris, McDonnell, Cardella, & Borgford-Parnell, 2014), and leverages experiential learning principles put forward by Dewey (1938), Kolb (1984) and others.

Design reviews are a key element of project-based studio methodology, which continues to be the main educational method adopted by design related disciples at a university level (Curry, 2014). In architecture for instance, project-based studio has been the way to introduce to students some of the core aspects of designing, such as analytical and representations skills, problem solving and design principles (Curry, 2014). It is plausible to consider that similar knowledge transfer takes place in project-based studio in other related design disciplines.

1.2 Research aims and research questions

A number of studies have focused on different aspects of instructor-student interactions in the design studio during design reviews (e.g. Goldschmidt *et al.*, 2010; Sachs, 1999). In our study, we are particularly interested in the type of questions that are formulated during these reviews by instructor, students and clients. In the context of the design reviews analyzed in this paper, we identify *low-level* and *high-level* questions (Section 2.2). *Low-level* questions cover primarily issues about clarification and missing/incomplete information the inquirer is trying to obtain. *High-level* questions, which we later explain are subdivided in *deep reasoning* and *generative design* questions (Section 2.2), relate to higher levels of reasoning (i.e. "higher level of learning objectives", Section 2.2). Our premise is that designing is an inquiry driven process (Eris, 2004). Consequently, this research aims to understand and characterise design reviews through an inquiry-based framework, and explores how inquiry facilitates design thinking and learning between students and instructors in such settings. More specifically, the following research questions guided the research:

RQ#1: How does question asking develop during a design review, and in the course of successive reviews throughout a student design project?

RQ#2: Who initiates what type of inquiry in design reviews in project-based design courses?

RQ#3: How does high-level question asking during design reviews affect the creative outcome?

The remainder of this paper is as follows. Section 2.1 provides a brief overview of the role of instructors in the design studio, particularly instructors from practice. This is followed by Section 2.2, which describes how the study of question-asking in design originates and differs from previous studies using other taxonomies of questions. In Section 3 we present our analysis of the dataset selected for this study (i.e. junior industrial designers), and in Section 4 the results and preliminary discussion. Section 5 presents our observations about the role of, and behaviors exhibited by, the instructor in the design reviews we analyzed. Section 6 proposes a new theoretical framework for design reviews. The paper ends in Section 7 with a brief conclusion about this study.

2.Background

2.1 The role of instructors in design reviews

During design reviews instructors play an important role as sources of relevant content and process knowledge. Consequently, instructors are often seen as role models, especially when they have industry experience and a remarkable design portfolio (Goldschmidt *et al.*, 2010; Curry, 2014). However, despite their extensive professional understanding, instructors are

often not trained as educators and might never receive constructive feedback about their teaching performance (Goldschmidt *et al.*, 2010). Curry (2014) points out that the main problem is that instructors from practice tend to base their teaching strategies on a depiction of how they design, and expect students without domain or procedural expertise to act at that level. Furthermore, although expert designers often use of their tacit knowledge when designing (Dreyfus & Dreyfus 1986; Lawson 2006; Cross 2004), they are often unconscious about its underpinning and lack the instructional skills to communicate and contextualize them to a novice audience (van Dooren, Boshuizen, van Merriënboer, Asselbergs & van Dorst, 2014). Therefore, it is often the case that experienced designers see the design process as an undivided whole, grounded on common practice or routine (van Dooren *et al*., 2014).

Consequently, whilst instructors from practice bring in their knowledge and broad professional experience into design reviews, they usually have limited pedagogical training that would enable them to meet the demands of complex pedagogical interactions required from contemporary curricula (Goldschmidt *et al.*, 2010). In fact, Curry (2014) claims that designing goes beyond the development of innate abilities in the studio system. He posits that it entails a complex transformation of how one thinks about problems, the capacity to accrue declarative/conceptual knowledge (in-depth info related to a field), the mastery of procedural knowledge (methods for solving problems) and the necessary experience to achieve strategic knowledge (Curry, 2014). Ultimately, Curry claims that current teaching strategies adopted by design instructors from an industrial background seldom take all these dimensions into account.

Furthermore, Curry (2014) proposes the introduction of specific design methodologies in the design studio as a teaching strategy to gradually support students throughout the different stages of the design process. In tandem, Goldschmidt *et al.* (2010), who conducted a qualitative investigation of teacher's performance during design reviews/crits, claim that a uniform model of "best practice" (to provide teachers with detailed feedback for improving the effectiveness of such reviews) is due if we want to develop a much needed design teaching pedagogy. Goldschmidt *et al.* (2010) used a consolidated existing taxonomy of design teacher profiles to analyze three case studies (i.e. three different instructors as subjects, and three different students), namely: instructor as source of expertise or authority; instructor as coach or facilitator; and instructor as buddy. They found out that *coaching*, whereby the instructor supports the development of a student's potential abilities and tacit knowledge in the attainment of experience, was the most productive role in their study (Goldschmidt *et al.*, 2010). The coaching paradigm has not only been tightly coupled and even necessitated in design learning, especially within the context of project based learning, it has also been observed to be influential and beneficial in industry design practices (Eris & Leifer, 2002; Reich, Ullmann, van der Loos & Leifer, 2009). With a focus on improving the effectiveness of design reviews, they suggest providing instructors with comprehensive feedback and training about what does/does not work, and why.

2.2 Question asking in design

Questions have been the subject of various research studies to understand their role in the thinking and learning process. Eris developed a question driven design thinking model (Eris, 2004). Building on Eris' (2004) work, Aurisicchio *et al.* (2010, 2013) showed that design questions are descriptive of the principal activities in design and diagnosis models. In this study, we use Eris' (2004) question driven design thinking model as the primary lens through which we explore the role of inquiry in design reviews.

The model identifies an interplay between two classes of *high level questions* that shape the boundaries of the conceptual design space during the design discourse. Incidence of high level questions by designers was shown to correlate with design performance in a design task carried out in the laboratory (Eris, 2004).

