Fostering Cognitive Processes of Knowledge Integration through Exploratory Question-Posing

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by

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Dedicated to

Article 51A(h) of the Constitution of India which states that
"developing the scientific temper, humanism and the spirit of inquiry and reform,"
is one of the fundamental duties of every Indian citizen.

Approval Sheet

This thesis entitled **"Fostering Cognitive Processes of Knowledge Integration through Exploratory Question-Posing"** by Shitanshu Mishra is approved for the degree of Doctor of Philosophy.

Examiners

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Abstract

When students encounter new knowledge, it is often fragmented and not well connected with their existing knowledge. Knowledge fragmentation is often larger for a learner who is new to a topic. Supporting knowledge integration (KI) is crucial to overcoming learners' knowledge fragmentation. Moreover, better KI ensures deeper conceptual understanding of a science topic. This thesis aims to explicitly target the improvement of learners' cognitive processes of KI.

KI has been defined as, *"the process by which learners sort out connections between new and existing ideas to reach more normative and coherent understanding of science."* It is recommended that instruction should support at least following cognitive processes: (i) Eliciting prior knowledge that may be related to the new knowledge; (ii) Focusing on the new knowledge; (iii) Distinguishing ideas - identifying conflicts, inconsistencies, and gaps. Prior research typically aim at devising instructional supports for KI for specific topics. However, this thesis targets the improvement of learners' cognitive processes of KI, which once improved, may be applied in different topics, even if it has been acquired through another topic. Our broad research objective is: "Designing and evaluating a technology-enhanced environment (TEL) environment to improve learners' cognitive processes associated with knowledge integration."

Our solution is based on using exploratory question-posing (EQP) as a cognitive tool for fostering cognitive processes of KI. EQP is a kind of question-posing wherein learners pose questions with an aim to explore more knowledge around a given set of knowledge. We have empirically found that to do EQP a learner needs to link knowledge pieces from the given new knowledge and her/his prior knowledge. This means that linking leads to EQP. However, EQP may further lead to more linking which can be considered as a positive feedback loop.

The primary research question that we answer in this thesis is: "How to employ EQP in a TEL environment to improve students cognitive processes associated with KI in a Data Structures course?" Our field studies have been administered in a number of topics in the

domain of Data Structures. The target population of this research are first and second year engineering undergraduates. The artifacts produced are applicable to the Data Structures and similar domains.

We have used design based research (DBR) as our overall research framework. DBR is a research methodology that aims at the development of educational interventions and/or learning environments through iterative analysis, design, development, implementation, and evaluation. The research activities are based on collaboration among researchers and practitioners in real-world settings, and they lead to contextually-sensitive design principles and theories.

We have executed two research cycles of DBR where each of the cycles involved the research activities of problem analysis, solution design, evaluations and reflections. By the end of the two DBR cycles we designed, developed and evaluated the following: (1) An EQP-based pedagogy known as "Inquiry-based Knowledge Integration Training (IKnowIT) - pedagogy" and (2) A web-based self-learning environment known as "IKnowIT-environment" as an operationalization of the IKnowIT-pedagogy. In addition to the IKnowIT-pedagogy and the IKnowIT-environment the thesis contributes by: (1) Identifying the frequently-employed EQP-strategies which explain how learners integrate different knowledge pieces to arrive at any exploratory question in the domain of data structure and (2) Extracting local learning theories that explain how learners engagement with the features of the IKnowIT-pedagogy, including question-posing and EQP-strategies, lead to the improvement of cognitive processes of KI in them. The results show that the designed IKnowIT-pedagogy successfully fosters learners' cognitive processes of KI using EQP.

Keywords: Knowledge Integration, Student Question-Posing, Cognitive Processes of Knowledge Integration, Data Structures

Table of Contents

List of Figures

List of Tables

Abbreviation and Nomenclature

CMap	Concept Map
CS	Computer Science
DBR	Design Based Research
DQ	Design Question
DS	Data Structures
EQP	Exploratory Question-Posing
iDEEN	Iterative Design Evaluation and Evolution
IKnowIT	Inquiry-based Knowledge Integration Training
IT	iDEEN Iterations
KI	Knowledge Integration
LeD	Learning Dialogue
LLT	Local Learning Theory
LQ	Literature Question
QP	Question-Posing
RQ	Research Question
SUS	System Usability Survey
TEL	Technology Enhanced Learning
TELE	Technology Enhanced Learning Environment
TELoTS	Technology-Enhanced Learning of Thinking Skills
UI	User Interface

Chapter 1

Introduction

1.1 Background and Motivation

When learners encounter new knowledge, it is often not well connected with their existing knowledge. According to Linn (2013), learners generally have "fragmented, fragile and incoherent repertoire of ideas" (Linn, 2013). This thesis views learning as "a process of integrating ideas," viz., adding, sorting, evaluating, distinguishing and refining accounts of experiences, phenomena and abstractions (Bransford et al., 1999; Linn and Eylon, 2006; Smith III et al., 1994). In order to make sense of new knowledge and attain deeper conceptual understanding, it is desired that the learners integrate different knowledge pieces into a coherent whole (Linn et al., 2003).

