Question-Posing Strategies Used by Students for Exploring Data Structures

Shitanshu Mishra
Inter-Disciplinary Program in Educational Technology
Indian Institute of Technology Bombay
Mumbai, India
shitanshu@iitb.ac.in

Sridhar Iyer
Department of Computer Science and Engineering
Indian Institute of Technology Bombay
Mumbai, India
sri@iitb.ac.in

ABSTRACT

Question posing by students is a valuable mechanism for learning. In this paper we demonstrate how student generated questions can result in unfolding of knowledge. We conducted field studies in Data Structures courses, where we provided a semi-structured question-posing situation to students. We analyzed the questions generated by students using inductive qualitative data analysis. We found that students pose exploratory questions and unfold knowledge using seven strategies, viz., *Apply, Organize, Probe, Compare, Connect, Vary, and Implement*. These strategies were validated within the data structures domain and were also found to be valid in another CS application domain (Artificial Intelligence). The content analysis of the questions has shown that students tend to unfold more conceptual knowledge than procedural knowledge.

Categories and Subject Descriptors

K.3.2 Computer Science Education.

Keywords

Question-posing; Data Structures; Knowledge unfolding; Inductive qualitative analysis; Question-posing strategies

1. INTRODUCTION

Learning science requires that students ask the right questions and get the right answers. It has been argued that asking questions is both harder and more important [24]. Asking question enables students to seek information to address their knowledge deficit and is a way to promote the independence in learning. We refer to Question Posing (QP) as the generation of a new question or a problem by a student based on the given situation [12]. The situation could be a given classroom room lecture, a piece of text, a video lecture, etc. We have employed a semi-structured [26] QP situation in which, the generated questions are neither very unfocused nor are they confined to only a single question, unlike the free and structured situations [26], respectively. The semi-structured situation comprised a short 10-15 minutes seed instruction followed by question posing, so that knowledge unfolding happens around the seed knowledge. **"Seed knowledge"**, as used in this paper, refers to the knowledge delivered by the instructor explicitly during the lecture.

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We conducted three question posing sessions and generated a corpus of 104 questions. We performed inductive qualitative analysis of this corpus to answer our first research question (RQ1): "How do students integrate prior knowledge and seed knowledge to arrive at a question during question posing?" Here **"prior knowledge"** refers to the all past knowledge and experiences of the student *except* those which were explicitly contained in the seed knowledge. Further we performed content analysis of the generated questions to answer our second research question (RQ2): "What type of knowledge do the generated questions unfold?". Here the term **"unfolded knowledge"** is the knowledge which constitutes the answer to a student generated question. Unfolded knowledge is new to the student and not part of either prior knowledge or seed knowledge.

Finally, we validated the evolved strategies within data structures (DS) course and artificial intelligence course. We found that students pose questions using eight strategies: *Apply, Organize, Probe, Compare, Connect, Vary, Procedurize* and *clarify*. The first seven strategies (not *clarify*) are exploratory and found to result in the unfolding of knowledge. These strategies are generalizable to CS application courses, as the strategies identified in the Data Structures (DS) course questions are also applicable to the Artificial Intelligence (AI) questions. It was found that students were able to unfold new topics/ concepts through QP activities.

2. BACKGROUND AND RELATED WORK

In this section we describe the theoretical motivation behind our research in question posing. We also discuss how existing question categorization schemes fail to come up with successful strategies of unfolding new knowledge based on the prior and current knowledge.

2.1 Question Posing

The notion of QP that we are interested in is question posing involving the generation of new questions (questions/ issues) around a given situation. We want student to pose questions, such that students use the QP activity as a way to unfold new knowledge, around conceptually preceding and/or related seed knowledge, in any given domain. We want that the QP situation should not restrict the posed questions around a specific problem solving task, as in [6]. At the same time we also want the posed questions to be within the scope of a course, or a domain. This QP situation is described as a "semi-structured" [26] QP situation, as opposed to the "free" and "structured" QP situations [26]. It enables divergent thinking, and it is driven by students intrinsic motivation and therefore positively affects question posing [17].