Eris' model is based on the literature on inquiry. More specifically, it leverages and extends canonical taxonomies of questions, and is informed by the role questioning plays in classroom interactions between students and instructors. In doing so, the model makes a distinction between three classes of questions that are asked in design discourse: low-level questions, deep reasoning questions (DRQ), and generative design questions (GDQ).

The concept of *deep reasoning* questions has been initially proposed by Graesser and McMahen (1993), who investigated the cognitive aspects of inquiry in education by assessing the influence of question asking on learning, and identifying mechanisms that generate questions. Building on the artificial intelligence literature, Graesser and McMahen extended Lehnert's (1978) taxonomy of questions with five new categories (see Table 1). They then used the taxonomy to analyze the incidence of different type of questions asked by students during a series of tutoring sessions related to an undergraduate class (Graesser & Person, 1994). The incidence of a class of questions that are primarily used to establish causality correlated positively with student learning outcomes. They termed those questions deep reasoning questions, or DRQs. Also, they empirically mapped the extended version of Lehnert's taxonomy onto Bloom's (1956) taxonomy of educational objectives in the cognitive domain, and demonstrated that the DRQ categories are associated with the higher level learning objectives.

Table 1. Classification of questions that occur in design discourse.

Question Class	Graesser, 1994	Eris, 2004
Low-level Questions	Verification	Verification
	Definition	Definition
	Example	Example
	Feature Specification	Feature Specification
	Concept Completion	Concept Completion
	Quantification	Quantification
	Disjunctive	Disjunctive
	Comparison	Comparison
	Judgmental	Judgmental
Deep Reasoning Questions (DRQ)	Interpretation	Interpretation
	Goal Orientation	Rationale/Function
	Causal Antecedent	Causal Antecedent
	Causal Consequent	Causal Consequent
	Expectational	Expectational
	Procedural	Procedural
	Enablement	Enablement
Generative Design Questions (GDQ)		Proposal/Negotiation
		Enablement
		Method Generation
		Scenario Creation
		Ideation

A common premise behind *low-level* and DRQs is that the answer is known, if not by the subject of the question, by someone else. Such questions are characteristic of convergent thinking, where the questioner is attempting to converge on "the facts." The answers are expected to hold truth-value since the questioner expects the answering person to believe his/her answers to be true. DRQs are different from low-level questions (indicated on Table 1)

in the sense that latter are used to communicate and confirm what is known, whereas the former are used to provide causal explanations of facts. For instance, "Why does the moon rise at night?" is a DRQ (*rationale* category). However, questions that are raised in design situations can operate under the converse premise: that, for any given question, there exists, regardless of being true or false, multiple alternative known answers *as well as* multiple unknown possible answers that are yet to be created. The questioner's intention is to disclose the alternative known answers, and to generate the unknown possible ones. Such questions are characteristic of divergent thinking, where the questioner attempts to move away from the facts to the possibilities that can be generated from them. Eris (2004) termed these types of questions *generative design questions* (GDQs), and identified five categories (see Table 1 and Eris, 2004 for a more detailed discussion). For instance, "How can one reach the moon?" is a GDQ (*method generation* category).

Graesser *et al.* (1994) reported that the students in the tutoring sessions formulated 21.1 questions *per* hour, compared to the tutors that formulated 95.2 questions per hour (yielding a combined rate of 116.3 questions/hour for the student-tutor couple). This is a high number compared to the 0.11-0.17 questions formulated per hour in the classroom by individual students (Flammer, 1981; Kerry, 1987). In Graesser's tutoring interaction analysis, DRQs are asked at a rate of 4.6 questions per hour by students, and 15.2 by tutors during one-on-one tutoring sessions (yielding a combined rate of 19.8 questions/hour). There are no data on the DRQ asking rates of students in classrooms.

3. Method

3.1 Data set: participants

We analyzed the undergraduate (i.e. labelled as 'Junior' in the original dataset) industrial designer dataset that is comprised of selected design reviews of seven individuals (two males and five females). These students are in their third year undergraduate course, of a four-year program. Also, part of the set of participants is their instructor (always the same for all students) and the client's representatives, practitioners from different fields of expertise (e.g. industrial design, engineering, marketing).

3.2 Data analysis

We considered all of the design reviews (transcripts) for the undergraduate industrial designers, their instructor and clients, and extracted all of the questions from the discourse. We defined a question as a verbal utterance that requests an explicit response in dialog. We excluded directives (e.g. "Can you hand me that sketch?") from the analysis. In total, we analyzed the transcripts from 22 reviews (see Table 2 for an overview). We also watched the videos to better understand how some questions were posed, answered and reflected in final concepts. We coded all of the extracted questions.

3.2.1 Frequency and type of questions

We analyzed the *frequency* and the *type* of questions asked by the instructor, clients and students, using the question categorization framework (and respective definitions) presented in Table 1 as a coding scheme. The first author was the primary coder, and the second author verified a subset of the coded questions for a reliability check. Any minor differences in coding were discussed and resolved before the entire dataset was coded.

Table 2. Overview of the design reviews and available data (transcripts, video and sometimes presentation slides) for each student.'1st and 2nd reviews' are about the presentation, discussion and selection of concepts for preliminary presentation in the '3rd review'. '4th review' serves as a debrief design review about the previous encounter with the client, and preparation for the '5th review', where the final concept is presented to the client. Available data marked with an "X" are depicted in a grey cell.

Students	**1st review** (student and instructor)	**2nd review** (student and instructor)	**3rd review** (student and clients)	**4th preview** (student and instructor)	**5th review** (student, clients and instructor)
Student 1			X	X	X
Student 2		X	X		X
Student 3		X	X		X
Student 4			X	X	X
Student 5		X	X	X	X
Student 6	X		X	X	X
Student 7	X		X		

3.2.2 Assessing students' creative performance

In order to compare the type of questions posed during the design reviews against how they might have been reflected in the students' performance, we assessed the final concepts developed by the undergraduate designers. Two independent expert judges, unaware of the conditions being investigated, assessed those concepts. The judges were senior PhD candidates with a background in industrial design and quite familiar with assessing creative output.

