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# LEARNING TO QUESTION: A LONGITUDINAL ANALYSIS OF QUESTION ASKING BEHAVIOUR AND ENGAGEMENT IN PROJECT-BASED LEARNING

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## ABSTRACT

This paper explores the nature of questions students ask while undertaking engineering design work, how the nature of those questions changes as students' cognition develops, and what the possible relationship is between those changes and the types of curricular experiences students have. Preliminary findings indicate that the question asking behaviour of engineering students do change over time; they are more likely to ask questions that are divergent in nature as they advance in their education. Findings also suggest that a potential mechanism for that change might be engagement in project-based learning experiences.

*Keywords: Question Asking, Design Thinking, Project-based Learning*

## 1 INTRODUCTION

Inquiry plays a critical role in the design thinking of engineers as it serves as a reasoning and exploration mechanism, and guides analytical and creative processes. But, how does an engineer learn to ask questions? And, how does inquiry develop as a mechanism in the design thinking of an engineer? Does the design curriculum an engineering student is exposed to affect his/her questioning behaviour? This last question has been the primary motivation for the research presented in this paper.

Although being an inquisitive learner means actively exercising control over the material to be learned by asking questions, most students remain passive in the classroom, and ask infrequent and unsophisticated questions [1-3]. The same body of research indicates that students initiate approximately 1% of the questions asked in a classroom, at an average rate of one question per hour. Questions asked by students tend to involve the recall and interpretation of explicit material rather than involving inferences, application, synthesis and evaluation. Unfortunately, attempts at facilitating the asking of more questions by students have resulted in an increase in the number of unsophisticated questions.

Building on this insight, this research aims to explore how the question asking behaviour of undergraduate engineering students change over time as they advance through their engineering curricula, and more specifically, gain exposure to engineering design thinking principles.

## 2 WHY INQUIRY MATTERS IN DESIGN THINKING AND HOW CAN IT BE LEARNED?

### 2.1 An Inquiry-based Design Thinking Model

A recently introduced inquiry-based design thinking model, together with the empirical findings that drove its development, can be used to substantiate the relevance of inquiry to design thinking. The main premise of the divergent-convergent inquiry based design thinking model (the DCIDT model) is that the cognitive activities which form the basis of engineering design projects are question-driven, and that engineering tasks require one to continuously question [4].

The DCIDT model, derived from data collected in the field and the laboratory, demonstrates that inquiry takes place in two fundamental modalities in design thinking: divergent and convergent questioning. It identifies the incidence of a specific class of questions, deep reasoning questions (DRQs), in engineering design team discourse as a manifestation of convergent thinking, and the incidence of another class of questions, generative design questions (GDQs), as a manifestation of divergent thinking. The key distinction between the two classes of questions is the truth-value of the propositions that can be offered as answers. By definition, the answers to DRQs are expected to hold truth-value, whereas the answers to GDQs are not.

The model also demonstrates that an effective inquiry process in design thinking entails the asking of GDQs to create, synthesize, and expand concepts, as well as the asking of DRQs to analyze, evaluate, reduce, and validate concepts and to arrive at decisions.

The importance of this complementary relationship is supported by the discovery of a significant correlation between only the *combined* incidence of deep reasoning questions and generative design questions and design performance of engineering teams during a simulated design exercise [4]. Moreover, DRQs (termed by Graesser [5]) were used to study learning interactions. In that context, their incidence was shown to correlate with student comprehension of scientific information [6].

### 2.2 Project-based Learning: the Pedagogy of Choice for Design Learning

The model discussed in the previous section argues for the relevance of inquiry to design thinking from a cognitive perspective. Building on that dimension, this study aims to identify pedagogical approaches which might facilitate the learning of that type of cognition.

A survey paper on engineering design thinking learning and teaching reviews the literature and identifies project-based learning (PBL) as a key pedagogical mechanism for motivating and integrating design learning [7]. The paper differentiates PBL into two categories according to the types of projects that are used: design-oriented projects and problem-oriented projects. Design-oriented projects “deal with know how, the practical problems of constructing and constructing on the basis of a synthesis of knowledge from many disciplines.” Problem-oriented projects “deal with know why, the solution of problematic problems through the use of any relevant knowledge, whatever discipline the knowledge derives from.”

Based on these definitions, it is hypothesized that design-oriented projects facilitate a higher degree of divergent thinking than problem-oriented projects, and therefore, relatively speaking, might be more effective in promoting students to explore generative design questions. The converse statements can be assumed for problem-oriented projects and deep reasoning questions. This observation clarifies why problem-oriented projects should be carried out in conjunction with design-oriented projects in engineering curricula since DCIDT presents empirical evidence demonstrating that an effective design inquiry process has complementary divergent and convergent components.

## 3 LONGITUDINAL STUDY DESIGN

This study investigates relationships between the inquiry-based design thinking model and the PBL pedagogy in the context of a *longitudinal* study, and intends to provide insights on the cognitive development of the engineering student. In realizing this, two data gathering instruments were used longitudinally over a period of three years: A performance task and a survey.