2.2 How do students pose questions

Graesser et al. (1992) identified four different psychological mechanisms that underlie the asking of questions. The mechanisms [11] are: (i) *Correction of knowledge deficits* (ii) *Establishing Common grounds* (iii) *Social coordination of actions* (iv) *Conversational Control*. Out of these four psychological mechanisms, only the first one i.e., "correction of knowledge deficits", is directly useful for learning, and prevalent in academic settings, where students pose questions in order to scaffold learning by identifying gaps in understanding. It describes the natural QP strategy that is followed by a learner. Based on this motivation, many researchers have devised a number of question posing strategies. Some of the frequently used QP strategies in literature are as follows: (i) "Modifying givens" - It is a QP strategy where questions are generated by modifying the conditions in a given problem statement [7]. (ii) *"What if not"* – As described in [16], in this strategy new questions are posed by negating any data, objects, operations or any other component of another question. (iii) "What if Strategy" - In this strategy [25] components of a given question are changed to generate new questions. (iv) *"Imitation strategy"* - It was presented by Kojima et al. [15], where the learner generates questions by reproducing the QP strategy demonstrated by examples of questions and their generation processes [15]. Cruz Remirez (2006) proposed a strategy consisting of six non sequentially dependent steps – searching, selection, transformation, classification, association and posing. [5]

2.3 Question Analysis Schemes

There have been a variety of question analysis schemes proposed by researchers. Graesser et al. (1992) proposed a scheme [11] in which 18 question categories are defined based on the content of the information requested. They also presented a dimension called degree of specification (low, medium high) which describes how specific or vague the information requested by the question is. [11].

Nielsen, et al. presented another scheme of question categorization based on the content of the information requested, and proposed 5 broad question categories, viz., Description Questions, Method Questions, Explanation Questions, Comparison Questions, and Preference Questions [22]. Olney, et al. proposed three categories of specificity of questions (high, medium low), based on whether information sought by a question is vaguely or explicitly marked [23]. Many of the researchers use revised Blooms Taxonomy [1] to categorize questions based on cognitive levels and/ or knowledge type of the information requested.

Most of the question analysis schemes cater to questions posed in general situations, and do not talk specifically about questions generated in semi-structured [26] QP situations. Moreover, none of the schemes were based of reflecting on how a question utilizes prior knowledge and the knowledge presented in the current QP situation, to arrive at a question. To fill this gap, in this paper we have developed a question classification scheme using grounded theory based inductive qualitative analysis of a question corpus generated in a semi-structured situation.

3. IMPLEMENTATION AND RESEARCH METHODOLOGY

In this section we describe the QP sessions, in which we collected questions generated by students, and the research method followed in our study.

3.1 The Question Posing Sessions and Data Collection

Each QP session described below was implemented in two phases 1) Instruction Phase, and 2) Question posing phase. The instruction phase was used as a semi-structure QP situation [26], which was characterized by an initial lecture (seed), and was light (less in content), and short (of short time), to ensure that student assimilates [20] most of the contents of it.

In the second phase, students were asked to pose questions based the content they studied in seed. Students were explicitly told that they can generate questions for two purposes – (a) when they want to clarify any muddy point (doubts) related to the seed or any previous lecture, and (b) when they want to discover more knowledge related to, or based upon, the contents of the seed instruction.

3.1.1 Data Structure Sessions

We administered a QP session in a 4th semester engineering classroom of 60 students. The instruction phase was executed for 15 minutes. Topics covered in the seed lecture were "Node Structure" and "Linking two nodes". The learning objective of the seed instruction was: "By the end of the seed instruction, student should be able to define, declare, construct, and access their own nodes and linkages between nodes using Java."

The QP phase continued for 10 – 15 minutes. Students were told to write their questions on paper slips and submit to the TAs. We collected all the generated questions (corpus 2) and after discarding the redundant and irrelevant questions, we were left with a corpus of 56 distinct questions.