The students' final concepts were assessed in terms of *novelty* and *usefulness*, which are the most common elements of the definition of creativity (e.g. Runco & Jaeger, 2012; Sarkar & Chakrabarti, 2010).

Novelty in this study is interpreted as a measure of how unusual a concept is when compared to the other concepts generated, as well as to existing ideas, concepts or actual entities one might be aware of at the time of the analysis. *Usefulness*, was presented to the judges as the extent to which the final concepts answered the design briefs in a useful and practical manner (that end-users can actually benefit from). Each single concept generated by the different groups was assessed using a 7-point scale, which ranged from: 1 (not original/useful at all) through to 7 (very original/useful). Inter-rater agreement between judges was measured using Cronbach's alpha coefficient.

4. Results and Discussion

4.1 Frequency and type of questions

In terms of duration, and despite some gaps in the available data (Table 2), the average length of the design reviews are within a typical range (Table 3), according to Goldschmidt *et al.* (2010). The 1st, 2nd and 4th reviews took longer, mainly due to the fact that students were at a stage where they had more discussion with the instructor about which concepts to selected and explore further. As the clients were not present in these reviews, the instructor is the only person posing questions to the student. The 3rd and 5th reviews were presentations to the clients where students had a limited amount of time to present their concepts. Although the instructor was always present in these reviews, the client was primarily the one posing questions to the students.

In the figures below (Figures 1, 2 and 3), we present the combined question counts and rates of the instructor and client because we are considering the role they take in the reviews, rather than which individual is asking questions. The remainder of this section addresses the first two research questions (Section 1.2).

Table 3. Overview of the *average* duration of each design review and *average* number of questions posed by students and instructors/clients.

	1st review	2nd review	3rd review	4th review	5th review
Duration (min)	23,0	14,0	5,9	13,3	6,5
All questions Student	9,5	3,3	0,7	9,5	0,5
All questions Instructor and Client	19,0	10,3	5,3	14,0	6,2
Low-level questions Student	8,0	2,7	0,6	7,3	0,5
Low-level questions Instructor and Client	15,5	8,0	4,1	10,8	4,7
D.R.Q. Student	1,0	0,0	0,0	1,8	0,0
D.R.Q. Instructor and Client	0,5	0,0	0,4	1,0	0,2
G.D.Q. Student	0,5	0,7	0,1	0,8	0,0
G.D.Q. Instructor and Client	3,0	2,0	0,7	2,3	1,2

4.1.1 Incidence of all questions

When comparing the sole incidence of questions, it is obvious that instructors and clients seem to ask significantly[1] more questions than students per unit time (Figure 1). This is expected to some extent since the reviews in this dataset are primarily about students presenting their design work to an instructor and a client. Hence, the instructor and the client pose questions about technical and material aspects of the students' work that are not yet clear to them, because they are trying to access the students' mental model. The instructor's and clients' inquiry rates do not seem to differ much across the five reviews. However, that does not seem to be the case for students. There are two visible peaks: the 1st and 4th reviews. The peak at the 1st review is expected as the students are attempting to access the instructor's mental model on the project and the course. The peak at the 4th review is somewhat surprising in so far that it appears right after the client's initial presence in reviews. We would have expected the students to be more active in questioning the client at the 3rd review. However, the peak at the 4th review might be associated with the fact that it is the last discussion with the instructor before the project is presented to the client panel during the 5th review. Therefore, the students seem to be driven by the level of uncertainty about the pending finale of the project, and try to access the instructor's mental model regarding the final delivery and presentation to the client at the 5th review - especially given that they do not seem to have actively engaged the client through inquiry in the 3rd review.

[1] We have not, at this stage, run the analysis to determine if there were statistical differences on the question rates between students, instructors and clients, because in some of the design reviews there was only data available from two students (out of seven).

4.1.2 Incidence of low-level and high-level questions

Regarding the incidence of *low-level questions* asked, the instructor and the clients seem to have formulated more questions than any of the students across all reviews per unit time (Figure 2). For instance, low-level questions (Figure 2) posed by the instructor and the client are formulated to:

- confirm a particular aspect of the design:

Instructor: "*Are these all fixed together?"* (Verification/Disjunctive question)

- inquire about specific characteristics of a given concept:

Instructor: "*What material in production do you think it is?"* (Feature Specification question)

- clarify and acquire missing information:

Instructor: "*What are you gonna see on the edge?"* (Concept Completion question).

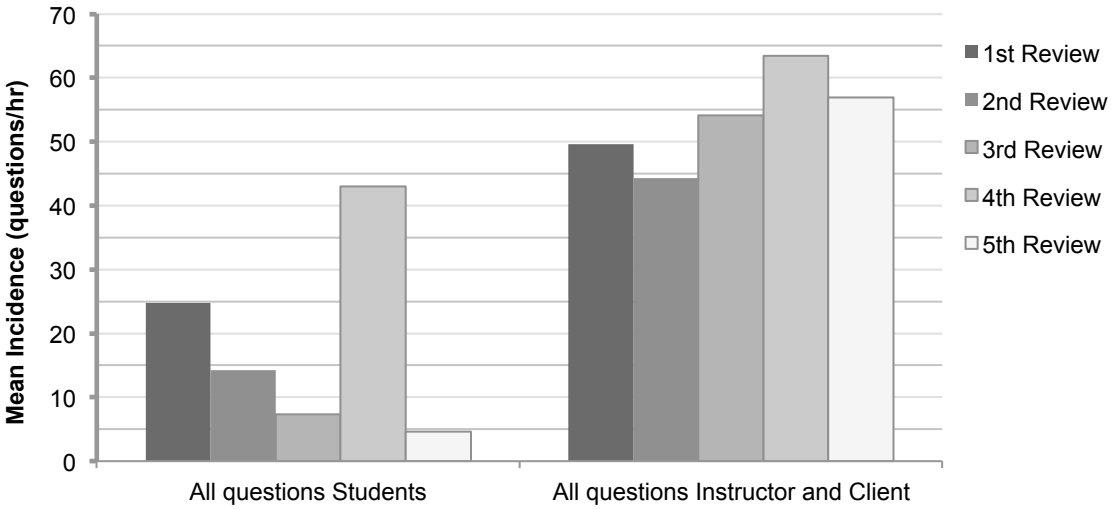

Figure 1. Average incidence (per hour) of all questions formulated by students and instructor and clients per design review.

