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# ASKING GENERATIVE DESIGN QUESTIONS: A FUNDAMENTAL COGNITIVE MECHANISM IN DESIGN THINKING

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## Abstract

Question asking is a fundamental cognitive mechanism in design thinking, and can be treated as a process. A key aspect of characterizing that process, formulizing the nature of questions asked while designing, is explored by reviewing and building upon existing knowledge on questions. Published taxonomies of questions are extended by the addition of five new question categories, which fall under the newly termed class, "Generative Design Questions." A conceptual framework that can serve as an analysis scheme for further empirical research is synthesized from the findings.

*Keywords: Question asking in design, design cognition, empirical study*

## 1 Introduction

Designing is question intensive. When compared to two other contexts for intellectual interaction, reading comprehension and classroom learning, designing promotes the asking of more and deeper questions [1]. However, our knowledge of the role of question asking during designing is rather understudied and limited. The research presented in this paper provides the preliminary understanding design researchers currently lack on the topic, and presents a canonical conceptual framework for studying questions in design.

The subject of question asking processes of design teams first attracted the attention of the author during a video interaction analysis session aimed at hypothesis generation. The video data for the analysis were collected during a two week design project carried out by graduate engineering design students whose goal was to design, prototype and race a paper bicycle. During the analysis, close attention was paid to the questions raised in the interaction, and their effect on the design decisions that followed. Some questions seemed to have a strong effect on pivotal decisions, and others dissipated and had no discernable impact. In either case, questions and decisions appeared to be being tightly linked at a conceptual as well as at a pragmatic level.

However, it quickly became clear that the current understanding of questions—as they occur in a design context—was not comprehensive enough to allow for the study of their relationship to other subjects such as decision making. It was necessary to formulize aspects of question asking in a design context before it could be related to another subject. Reviewing published taxonomies of questions was a good starting point in gaining the lacking knowledge on the nature of questions and reaching that formulization. Also, the insights gained would be useful in laying out the foundations of a theoretical framework that would serve as an analysis scheme for empirical research in the field and the laboratory as the categories of a taxonomy would constitute natural units of a coding scheme that could be used for observation and analysis.

Therefore, relevant taxonomies of questions from four different disciplines were reviewed and compared: philosophy [2], education [3], artificial intelligence [4], and cognitive psychology [5].

## 2 Review of Taxonomies of Questions

Dillon's work was aimed to understand more about the "kinds of questions that may be posed for research." He undertook a comprehensive review of twelve categorization schemes for research questions published in the fields of education, philosophy, psychology and history, which yielded mixed results [3]. He found that a significant portion of the categorization schemes did not operate on specific and consistent differentiating principles. The principles used in forming the categories were not made explicit, and examination of the categories failed to reveal them. Therefore, he concluded that most of the published taxonomies have limited utility. However, he perceived significant value in Aristotle's approach.

Aristotle's fundamental premise was to assume that our knowledge resides in the questions we can ask and the answers we can provide [2]. Dillon interpreted the progression between Aristotle's four categories (Table 1, column 1) as a "sequence of inquiry." He then presented his own categorization scheme, which he based on "Aristotle's few, short, and encompassing propositions." His scheme distinguishes between kinds of questions according to the level of knowledge entailed in the answers (Table 1, column 2).

Lehnert's work was aimed at laying out the theoretical foundations of a computational model—an artificial intelligence—that could answer questions [4]. In her model, she treated question answering as a process that can be broken down into two parts: understanding the question, and finding an answer. The first part has to do with interpreting the question, the second with searching the memory of the artificial intelligence for the best answer. The first part of her approach required the development of a taxonomy of questions.

According to Lehnert, the most important dimension of a question that needs to be interpreted for it to be understood and answered appropriately is its conceptual meaning. She proposed 13 distinct conceptual question categories, which can be thought of as "processing categories that are predicted by features of conceptual representation" (Table 1, column 2).

Graesser work dealt with the cognitive aspects of question asking in an education context by assessing the influence of question asking on learning, and identifying mechanisms that generate questions [5]. Graesser adopted Lehnert's taxonomy, and extended it with five new categories (Table 1, column 4). He then used the framework to analyze the frequency and the type of the questions asked by students during a series of tutoring sessions related to an undergraduate class on research methods. The incidence of a certain class of questions correlated positively with student learning. He termed them "Deep Reasoning" questions, or "DRQs." Also, his comparison of the extented version of Lehnert's taxonomy he used with Bloom's taxonomy of educational objectives in the cognitive domain [6] demonstrated that the DRQ categories map onto the higher level of learning objectives.