Another set of questions were collected (corpus 3) from three other similar QP sessions which were administered in Data Structures course with 12 third semester engineering undergrads respectively.

3.1.2 AI Sessions

Similar to the data structure session, we administered two QP sessions in a 7th semester engineering classroom of 35 students in the Artificial Intelligence course. The first phase or the seed instruction phases were of 15 minutes each. The topic covered in the seed lecture of the first AI session was "*Comparison of Attributes of Intelligence in Utility based, Goal Based, and Simple Reflex agents*". The learning objective for the first session of the seed instruction was: *"By the end of the seed instruction student should be able to identify differences between simple-reflex, goal-based, and utility-based agents, with respect to the level and attributes of intelligence."*

Topic covered in the seed lecture of the second AI session was "*The architecture of learning agents."* Learning objective for this session of the seed instruction was: "By the end of the seed instruction student should be able to identify the attributes of intelligence present in the learning agents".

The QP phases in the both sessions continued for 10 minutes. Here also students wrote their questions on paper slips and submitted to the TAs. Students were explicitly told about the types – clarification and exploratory – of questions, similar to the Data Structures sessions. We collected 25 distinct questions in the first session and 23 distinct questions in the second session (corpus 1).

3.2 Research Design

We wanted to conduct an in-depth study of student question statements and our research question was broad. The grounded theory [21, 27] based approach is appropriate for this kind of study since "the grounded theory approach is a qualitative research tool that enables the researchers to seek out and conceptualize the latent social patterns and structures of the area of interest" [19]. We adapted grounded theory and performed inductive qualitative research. Grounded theory traditionally requires that data collection and analysis be intertwinned. However this was not possible in our case as the entire question set was collected at once and hence interleaving of data collection and analysis was not possible.

After the question set collection, we followed the first two coding procedures prescribed in the grounded theory to further investigate patterns in the questions. We did the data analysis for both AI and the DS questions separately. The first two coding procedures, i.e., open coding and axial coding, were carried out **separately** for each of the question sets (corpus 1 and 2). This helped in testing if the results of the axial coding are valid across the Computer Applications domains (DS and AI). Coding procedures, along with their results are presented in the next section. In addition to this we validated the results of our axial codding using corpus 3 to see if the results are applicable for another instance of QP activity in DS.

4. DATA ANALYSIS AND RESULTS

In this section we explain the two coding procedures [4] – open coding and axial coding, and present the incidents, the strategies and the core strategies emerged for the analysis. We also present results of the content analysis done and present an account of knowledge unfolding.

4.1 Open coding to generate incidents

The goal of the open coding was to explore the question data and identify incidents, i.e., units of analysis to code for meanings, feelings, actions, events and so on [21]. We started reviewing the question set (Corpus 1 and 2) with the research question "How do students arrive at questions in our semi-structured QP situation?" We did not predefine any rubric or predetermine any concepts to aid the qualitative conceptualization of the data. This was done to ensure that we do not get biased to any of the possible answer to the broad research question. We adopted the method of constant comparison [4], i.e., the emerging incidents were compared, merged, modified, and renamed. When we identified any new incident, we reviewed the dataset back and forth to compare the new incident with the older ones. If the new incident came to be similar, then it was merged and modified, and renamed with the older ones. There were two researchers working together, therefore the inter-rater reliability was not calculated.

Both researchers analyzed each question within the question corpus while working together. They start with reading the question, reading the focused research question, discussing the possible observable strategy of question posing, and coded the potential incident(s). For example: the question (from 2nd QP session in AI) - "Can we use neural network and fuzzy logic to create an agent?" yielded following two possible incidents to start with: "Applied prior known concepts."; "Making a richer understanding of the seed concept." After some iterations of constant comparison these two incidents were modified to "Use of concept(s) from prior knowledge to develop a richer understanding about the seed knowledge."

At the end there were a total 15 different incidents identified for the Data Structure question set, and 13 different incidents in the Artificial Intelligence question set. These are given in figure 1.