With the exception of the spike in low-level questions in the 4th review, low-level and high-level questions asked by the instructor and client are asked at similar rates across the reviews (Figure 2). Students ask a high number of low-level questions in the 1st and 4th reviews, probably because of the reasons mentioned earlier (Section 4.1.1). However, the students do not formulate high-level questions during the 5th review. This is understandable from a product perspective, as they might feel the need to present their final designs with confidence and not question them. However, in an educational context, that reasoning is flawed; learning is done and complete, and reflection should always play a role. The final review would be a particularly good time point for *reflecting-on-action* (Schön, 1984) through inquiry by the students.

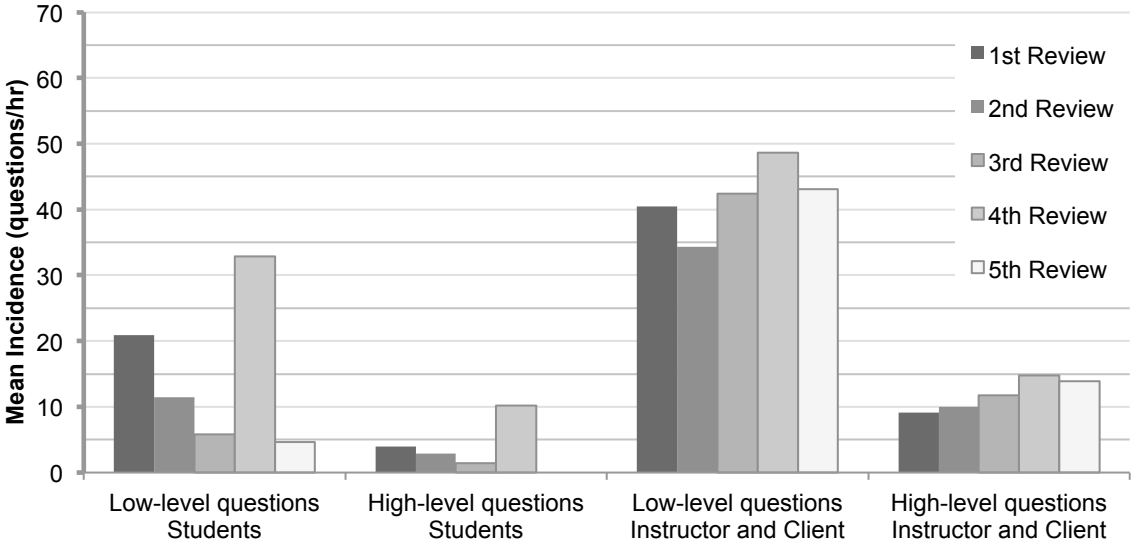

Figure 2. Average incidence (per hour) of the *type of questions* (low-level and high-level) formulated by students and instructor and clients per design review.

4.1.3 Incidence of DRQs and GDQs

Instructors and clients also seem to have asked more Generative Design Question (GDQs) than students per unit time (Figure 3). For instance:

Instructor: "*Well, is there anything you could do in this area here minimally between this surface and that surface, maybe, to create a shelf?"* (GDQ – Proposal/Negotiation)

Instructor: "*So what's gonna attract whatever you design, a customer from buying your design versus what's already out there now. So what would be the next level?"*(GDQ – Ideation)

Client: "*I guess what is your vision for…obviously you want these two to be able to turn multiple…to be able to give different seating configurations, right?"* (GDQ - Proposal/Negotiation).

There are a few reasons why this might have happened. First, students might have been somewhat intimidated by the instructor's authority, taken his comments as directives and chosen not to attempt to reframe them through inquiry. Second, although instructors seem to question at a higher rate than the students, their high-level questioning rate is not particularly high (for instance, as compared to the rates we observed during design team meetings; see below). If the educators with whom students often interact do not frequently 'challenge' them with high-level questions, students might end up mimicking/modelling the behavior. Third, the scarcity of student GDQs in these design reviews might be because students formulated them primarily between design reviews. Consequently, there might have been less of a need for students to ask GDQs during the reviews, as their purpose in this dataset seem to be mainly about describing the current state of the project, rather than generating new framings and reflecting deeply. Deep Reasoning Questions (DRQs) were asked too infrequently for us to draw conclusions, but with exception of the 4th review the students practically did not formulate these type of questions (Figure 3). Therefore, in addition to discussing factual technical/material aspects of the final concept at 4th review (covered by low-level inquiries), both instructor and students could be trying to ensure that all relevant design rationale are adequately constructed and argued for before the design is presented to the client for evaluation.