Comparison of these four taxonomies demonstrates the existence of a conceptual mapping between the frameworks (Table 1, columns 1-4). That is a positive finding as it indicates a strong degree of agreement in the thinking of the authors, and suggests that Lehnert's framework constitutes a sound basis for analysis and further development.

Table 1. A comparison of the categories of five taxonomies of questions. Dillon's categories are an expansion of Aristotle's. Graesser's and Eris's categories are an extension of Lehnert's. ■ denotes the types of questions termed as "Deep Reasoning Questions" by Graesser. ● . denotes the types of questions termed as "Generative Design Questions" by Eris.

| ARISTOTLE | DILLON | LEHNERT | GRAESSER | ERIS |
|---|---|---|---|---|
| Existence (Affirmation) | Existence/affirmation | Verification | Verification | Verification |
| | Instance/identification | | | |
| Nature (Essence/Def.) | Substance/definition | | Definition | Definition |
| | | | Example | Example |
| Fact (Attribute/ Description) | Character/description | Feature Specification | Feature Specification | Feature Specification |
| | | Concept Completion | Concept Completion | Concept Completion |
| | | Quantification | Quantification | Quantification |
| | Function/application | Goal Orientation | Goal Orientation ■ | Rationale/Function ■ |
| | Rationale/explication | | | |
| | Concomitance | Disjunctive | Disjunctive | Disjunctive |
| | Equivalence | | Comparison | Comparison |
| | Difference | | | |
| Reason (Cause/ Explanation) | Relation | | Interpretation | Interpretation ■ |
| | Correlation | | | |
| | Conditionality & Causality | Causal Antecedent | Causal Antecedent ■ | Causal Antecedent ■ |
| | | Causal Consequent | Causal Consequent■ | Causal Consequent ■ |
| | | Expectational | Expectational ■ | Expectational ■ |
| | | Procedural | Procedural ■ | Procedural ■ |
| | | Enablement | Enablement ■ | Enablement ■ |
| | | | | Proposal/Negotiation● |
| | | | | Enablement ● |
| | | | | Method Generation ● |
| | | | | Scenario Creation ● |
| | | | | Ideation ● |
| | | Judgmental | Judgmental | Judgmental |
| | Rhetorical | | Assertion | |
| | | Request | Request/Directive | Request |
| | Deliberation | | | |
| | Unspecified | | | |
| | Unclear | | | |

# 3 Question Asking in Design Contexts: An Argument for the Search for the "Possible" and Its Characterization as Question Categories

The comprehensiveness of the reviewed taxonomies was tested empirically by attempting to use them as coding schemes to categorize questions asked while designing. More specifically, that entailed:

1) Considering the appropriateness of treating the principles and question categories associated with the published taxonomies as analysis dimensions and units for studying the question asking processes of designers.

2) Identifying any dimensions of the question asking processes of designers that are not addressed by those principles and categories.

3) If such gaps exist, proposing new principles and categories that will address them.

The empirical data from which questions were extracted was collected in three different design settings. The first setting was the product development center of a US automobile manufacturer, where global design teams developed passenger vehicles and light trucks [7]. The second setting was a two week long design project where a team of 4 graduate mechanical engineering students designed, prototyped, and raced a paper bicycle [1]. The third setting was a series of 90 minute long quasi-controlled laboratory experiments where 14 teams of 3 graduate mechanical engineering students designed and prototyped a device that measures the length of body contours [1].

When extracting questions from audivisual and transcript data, a question was taken to be a "verbal utterance related to the design tasks at hand that demands an explicit verbal and/or nonverbal response." When the published taxonomies were used to categorize the questions, 15.4% of the questions could not be accounted for. Analyzing the nature of the unaccounted questions and reflecting on why they were not represented in the published taxonomies resulted in the identification of an overlooked domain.

The common premise behind the framework of the published taxonomies is that a specific answer, or a specific set of answers, exists for a given question. Lehnert and Greaser also seem to assume that the answer is known—not necessarily by the person asking the question, in which case it would be a rhetorical question, but possibly by the person to whom the question is directed. Such questions are characteristic of convergent thinking, where the questioner is attempting to converge on "the facts." The answers to converging questions are expected to hold truth-value since the questioner expects the answering person to believe his/her answers to be true. DRQs are such questions.