<table>
<tr><th colspan="2">Common incidents identified in the DS and AI question sets</th></tr>
<tr><td colspan="2">• Identifying an application of a knowledge component(s) in the seed from real life. (P1)
• Use of concept(s) from prior knowledge to develop a richer understanding about the seed knowledge. (P3)
• Variation on some attribute of the seed knowledge. (P6)
• Using prior procedural knowledge, create an operation that can be done on the seed concepts. (P7)
• Using prior knowledge about an operation transform the state of the seed concept(s). (P7)
• Clarifying a concept in the seed knowledge. (P8)
• Requesting reiteration of a concept from previous lectures. (P8)</td></tr>
<tr><th>Additional incidents identified in the DS question set</th><th>Additional incidents identified in the AI question set</th></tr>
<tr><td>• Identifying an application of a knowledge component(s) in the seed from the same domain. (P1)
• Identifying an application of a knowledge component(s) in the seed from other domain. (P1)
• Reorganize components of SK to create a new structure of the SK. (P2)
• Comparing the SK procedural knowledge with prior procedural knowledge. (P4)
• Comparing SK with prior knowledge from other domain. (P4)
• Associating prior knowledge from same domain with SK. (P5)
• Creating a procedure using prior knowledge to perform a target operation on the seed. (P7)
• Resolving a conflict about the seed knowledge. (P8)</td><td>• Examining how to apply SK in a known context. (P1)
• Use of alternate conceptions from prior knowledge to develop a richer understanding about the seed knowledge. (P3)
• Comparing SK with prior knowledge from real life. (P4)
• Making an analogy between prior knowledge and seed knowledge. (P5)
• Associating SK with prior knowledge from other domain. (P5)
• Associating experiences from real world with the seed. (P5)</td></tr>
</table>

Figure 1. List of different incidents identified in the DS and AI question set after open coding. Strategies are given in *( )*.

4.2 Axial coding to generate QP Strategies

Axial coding, as stated by Strauss & Corbin [27] is done to reorganize the incidents obtained from the open coding on the basis of connections between the incidents. During the axial coding, the incidents obtained from the open coding were grouped into subcategories and core categories. Final categories and sub categories were identified using a group review process [8], which was operationalized using a series of meetings between researchers. The researchers continued working together in this manner to group related incidents together until consensus was reached. In some cases, incidents seem to be relevant in more than one category. For example, "Comparing the seed procedural knowledge with some procedural prior knowledge." fit in both "Operate", and "Associate" categories. In these situations, we either re-reviewed the questions, or if needed we re-specified the definitions of different categories. We call these categories as Question Posing Strategies, as these categories reflect different ways in which students arrived at a question in the semi-structured QP situation. We arrived at 4 core-strategies, and 8 strategies at the end of the iterations.

4.2.1 *Question Posing Strategies*

The axial coding of the incidents obtained from the open coding revealed 8 different QP strategies. It was evident that students make use of seed (and/or prior) knowledge in various ways to arrive at questions. In the subsequent section we describe all these 8 categories with examples. The examples used in the next subsections come predominantly from the question set collected from Data Structures QP-session.

Strategy 1 (P1): Apply

In this strategy, student employ the concept(s) from the seed knowledge to create a 'known application' from prior knowledge. These prior known applications are either from 1) the same domain, or 2) a different domain. The different domain could either be 2a) a different academic domain, or 2b) some real life experience. We note that the explicit identification of prior known application is mandatory in this strategy. Examples:

"*Can trees be made using nodes*?"
Here application ("tree") comes from same domain i.e. Data Structures.

"We can create groups?"
Here application ("groups") comes from different domain, i.e., Discrete mathematics.

"social network graph, is it possible?"
Here application ("social network graph") comes from real life experiences.

Strategy 2 (P2): Organize

In this strategy, student pose question to unfold an arrangement of the seed knowledge by organizing multiple instances of the seed concept to obtain a structural arrangement (which comes from prior experience). Example:

"Cyclic list of nodes possible?"
Here multiple instances of the concept (from seed) node, i.e., large number of nodes are proposed to be organized in a cyclic manner to unfold a variant of the seed (i.e. circular linked list).