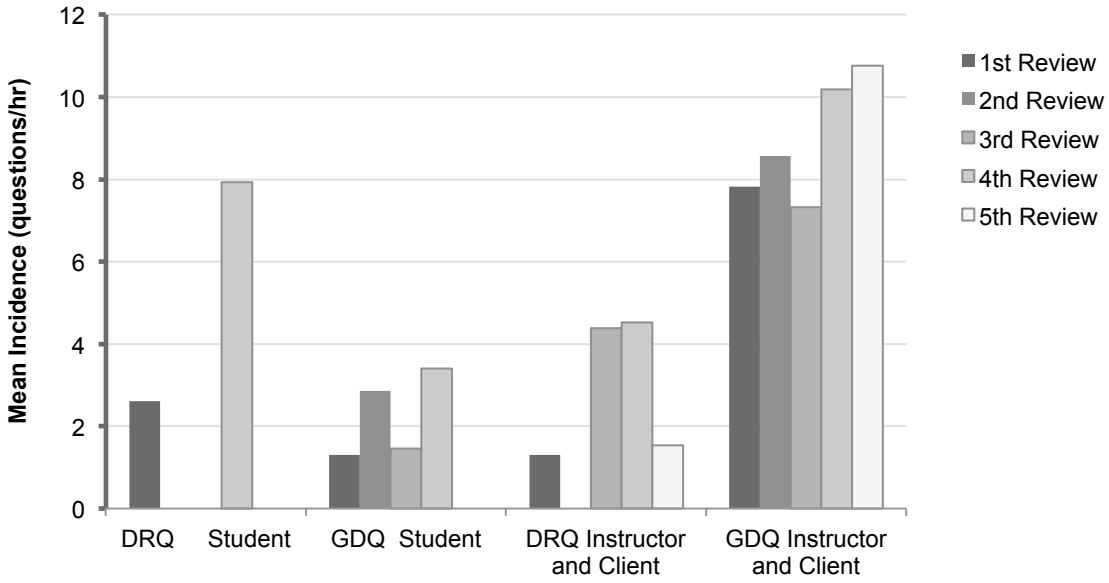

Figure 3. Average incidence (per hour) of the *deep reasoning question* (DRQs) and the *generative design questions* (GDQs) formulated by students and instructor and clients per design review.

Some of the DRQs asked in the 4th review take the form of:

Student 6: "*What do you mean?"* (Interpretation question)

Instructor: "*How are you going to get your thickness in the cardboard?"* (Instrumental/procedural question).

Students' low DRQ asking rates compared to the instructors could be because there is a tendency for communication to be one way, and thus there is not a real high-level dialog. It could also be due to time pressure, as some of the reviews only last six minutes on average, and it is not possible to establish a meaningful high level dialog in such a timeframe.

In our former study (Eris, 2004) our analysis of twelve 90-minute design sessions carried out by teams of three engineers resulted in the following questioning rates in average: 103.9 low-level questions/hour, 8.2 DRQs/hour, and 20.3 GDQs/hour on average. Moreover, successful teams had higher DRQ and GDQ asking rates then these averages. Therefore, if we consider the student and the instructor and client a team, their questioning rates as a group during design reviews reported in this study are about half of the questioning rates of design teams during working meetings reported in our former study for all three classes of questions (Figure 3). Again, this is somewhat expected given a good portion of a design review is used by students to inform the instructor of their progress, which can resemble a formal presentation at certain points. Conversely, it can also be argued that presenting new and rich information to an audience should trigger inquiry given the audience's need to rapidly comprehend and interpret the new information.

4.2 Assessing students' creative performance

On the matter of how inquiry might be related to creative performance, we asked how high-level questioning might affect creative outcome (Section 1.2). As mentioned earlier (Section 3.2.2), two independent judges assessed the *novelty* and *usefulness* of the final concepts developed by the students in order to assess the creative outcome of the projects. The level of

agreement between the judges was computed using Cronbach's alpha coefficient. The two judges showed *excellent* agreement for both novelty (α = .961) and usefulness (α = .986) of all final concepts. We then analyzed the resulting novelty and usefulness scores in conjunction with the questioning rates of the individual students. The results of the descriptive analysis are presented on Table 4.

In order to explore the relationship between question asking during the design reviews and the creative outcome of the projects, we ran eight linear regression analyses by treating the questioning rates as the independent variables (all questions, DRQs, GDQ, and combined DRQ and GDQ), and the creativity dimensions as the dependent variables (usefulness and novelty). The only regression that yielded a significant result was between the combined DRQ and GDQ asking rate and novelty $R^2 = .64$, $F(1, 6) = 7.18$, $p = .055$. This finding suggests that active and critical inquiry during a design review can positively influence project outcome. However, considering that the number of questions that led to the measurements and the number of participants used in this analysis are low, this result needs to be followed up with a more detailed study to be conclusive.

Table 4. Question asking rates (per hour) of each individual student in the dataset, and the creativity scores (novelty and usefulness) of their final concepts. Student 7 (Table 2) was not included in the creativity assessment because there was no data available about the student's final concepts.

Student	*All Qs*	*DRQ+GDQ*	*GDQ*	*DRQ*	*Novelty*	*Usefulness*
Student 1	39.4	6.7	3.3	3.3	1.0	2.0
Student 2	65.2	11.1	8.2	2.9	2.5	3.0
Student 3	57.1	9.5	6.7	2.9	4.0	6.0
Student 4	87.2	23.5	21.7	1.8	3.0	3.0
Student 5	82.2	11.5	8.7	2.7	2.0	6.5
Student 6	98.9	34.8	20.8	14.0	6.0	2.0

Regardless, this finding is remarkably similar to the correlation we reported between the combined DRQ and GDQ asking rate and design task performance in our previous study (Eris, 2004) in the sense that treating all questions, or DRQs and GDQs individually, as the independent variable does not yield significant results.

5 The role of the instructor: observed behavior

The instructor observed in this study is mostly enthusiastic about the students' work, providing timely compliments and constructive feedback. He also often encourages the students to sometimes step back and consider a more holistic view about the design project at hand. The instructor regularly expresses that the students are the ultimate decision makers in their design project. The instructor raises issues that the students should take into account while preparing to meet with the client. After the presentations with the clients, the instructor meets with the students to discuss how the client's feedback might be integrated as the project reaches its stage of final concept completion. The instructor is also quite explicit on reminding the students of time management issues, and to plan according to what is feasible within the project timeframe. He also brings up deadlines (this involves, for instance, usage and sharing of the workshops and machinery for building working models of their design concepts).