An example of a DRQ illustrating this concept is, "Why does the moon rise at night?" In this question, the questioner is interested in revealing the reasons which lead to the moon rising in the sky at night, and seeking a definitive truthful explanation.

However, questions that are raised in design situations tend to operate under the diametrically opposite 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. The questioner's intention is to disclose the alternative known answers, and to generate the unknown possible ones—regardless of their being true or false. Such questions are characteristic of divergent thinking, where the questioner is attempting to diverge away from the facts to the possibilities that can be generated from them. It is useful to establish a terminology for those types of diverging questions, and appropriate to refer to them as "Generative Design Questions," or GDQs.

An example of a GDQ illustrating this concept is, "How can one reach the moon?" In this question, the questioner is interested in generating possible ways of reaching the moon, and most likely, at the time of posing the question, is not too concerned about the truthfulness of the potential answers that might be triggered and emerge.

# 4 Extending the Taxonomies of Questions: Generative Design Questions

The unaccounted questions by the published question categories, the GDQs, were analyzed further, and the following five GDQ categories were constructed and proposed as additions to the existing taxonomies of questions (Table 1, column 5): Proposal/Negotiation, Scenario Creation, Ideation, Method Generation, and Enablement.

## 4.1 Proposal/Negotiation

The questioner wants to suggest a concept, or to negotiate an existing or previously suggested concept. Even though these types of questions initially appear to fall under the "Judgmental" category, which covers questions where the questioner wants to solicit a judgement from the answerer by requiring a projection of events rather than a strict recall of events, upon further consideration, it becomes clear that a there is a fundamental conceptual difference between making a suggestion and soliciting a judgement.

An example of a Judgmental question is, "Do you think the wheel is more accurate?" The questioner is asking for the answerer's opinion on what should be done, and is not offering any opinion herself/himself. The answerer is expected to supply a single definitive opinion. On the other hand, "How about attaching a wheel to the long LEGO piece?" is a Proposal/Negotiation question. The questioner is offering an opinion on a concept, and expecting the answerer to supply her/his own corresponding opinion(s), which would not be definitive. The questioner intends to establish a negotiation process by exchanging opinions, and to open up the possibility to new concepts. The suggestion of the new concept usually requires a consideration of the hypothetical possibilities the new concept can lead to. Proposal/Negotiation questions are significant because proposing an idea in the form of a question promotes consideration and feedback, and negotiation promotes synthesis.

## 4.2 Scenario Creation

The questioner constructs a scenario involving the question concept and wants to investigate the possible outcomes. In a strict sense, such questions could be categorized under Lehnert's "Causal Consequence" category. However, Causal Consequence questions involve one causal chain of two conceptualizations—the second conceptualization is partially or completely unknown. Scenario creation questions differ from causal consequence questions in two ways: there are multiple possible causal chains and linked concepts, and the causal chains are hypothetical.

An example of a causal consequence question is "What happened when you pressed the pulley?" The questioner is assuming that when the person pressed the pulley, something specific happened. In other words, the person pressing the pulley led to a specific outcome, and the questioner wants to know what that was. On the other hand, "What if the device was used on a child?" is a Scenario Creation question. The questioner wants to generate and account for as many possible outcomes as possible from the scenario(s) that can be constructed. Scenario Creation questions are significant because accounting for possible outcomes generates and refines design requirements.

## 4.3 Ideation

The questioner wants to generate as many concepts as possible from an instrument without trying to achieve a specific goal. Such questions involve multiple possible conceptualizations and causal chains. The first conceptualization is partially unknown, and the second conceptualization is partially or completely unknown.

An example of an ideation question is, "Are magnets useful in anyway?" The questioner does not intend to achieve a specific goal by using the magnets. He/she does not have a purpose other than to generate as many ways of utilizing magnets as possible. Ideation questions are significant because operating without a specific goal frees associations and drives concept generation.