Strategy 3 (P3): Probe

In this strategy, students pose question to associate prior knowledge to the seed knowledge with an objective to add more understanding to the latter. Here prior knowledge is NOT the prior known application, as in P1. The review of questions shows that these associations use prior knowledge as a basis to make a richer enquiry into the seed knowledge.

Example: *"address (next) is relative or direct?"*
Here concepts from prior knowledge ("relative/direct addressing") has been used to make a richer understanding of the construct "next", which is a part of seed.

Strategy 4 (P4): Compare

In this strategy, question is posed to unfold associations between prior knowledge and seed knowledge with an objective to compare or contrast some concepts in the seed knowledge with some concepts from prior knowledge.

Example: *"chain of nodes vs. array?"*
In this question the prior knowledge (*array*) is contrasted with seed concept (*chain of nodes*).

Strategy 5 (P5): Connect

In this strategy, student associates the seed knowledge to some prior knowledge from same domain, from other domains, or from real life. This strategy can lead to learning of additional knowledge (distinct from prioir or seed knowledge) rather than enriching the understanding of the seed. Making analogy between some prior knowledge with seed knowledge can come into this strategy. Contrasting or comparing the seed with some prior knowledge does NOT come under this strategy.

Example: *"Can we use neural network and fuzzy logic to create an agent?"*
In this question the prior concept of neural netwobe rk and fuzzy logic is connected with the context (*agent*) of seed knowledge.

Strategy 6 (P6): Vary

In this strategy the objective of the question is to modify/vary a component(s), attribute(s), or part(s) of the seed to unfold the variants of the seed concepts. These questions may or may not give rise to some application of the seed, but applications are not explicitly identified as in P1. Example:

"Can we have 'previous' node in addition to 'next'?"
In this question, instead of having just one pointer/reference to another node, the idea of having two reference/ pointer variables in the node structure, is proposed. In this way a variant of singly-linking (i.e. a doubly linking) is unfolded.

Strategy 7 (P7): Implement

In this QP strategy the objective of questioning is to inquire about operations/procedures that can be performed on the seed knowledge to achieve a goal state related to the seed. It should be noted that prior knowledge, in the form of an operation/procedure, is explicitly evident from the question statement. Example:

"How to perform inheritance from a node possible to give "multi-nodes"?
Here the operation inheritance has been explicitly identified, and question is about how to implement that operation on the seed concept (nodes).

Strategy 8 (P8): Clarify

The analyses revealed that students ask question to clarify their doubts. All the questions which need reiteration of the content that has been explicitly been taught in the seed lecture are categorized under this strategy. It should be noted that *Clarify* questions do not unfold any new knowledge. Example:

"What is the use of 'this' method?"
The use of "this" operator was explicitly taught in the seed.

Some observations from an examination of the incidents and categories are:

i. Students have used a range of question posing strategies;
ii. During question posing students use different types of prior knowledge;
iii. Students use prior knowledge from same and/or different domains;
iv. Student may employ more than one strategy for generating a single question.

Typically axial coding is followed by selective coding, which is performed to identify a "story line" that emerges out of linkages between categories from axial coding. In our case, our research objectives are fulfilled with axial coding.

4.2.2 Further grouping of the QP strategies

Figure 2 shows the core-strategies and their underlying subcategories. We can see that the two broad purposes of QP are to explore/ unfold unknown knowledge and to clarify the muddy points from the given lesson. The Exploratory QP can further be grouped into three core categories: 1) *Employ*, where the concepts from seed knowledge are used to create some goal 'application' or 'arrangement'. 2) *Associate*, where concepts from seed and prior knowledge interact with each other to give insight about the seed knowledge or about some new knowledge. 3) Operate, where the question posing aims at exploring the operation(s) required for achieving a goal state or modification related to the seed concepts.