Despite the instructor's supporting role, there are a few other frequent behaviors that potentially deviate from "best practice" according to, for instance, Goldschmidt *et al.* (2010). Whereas we only explicitly address a single instructor here, we also analyzed the design reviews for the graduate industrial design students (17 design reviews). The graduate students had another instructor, whose behavior showed similar patterns to the one interacting with the junior students. Moreover, these observations are also congruent with our informal observations in the design studio in general. Specifically, in this dataset, the instructor is often too explicit about what the students should be doing. He poses a lot of clarification questions (e.g. 'verification' and 'concept completion' – basically low-level questions) about the students' work. However, he does not engage in the sort of high-level inquiry (DRQ - deep reasoning questions) that questions the students' past, present and future decisions. There are very few questions that directly challenge students to construct causal explanations of their thinking and actions. As a result, students end up being too descriptive of their process and do not seem to initiate a more in-depth level of argumentation of proposed design solutions. In a way, by not questioning the students at a higher level, the instructor often ends up behaving more as an enthusiastic co-designer, making a number of decisions on behalf of the students rather than leaving more room for reflection. Therefore, once the instructor formulates his queries, he has a clear tendency to verbalise a number of directives on what he thinks will work, and consequently on how the students should proceed. He often answers his own questions!

Why is this happening? Why is the instructor acting too much like an "expert authority" (who is expected to transmit knowledge and know-how to the student), rather than closer to a "coach or facilitator" triggering the student's potential abilities and tacit knowledge for gaining experience?

The following explanations might apply:

1. *Time pressure*. The instructor has a certain number of students under his supervision (most likely a number of additional students in parallel with this project), and as a result the number and length of (one-to-one) reviews will have to be efficiently managed. Consequently, it might often be more feasible to explicitly guide the students on their next steps, rather than posing questions that will probably need time to be thoroughly reflected upon and addressed. Also, as a real client is involved in this project, and thus stricter deadlines are imposed, there is probably a greater concern in making sure students do not fall behind in their planning. Ultimately, challenging the students with high-level inquiry would introduce the need to increase either the number or duration of design reviews, or rethink how these design reviews are being structured.

2. *Structure of the design reviews*. Another reason why (high-level) questioning does not seem to be playing a significant role in these design reviews could be related to the structure of such encounters. The structure of the reviews seems to vary arbitrarily between students. For instance, sometimes the same review along the project could vary from 5 to 21 minutes between two different students. Most of these reviews start with a recap of the status of the project and end with a discussion about which concepts and tasks will be performed next. However, the main content, focus and level of detail of what is being discussed in a given design review could vary considerably between students. Therefore, high-level queries can either emerge accidently, or not be present at all in one of these reviews. Moreover, the act of

questioning does not seem to explicitly build into the format of the design reviews. For instance, there are no planned time points for the posing of questions by specific parties during the reviews. In other words, questioning does not come across as an expected behavior.

3. *Teaching philosophy adopted in the school*. Other factors that might sustain the instructor's assertiveness as a more authoritarian attitude, could be related to the schools philosophical view on the instructor-student relationship in project-based learning. Teaching staff could have the perception that students at an undergraduate level need tighter guidance to advance their work because they might feel insecure unless they get the instructors' approval (Goldschmidt *et al.*, 2010).

4. *Instructor's experience (educational, industry/professional)*. The instructor in this design reviews is an award-winning industrial designer with over 30 year of professional design experience. His work and contributions to industry have been highly appraised. However, and as mentioned before (Section 2.1), experienced professionals may approach teaching based on their own understanding of expert design performance. This tendency could 'prevent' them from more actively considering new insights in design methodology as a teaching strategy unveiled through research (Curry, 2014), and thus there would be not precedent in their repertoire for asking these types of high-level questions.

6. A theoretical framework for design reviews

Our analysis in this research prompted us to consider the role of design reviews in education, how they can be better structured, and how the different actors play their part. We acknowledge that our research is based on a very small number of reviews, educators, students and other stakeholders.

Nevertheless, we jointly consider our structured observations of this small dataset with our informal experiences as design educators topropose a theoretical framework for design reviews that has two dimensions: the functions of design reviews, and inquiry-based cognitive processes and reflection in design reviews.

When articulating the functions of design reviews, we postulate how inquiry might enable and support each function. When articulating the second dimension, we pay specific attention to the cognitive moves different inquiry mechanisms facilitate and how they contribute to comprehensive reflection during design reviews.

Our aim is to revise and build upon the behaviors we analyzed and propose a more explicit structure for design reviews that deliberately addresses particular aspects of the design process. Ultimately, we suggest that instructors should be inquisitive about the students' design approach, and that the students should take responsibility for reflectively articulating their design thinking and actions.

6.1 Functions of Design Reviews:
Informed and inspired by our theoretical background on design reviews and inquiry in design, and our analysis and own pedagogical experiences, we propose the following:

1. *Providing status update to stakeholders:*
   Communication to stakeholders (e.g. instructor, clients) who are not part of the given design task/problem undertaken, and who require an update about what has been achieved since the last review. This may entail the use of different design representations to communicate generic or detailed aspects about the current state of the design project. This initial part of the design review is mainly descriptive and does not involve evaluation/reflection.

   Suggested inquiry approach:
   Low-level questions (e.g. verification, concept completion, feature specification, quantification, comparison) often posed by the stakeholders will, for instance, inquiry about different functional and material aspects of the students' ideas/concepts, as well as other aspects of user-product interaction, manufacturability and so on. We have observed in our analysis that these questions are usually well tackled by the stakeholders. However, if the descriptive information provided by the students is incomplete or conflicting, instructors might have to resort to DRQs to extract causal/high-level rationale.

2. *Initiating student reflection on state of the design*
   As ambiguity about different technicalities is clarified, instructors could explicitly prompt the students to reflect on the goal(s) of their designs. They could discuss about to what extent goals have been met, and whether they should be revised and modified. At this stage, the list of requirements, if available in operational format, can be used to carry out a detailed conversation about the goal. Thoroughly revising the goal should enable the students to also see if the objectives underlying such goals, implicitly or explicitly formulated, have been met and if any problematic issues arise at the task-level.

   Suggested inquiry approach:
   At this level, instructors ought to start formulating deep reasoning questions (DRQs) to ascertain how far students are conscious and confident about the status of their designs. This could entail, for instance: *interpretation* questions (e.g. "What is happening between these components?"), *procedural* questions (e.g. "How will you present this to the user?'), *expectational* questions (e.g. "Why is this 'thing/something' not happening?"). Additionally, instructors could consider also prompting students with GDQs, as they might be beneficial in this reflective function/stage, for instance: *method generation* questions ("Could you have done that differently?"), or *proposal/negotiation* questions (e.g. "How about changing/adding this?").