### 3.1 Performance Task

In order to gain insights to the design thinking of the participants, and more specifically, to their question asking behaviour, a performance task was administered. The performance task consisted of a design task that has been developed and used successfully in an unrelated study [8]. The participants were first presented with a design project statement, and then asked to consider the factors they would take into account in their design. The written instructions the participants were provided with are below:

*Over the summer the Midwest experienced massive flooding of the Mississippi River. What factors would you take into account in designing a retaining wall system for the Mississippi?*

The participants were given paper and a pencil and allowed to document their factors for ten minutes. Then they were asked to respond to the following prompt:

*What questions came to your mind as you were brainstorming your list?*

The participants were given further instructions to fully formulate their questions and not to speak in fragments. If they still were not sure how to respond, they were told to act as if they are playing the U.S. television game, Jeopardy. They were allowed to browse through their list of factors if they chose to do that naturally, but were not explicitly prompted to do so. The participants were allowed to voice as many questions as they would like. If a participant did not voice any questions at all, he/she was prompted again to reflect what came to his/her mind while thinking about the design task and to phrase some questions. If that did not have an effect either, no questions were recorded for that participant.

This same protocol was administered twice to the same participant population. The first administration was in March 2004 (during the students' first year in college, and the second administration was in March 2006 (during the students' third year in college).

### 3.2 Longitudinal Survey

In order to determine the extent of exposure the participants had to PBL methods, a question was incorporated into a survey that is part of a broader study [9-10]. The survey question read:

*This term, how often have you taken courses which required your engagement in individual and/or group projects?*

The response options were: Never, rarely, occasionally, and frequently. The same survey question was administered electronically to the same participant population a total of three times amid the administration of the performance tasks: in April 2005 (spring of the second year), December 2005 (fall of the third year), and April 2006 (spring of the third year).

### 3.3 Study Participants

61 undergraduate engineering students from 4 research extensive educational institutions (by Carnegie Classification) participated in all phases of the study. All of the participants were first year college students at the time of the first performance task, and studied engineering between then and the second administrations of the performance task.

## 4 ANALYSIS FRAMEWORK

Questions voiced by the participants were transcribed and then categorized according to the distinctions made in the DCIDT model. As discussed in section 2.2, the question classes that are of particular importance to this study are DRQs and GDQs. Any other questions were categorized as a third class of questions that were labelled, "Other."

It is important to note that, in addition to the empirical evidence that demonstrates a correlation between the combined incidence of DRQs and GDQs and design performance, it is possible to conceptually map DRQs and GDQs to the higher level categories, namely "Analysis, Synthesis, and Evaluation" of Bloom's taxonomy of educational objectives in the cognitive domain [11]. Graesser has demonstrated this relationship for DRQs [6]. This is not to say that the questions falling under the "Other" category in this analysis are insignificant. On the contrary, an effective inquiry process relies on the asking of lower level questions in order to establish a sound factual and conceptual basis for asking higher level questions. In other words, it would be pointless to reason about a phenomenon by asking DRQs or to generate and explore alternatives by asking GDQs without understanding the facts and attributes about the phenomenon first by asking lower level questions.

The question taxonomy used in the development of the DCIDT model has a total of 21 question categories (see [4] for a detailed discussion on the origins of that taxonomy): 7 under the DRQ class, 5 under the GDQ class, and 9 under Other. Although the questions were categorized under these three broader classes of questions for the purposes of this study, it is useful to provide examples for each question category so that the reader can grasp the semantic differences at a finer scale than the overarching convergent-divergent paradigm. Questions voiced by participants of this study are presented in Figure 1 to illustrate each question category.

| | Category | Example |
|---|---|---|
| Other | Verification | Are there people living there? |
| | Disjunctive | Is this a freak occurrence or is it increasing over time? |
| | Concept Completion | Where did it flood? |
| | Feature Specification | What kind of land is around? |
| | Quantification | How close are the houses? |
| | Definition | What is a drainage wall? |
| | Example | What are some past damns that have been used? |
| | Comparison | Which one was more effective? |
| | Judgemental | Will it annoy people? |
| Deep Reasoning Question (DRQ) | Interpretation | What would the environmental impacts be? |
| | Procedural | How were similar retaining walls constructed? |
| | Causal Antecedent | Why did the wall fail? |
| | Enablement | Who do I need to build a retaining wall? |
| | Rationale/Function | What is the purpose of the retaining wall? |
| | Expectational | Why did the wall not hold? |
| | Causal Consequence | What would be impacted if this was constructed? |
| Generative Design Question (GDQ) | Enablement | Are there new building materials that might stand up to time? |
| | Method Generation | Is there a way to have an alternative to the wall? |
| | Proposal/Negotiation | Would a channel be more aesthetically pleasing? |
| | Scenario Creation | What if the wall breaks? |
| | Ideation | Is there a better way to do it than a retaining wall? |

Convergent Thinking

Divergent Thinking

*Figure 1. Example questions for each question category that were voiced by the participants during the performance task.*

## 5 RESULTS

The questions collected during the first performance task were coded independently by two researchers according to the three question classes discussed in the previous section, who were in agreement 88.7% of the time. The questions collected during the second performance task were coded by only one of the researchers. The analysis outcomes are summarized on Table 1, which indicates the distribution of the questions among the three question classes for the two performance tasks, the percentage change for each class in between the performance tasks, and the statistical significance as expressed by the p-value for the paired two sample t-tests.