### 4.4 Method Generation

The questioner wants to generate as many ways as possible of achieving a specific goal. Even though such questions initially seem to be derivatives of Lehnert's "Procedural" category, they are fundamentally different. As Lehnert points out, "A Procedural questions asks about an act that was simultaneous with the main act of the question. If a question asks about an act that precedes the main act of the question, the question is either a Causal Antecedent or an Enablement question." A method generation questions falls into the second category since it asks about acts that precede the main act of the question. Then, according to Lehnert, it should be classified as a Causal Antecedent or an Enablement question. However, Causal Antecedent and Enablement questions involve a single causal link, whereas a method generation question has a completely known initial question concept and multiple possible and completely unknown secondary question concepts.

An example of a method generation question is, "How can we keep the wheel from slipping?" The questioner wants to generate secondary conceptualizations, which, if realized, will cause the initial conceptualization—keep the wheel from slipping. That question is clearly distinct from the causal consequence question, "What happened after you pressed the pulley?" Method Generation questions are significant because operating with a specific goal generates a set of methods for implementing concepts.

### 4.5 Enablement

The questioner wants to construct acts, states, or resources that can enable the question concept. This category is the GDQ version of the original Enablement category Lehnert proposed, which Graesser labelled as a DRQ. What differentiates it from Lehnert's, and makes it a GDQ, is the questioner assuming the existence of multiple possible initial conceptualizations.

An example of a GDQ Enablement question is, "What allows you to measure distance?" when the questioner is indeed aiming at identifying resources for measuring distance. However, the same questions should be categorized as a DRQ enablement question when the questioner believes there is a single or a set of specific known resources of measuring distance. That differentiation can only be made by taking into account the context in which the question was raised. (The need to understand the context is true for categorizing any type of question, however, it is more pronounced in this specific case.) Enablement questions are significant because identification of multiple resources promotes surveying and learning from existing design features.

## 5 Implications and discussion

The fifth class of questions in Table 1 containing the Generative Design Questions is the contribution of this paper. It is not addressed by any of the other schemes. For the most part, that can be explained by the diverging-converging thinking paradigm that was argued for in the previous section, where a fundamental distinction was made between questions that aim to converge on facts and questions that aim to diverge away from facts to the possibilities that can be generated from them. The classification schemes of Aristotle, Dillon, Lehnert and Graesser are concerned mainly with convergent questions.

One way of supporting that view, apart from interpreting the question categories directly, is to consider the motivations of the authors for constructing the taxonomies, and to assess if they aim to establish frameworks for understanding facts, or for creating possibilities from them. Aristotle's paradigm is epistemological; the main premise is: "The kinds of question we ask are as many as the kinds of things which we know." Thus, he focuses on what we know, on the existing, and not on the possible. Dillon explicitly stated that his taxonomy is descriptive of "research" questions, and his interpretation of research activity seems to entail discovering and better understanding existing phenomena—paralleling Aristotle's paradigm.

And finally, Lehnert, strongly influenced by cognitive science, was ultimately interested in developing a question answering process, consisting of two separate processes for understanding questions and finding answers. The second process of "finding"—not creating—answers entails retrieving answers from existing memory structures. (Even though she mentioned that multiple appropriate answers can be constructed for most questions using that procedure, that should not be taken to mean that possibilities can be created from known facts; it means that multiple known answers might exist and can be "found" in the memory structure.)

On the other hand, as argued for in the previous section, the Generative Design Question categories that are proposed here reflect divergent thinking. Therefore, they constitute a separate class of questions. However, it is not necessarily clear where that class should be positioned in Table 1 since its hierarchy is determined by the extent of knowledge in the answers. Does the knowledge in answers of GDQs encompass the knowledge in answers of the other class of questions? That is a problematic proposition since the purpose of GDQs is to create knowledge as opposed to discover or to construct it from fact, and it is inappropriate to guess at the extent of knowledge that is yet to be created before it is created. At this point, it can only be hypothesized that GDQs, similar to DRQs, are correlated with learning, and also that both GDQs and DRQs are correlated with design cognition, and, thus, with design performance. Verifying that hypothesis would imply that the extent of knowledge in answers to GDQs is comparable to the extent of knowledge in answers to DRQs and to the types of questions in Aristotle's Reason class.

## 6 Conclusion and further work

In conclusion, the framework presented in this paper demonstrates a cognitive paradigm associated with the type of questions designers ask while they design, which represents a convergent-thinking distinction in their thinking. It also strongly suggests the existence of a certain class of questions that are specific to and characteristic of design thinking. Finally, any coding scheme to be used in the analysis of questions asked while designing needs to account for the types of questions that fall under the GDQ categories if it is to be comprehensive.

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