A. Exploratory Questions:
  a. Employ
    i. Apply
    ii. organize
  b. Associate
    i. Probe
    ii. Compare
    iii. Connect
  c. Operate
    i. Vary
    ii. implement
B. Clarification Questions:
  a. Clarify

Figure 2. Question Types and categorization of QP strategies

4.3 Validation

We did a qualitative analysis of the corpus 3 (data structures) and tested if any question can be categorized as per the descriptions of one or more of the eight QP strategies. We found that each of the 25 questions satisfied at least one category of the identified QP strategies.

4.4 Content analysis to study unfolded knowledge

We have used the taxonomy of knowledge types proposed in the revised Bloom's 2-D taxonomy [1] and analyzed the corpus 1 and 2 for types of prior knowledge and unfolded knowledge associated with the generated questions. Table 1 shows the normalized frequency of knowledge types of the unfolded knowledge by in 104 questions (corpus 1 & 2). The frequencies do not sum to 1 because there are few problems which may have used more than one unit of prior knowledge.

Table 1. Frequency of types of knowledge requested (unfolded) by the 104 questions (corpus 1 & 2)

Knowledge Type	Normalized Frequencies (N= 104)	
	Prior knowledge	**Unfolded Knowledge**
Factual	0.04	0.19
Conceptual	0.58	0.43
Procedural	0.17	0.19
Meta -Cognitive	0.09	0.00

5. DISCUSSION & CONCLUSION

We have employed grounded theory based qualitative data analysis on the question set generated in a semi-structured QP situation. We identified 16 incidents, 8 sub-categories (strategies) and 4 core-strategies, from the two coding procedures – open and axial coding. Descriptions of the different strategies in the section 4.2 bring out how the prior knowledge and the seed knowledge are used to pose any question. (RQ1). Out of eight strategies, we found seven strategies, under "employ", "associate", and "operate" core-strategies, result in knowledge unfolding. (RQ2), whereas the "clarification" strategy was used to request the reiteration of information which was delivered explicitly during the seed lecture. Thus we discovered a total of seven strategies which generate exploratory-questions and one strategy that generates clarification questions. From the dimension of knowledge type, we found that the question posing activities resulted in the unfolding of the three types of knowledge - Factual, Conceptual, and Procedural, out of which the conceptual knowledge was predominant (RQ2).

We performed open coding and axial coding separately for AI and DS datasets (corpus 1 and 2 respectively). However we observed that while there were few different (but similar) incidents present in both the AI and DS datasets, results of the axial coding were same from both of the datasets. Therefore, it is important to note that the QP strategies that have emerged from the data are generalizable for CS Application domains. The analysis of the corpus 3 validates the results within DS domain. Yet we need more data to claim saturation of the strategies. Most of the existing QP strategies in literature deal with QP in a structured QP situation. Moreover no strategies exist which explicitly are based on how students use prior and seed knowledge to arrive at any questions in a semi-structured PP. This research can be an initiative to develop a new taxonomy of question posing strategies in Computer Science Applications domain.

While QP has the obvious benefit of addressing muddy points (doubts), it supports knowledge unfolding through generation of exploratory questions. Moreover, the seven QP strategies show the seven different ways by which students were found to integrate their prior knowledge and the seed knowledge. This shows that question posing by students initiates the knowledge integration process. We are now studying how student QP activities based on these question prompts influence their knowledge integration performance [18].

It is desirable to have teaching–learning activities that can elicit exploratory questions from students. In order to operationalize the emerged QP strategies as teaching–learning activities we have translated them into question prompts, as shown in (fig 3). These prompts can be used to scaffold QP activities (as in [14]).

Strategy	QP Prompts
Organize	Can we apply the concept_X to create structure_Y?
Compare	How is concept_X is compared to concept_Y?
Implement	How can we do procedure_Y on X to achieve something?

Note: Red colored text (with X) can be replaced by knowledge piece from the seed lecture. Blue colored text (with Y) can be replaced by a concept or idea from prior knowledge or experience.

Figure 3. Snippet of three QP prompts used in an ongoing study

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