3. *Initiating student reflection on process*:
   This is, to some extent, similar to function 2. However, the emphasis here is on the students' behavior while designing, their perception on the methodology/methodologies they employ and how they can analyse, understand and explain their design thinking process. This is an important reflection that could have more or less impact on the successful continuation of their project, depending on

whether (behavioral) changes have to take place and how far in the design process this is taking place.

Suggested inquiry approach:
At this level, instructors could pose DRQs that prompt the students to reflect and articulate their decisions and actions as designers. For instance: *procedural* questions (e.g. "How did you go from A to B?", "How did you go from that shape to that one?"), *expectational* questions (e.g. "Why did you not do this?")

4. *Requesting input from stakeholders*
   This function depends on the number of stakeholders present during the design review (i.e. instructor, clients, peers, others). At this stage, the students should (be encouraged to) proactively solicit feedback from the audience about the previous functions (i.e. 1, 2 and 3). The feedback may, for instance, result in prescriptive responses or generative input. Prescriptive feedback would be someone telling to the students: "I know how you could solve that, do it like this…"; or, "About your process you should do this…". Generative input might be formulated along the lines of a GDQ: *proposal*/*negotiation* question – e.g. "You might be able to try this, right?", or "How about trying that?".

   Suggested inquiry approach:
   The inquiry approach here is directed at the students, as they are the ones that could/should be asking to the stakeholders about their performance. Students might actually initiate a request for feedback by formulating certain low-level questions, such as: *judgmental* questions (e.g. "What do you think of this…?"). Subsequently, they could formulate GDQs to demonstrate that they can critically analyse their progress, and start conceptualizing about how they might continue to improve it further. This could for instance take the form of: *proposal/negotiation* questions (e.g. "How about if I did this and that?). Or, it could be *method generation* question (e.g. "We are stuck here. How can we do this without getting in the way of the user?")

Additional *functions* that do not necessarily occur during instructor-student interaction in the design reviews:

5. *Instructor's reflection about the students' performance*
   The instructor reflects (internally) on how the design review is going based on student's behavior and responses to the different issues discussed. This is function of design reviews that might take place during the interaction between instructor and student, but that does not necessarily involve an explicit discussion with the student. The instructor might use these reflective moments to steer the design review in an effective manner, in case it is feasible to do so while discussing about the design project. Alternatively, the instructor could retrospectively reflect about the student's behavior and consider possible 'actions' for the next review.

6. *Instructor's responsibility to 'manage' the client*
   The instructor should be responsible to ensure the clients are aware about their role and contribution to the students' development during a given course. This might involve an understanding about the courses' learning objectives, the tasks/assignments to be carried out and, possibly, how the students will be evaluated.

It should be clear for the client how any given design review ought to be conducted and what is to be expected from their input.

6.2 A model of inquiry-based cognitive processes and comprehensive reflection

In the previous section, while articulating the functions of a design review, we paid specific attention to reflection, and treated it as a primary outcome. We illustrated how inquiry might be supporting functions that are associated with student reflection. In this section, we articulate the second dimension of our theoretical framework, which focuses specifically on that relationship by modelling three inquiry-based cognitive processes as necessary components of comprehensive reflection (Figure 4).

The model treats the three questioning mechanisms we analyzed in detail earlier in the paper as inputs that facilitate three distinct *cognitive moves*. Low-level questions facilitate the elicitation of factual information and lead to the description of the design phenomenon under consideration. DRQs facilitate analysis and lead to the construction of causal understanding of the phenomenon. GDQs facilitate conceptualization and lead to alternative framings and perspectives of the phenomenon. Although, as argued previous by us (Eris, 2004) and others (e.g. Lehnert, 1978; Dillon, 1984), low-level questions need to precede high level questions (DRQs and GDQs) for effective inquiry, we postulate that these three threads always coexist in design thinking in a iterative manner. Ultimately, their continuous and balanced interaction shapes comprehensive reflection as a design process-focused outcome.

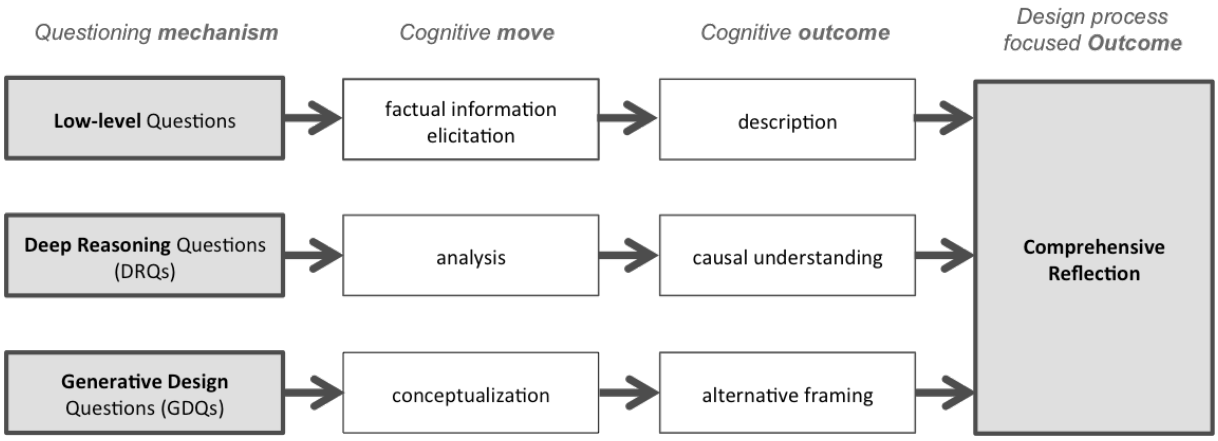

Figure 4. A model of inquiry-based cognitive processes and comprehensive reflection.