*Table 1. Distribution of questions among the question classes for the two performance tasks, the percentage change, and statistical significance of the change.*

| | Task 1 | Task 2 | Change | p-value |
|---|---|---|---|---|
| **Other** | 138 | 183 | 33% | 0.0004 |
| **DRQ** | 191 | 183 | -4% | 0.4561 |
| **GDQ** | 36 | 50 | 39% | 0.0041 |

The results indicate that the 39% increase in GDQs and the 33% increase in the Other questions are statistically significant, whereas the 4% decrease in the DRQs is not.

Second part of the analysis entailed testing for correlation between the change in the incidence of GDQs, DRQs and Other questions between the two performance tasks and the survey measures per administration and as an aggregate of all three administrations. The same correlation was also considered for the change in the combined incidence of DRQs and GDQs.

*Table 2. Correlations between the differences in the classes of questions (Task 2 minus Task 1) and the survey measures per administration and the sum of all three surveys.*

| | *Survey 1* | *Survey 2* | *Survey 3* | *Sum Survey* | *Dif Other* | *Dif DRQ* | *Dif GDQ* | *Dif DRQ+GDQ* |
|---|---|---|---|---|---|---|---|---|
| Survey 1 | 1.000 | | | | | | | |
| Survey 2 | 0.299 | 1.000 | | | | | | |
| Survey 3 | 0.122 | 0.079 | 1.000 | | | | | |
| Sum Survey | 0.815 | 0.700 | 0.447 | 1.000 | | | | |
| Dif Other | -0.051 | -0.107 | 0.100 | -0.051 | 1.000 | | | |
| Dif DRQ | -0.062 | -0.098 | -0.069 | -0.109 | 0.006 | 1.000 | | |
| Dif GDQ | 0.020 | -0.239 | **0.313** | 0.000 | -0.015 | 0.151 | 1.000 | |
| Dif DRQ+GDQ | -0.046 | -0.176 | 0.060 | -0.095 | -0.001 | 0.926 | 0.514 | 1.000 |

As can be seen on Table 2, the only statistically significant correlation is between the Survey 3 measure (administered in April 2006) and the difference in the GDQs (R=0.313, p=.013).

## 6 DISCUSSION

The increase in the GDQs over the two year time period is indicative of a developmental change in the questioning behaviour of the participants although it is not possible to identify the cause for that change based on the available information. The hypothesis introduced in Section 2.2 offers one potential explanation when the increase is considered in conjunction with the correlation between the change in GDQs and the survey measure: that engagement in project based learning might indeed be affecting the question asking behaviour of students. However, it is then necessary to consider why there has not been any change/increase in the DRQs as well. In order to answer that question, it is necessary to learn more about the nature of the projects the students have been exposed to during the two years since we have argued that design-oriented projects would be more likely to increase the asking of GDQs and problem-oriented projects would be more likely to increase the asking of DRQs. In other words, if analysis of the projects students have been engaged in were to reveal that the projects were mainly design-oriented, the current analysis outcomes could be explained.

Another interesting point is that only the measures of the last survey administration correlated with the increase in the GDQs. This also requires further consideration. Although it would be rather unfortunate, it is possible that the question asking behaviour of students are more likely to be affected by recent pedagogical experiences, and that the effect disappears with time.

This research is at an initial stage, and in its current form has several limitations:

- The participants were asked to verbalize the questions after they thought through the design task. It can be argued that post-activity verbalization is not representative of the actual thinking process of the participants. Regardless, it can also be argued that the types of questions that were voiced by the participants are representative of how they think about design situations in general.
- Following from the above limitation, it can be argued that questions were coded out-of-context, which resulted in coding errors. This is the most significant limitation of this study. When questions are extracted from natural discourse, they are relatively easy to code since, apart from the semantic structure of the question itself, several contextual cues are available to the coder as to the intention of the questioner. In this study, questions were not voiced by the participants in natural discourse, and this did indeed present a significant challenge in classifying some of the questions.
- The survey measure used in the study might not be an accurate metric for exposure to PBL for two reasons: it reflects the perception of the participants in a relative sense, and does capture the design vs. problem oriented distinction. Moreover, it does not capture extra-curricular activities that have a project flavour to them. This limitation can be addressed to a great extent if the academic transcripts of the participants are analyzed and coded for design-oriented and problem-oriented courses. That would result in a much more objective and comparable PBL exposure measure. The authors are currently carrying out this analysis.

## 7 CONCLUSION

This is an initial exploration of the effects of teaching and learning design thinking on how students question. Preliminary findings indicate that the question asking behaviour of students do change over time; they are likely to ask an increasing number of divergent questions as they advance in their undergraduate education. Preliminary findings also suggest that a mechanism for that change might be engagement in project-based learning methods. Further analysis is under way to test that relationship.


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