7. Conclusions

This study demonstrates that, within the dataset we analyzed, design instructors do not challenge their students to engage in higher levels of reasoning during design reviews. That is, instructors have a tendency to limit themselves to asking basic (low-level) questions, rarely prompting the students to articulate and rationalize their design thinking and actions. Therefore, the design reviews we analyzed entail the instructor asking a high number of low-level clarification questions, and uttering a number of directives for the students to follow in order to improve their work. Students formulate very few questions in general across design reviews, practically not articulating high-level inquires. In spite of the instructor's enthusiasm and supportive role in the design reviews we analyzed, we posit that a design educator in this function should be more inquisitive. This is especially the case with the formulation of high-level questions that challenge the students to further analyse their behavior while designing.

In tandem, students should be accountable for explicitly reflecting on their design thinking process.

Therefore, and primarily motivated by the scarcity of background research on design reviews, and inspired by the analysis we conducted in this study, we propose a structure for such reviews. The result is a tentative theoretical framework that proposes the implementation of clear *functions* to take place during design reviews, supported by inquiry to trigger students' analysis and reflection. This framework is further elaborated with a model of inquiry that aims to illustrate how both low-level and high-level questions are mutually important to facilitating comprehensive reflection in design reviews. Ultimately, we think that design instructors, with or without specific pedagogical training, ought to be questioning themselves about how far their 'coaching' prompts students to engaging in higher level thinking processes.

Acknowledgements
The authors would like to thank the two reviewers allocated to this paper for their thorough feedback in earlier versions of this document.

References

Aurisicchio, M., Bracewell, R.H. & Wallace, K.M. (2013). Characterising the information requests of aerospace engineering designers. *Research in Engineering Design*, *14(1)*, 43-63.

Aurisicchio, M., Bracewell, R.H. & Wallace, K.M. (2010). Understanding how the information requests of aerospace engineering designers influence information seeking behavior. *Journal of Engineering Design, 21(6)*, 707-730.

Atman, C. J., Eris, O., McDonnell, J., Cardella, M. E., & Borgford-Parnell, J. (2014). Engineering Design Education: Research, Practice and Examples that Link the Two.

Bloom, S. B. (1956). Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain, David McKay Company, New York, USA.

Cross, N. (2004). Expertise in design: an overview. *Design studies, 25(5)*, 427-441.

Curry, T. (2014). A theoretical basis for recommending the use of design methodologies as teaching strategies in the design studio. *Design Studies.*

Dewey, J. (1938). Experience and education. New York: Simon and Schuster.

Dillon, J. T. (1984). The classification of research questions. *Review of Educational Research, 54(3)*, 327-361.

Dreyfus, H. L., & Dreyfus, S. E. (1986). Mind over machine, the power of human intuition and expertise in the era of the computer. New York: Free Press.

Eris, O. (2004). Effective Inquiry for Innovative Engineering Design. Boston, MA: Kluwer Academic Publishers.

Eris, O. (2006). Insisting on Truth at the Expense of Conceptualization: Can Engineering Portfolios Help? *International Journal of Engineering Education, 22(3)*, 551-559.

Eris, O., & Leifer, L. (2003). Faciliating product development knowledge acquisition: interaction between the expert and the team. *International Journal of Engineering Education, 19(1)*, 142-152.

Flammer, A. (1981). Towards a Theory of Question Asking. Physiological Research, Vol. 43, 407-420.

Goldschmidt, G., Hochman, H., & Dafni, I. (2010). The design studio "crit": Teacher–student communication. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 24(03)*, 285-302.

Graesser, A. & McMahen, C. (1993). Anomalous Information Triggers Questions When Adults Solve Quantitative Problems and Comprehend Stories. *Journal of Educational Psychology, 85(1)*, 136-151.

Graesser, A. & Person, N. (1994). Question Asking During Tutoring. *American Educational Research Journal, 31(1)*, 104-137.

Kerry, T. (1987). Classroom Questions in England. Questioning Exchange, Vol. 1, p. 32-33.

Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Englewood Cliffs, NJ: Prentice-Hall.

Lawson, B. (2006). How designers think, the design process demystified. Amsterdam: Architectural Press.

Lehnert G. W. (1978). The Process of Question Answering, Lawrence Erlbaum Associates, Hillsdale, New Jersey.

Reich, Y., Ullmann, G., Van der Loos, M., & Leifer, L. (2009). Coaching product development teams: a conceptual foundation for empirical studies. *Research in Engineering Design, 19(4)*, 205-222.

Runco, M. A., & Jaeger, G. J. (2012). The standard definition of creativity. *Creativity Research Journal, 24(1)*, 92-96.

Sachs, A. (1999). Stuckness' in the design studio. *Design Studies, 20(2)*, 195-209.

Sarkar, P., & Chakrabarti, A. (2011). Assessing design creativity. *Design Studies, 32(4)*, 348-383.

Schön, D. A. (1984). The reflective practitioner: How professionals think in action.

van Dooren, E., Boshuizen, E., van Merriënboer, J., Asselbergs, T., & van Dorst, M. (2014). Making explicit in design education: generic elements in the design process. *International Journal of Technology and Design Education, 24(1)*, 53-71.

Biographies

Carlos Cardoso is an Assistant Professor of Design Theory and Methodology at Delft University of Technology in The Netherlands. He holds a Ph.D. in Engineering Design, and a Dip.DES in Industrial Design.

Ozgur Eris is an Associate Professor of Design Theory and Methodology at Delft University of Technology in The Netherlands. He received a B.S. in Mechanical Engineering from University of Washington, and an M.S. and a Ph.D. in Mechanical Engineering with a design concentration from Stanford University.

Petra Badke-Schaub is Professor of Design Theory and Methodology at Delft University of Technology in The Netherlands. She has a background in cognitive and social psychology and did her Ph.D. on 'Groups and complex problem solving' at the University Bamberg in Germany.

Marco Aurisicchio is a Lecturer in Engineering Design at Imperial College London. He holds a Ph.D. in Engineering Design from Cambridge University (UK) and a Laurea in Mechanical Engineering from the Universita' degli Studi di Roma 'La Sapienza'.