For richer integrations, it is desirable that the learner make richer relations among the ideas. Literature refers to these relations among ideas in the repertoire as knowledge webs (Linn, 2013; Linn et al., 2004c). A well-designed instruction helps learners strengthen the connections among ideas in their web, develop criteria for adding new connections, make connections across contexts or settings and create knowledge webs that make it easy to incorporate new ideas (Linn et al., 2004c). To help learners build and retain connections among scientifically relevant ideas and existing knowledge, we use the Knowledge Integration (KI) learning perspective (Linn et al., 2004a,c) in this thesis. The KI perspective is based upon research that asserts that the learners have rich, diverse and often conflicting ideas about any scientific phenomena from various contexts and experiences (Slotta et al., 1995; Davis, 2003; Disessa, 2000; Slotta et al., 1995). To attain a richer understanding, the learners make connections between surface ideas or deeper ideas, between concepts from same or different topics, courses or domains. These connections may come from the analysis of similarity, analogy, differences, applicabilities, applications etc. According to the KI framework (Linn et al., 2004b), promoting learning involves an instructional pattern that includes eliciting learner ideas (e.g. prior knowledge about hierarchical-tree-like structure), adding new ideas to build understanding (e.g. learner attending to concepts which are new to her/him while watching a video lecture on nodes and linked-list data structures), helping learners to sort out ideas (e.g. learner sorts out idea by asking for explanations how the idea of node and Linked list Data Structures can be extended to tree-like data structure?), and developing criteria for evaluating ideas (e.g. asking learners to assess their understanding of possible Data Structures) (Linn and Eylon, 2006).

Instruction from KI perspective seeks to build upon and leverage the rich repertoires of ideas and values that learners develop. KI instructional activities guide learners to add and distinguish ideas. When learners use evidence to sort out the alternative ideas, they generate about scientific phenomena, they engage in KI. To promote KI, successful instructional strategies do following (Linn and Eylon, 2011, 2006):

1. Instruction should start by eliciting ideas about scientific phenomena. This process recognizes the individual backgrounds and experiences that learners bring to learning contexts and enables them to make connections from new instruction to their existing ideas.

2. Encourage learners to distinguish alternative ideas. This process helps learners see how

existing ideas may conflict with new, normative ideas added during instruction.

3. Conduct activities to help learners construct coherent understanding by developing criteria for the ideas that they encounter. These criteria can be cultivated individually by deliberate and intentional learners or socially constructed in groups and communities of learners.

4. Help learners evaluate their understanding and connections among their ideas using these negotiated criteria and sort out and refine their knowledge based on these evaluations.

All these instructional patterns cater to the improvement of KI performances of the learners for chosen topics. According to the KI instructional patterns (Linn and Eylon, 2011) which lists the sequences of processes that reinforce each other to help learners create coherent views of instructed topics, the KI environments should support following processes (Gerard et al., 2016b; Chiu and Linn, 2011): (1) Elicit or generate ideas from a repertoire of ideas; (2) Add new ideas to help distinguish or link ideas; (3) Distinguish ideas; (4) Sort out ideas by promoting, demoting, merging, and reorganizing. From the instructional perspective, a successful instruction should have instructional features and resources to support these processes for a topic.

To develop lifelong learning competence we need to target the development of thinking skills of the learners (Fellows et al., 2002; Yokomoto and Ware, 1994; Beishuizen et al., 2004; Robotham, 2004; Fosmire et al., 2013). The competencies should ideally be pan domain (Murthy et al., 2016), i.e. they should be transferable among domains. This makes us think about the development of KI from the cognitive perspectives rather than just from the topics perspective. From the pan-domain cognitive or thinking skills (Murthy et al., 2016) perspective, a successful instruction should foster the learner's abilities to execute these processes whenever needed, irrespective of the topic, domain, or instructional environment.

We view KI development from this cognitive perspective where "eliciting ideas" from the repertoire of ideas is nothing but the learner's cognitive process of eliciting prior knowledge. 'adding new idea" refers to the learner's cognitive process of "refocusing" on the key missing or non-normative concepts from the new knowledge to link them with the candidate (elicited) prior knowledge (Chiu and Linn, 2011). The process of "distinguishing ideas" is about the learner's cognitive processes that monitor how the prior knowledge relate to, conflict with, or extend the refocused new ideas (Chiu and Linn, 2011). Using the cognitive process of "distinguishing ideas" learners might identify that they have conflicting ideas, gaps or discrepancies in their understanding and they might want to go back to refine and sort out their understanding. The fourth and the last KI process of the “sorting out ideas” cannot be fully viewed from the cognitive perspective, as it requires the learners to seek for the information not just inside their mind but also outside their mind to sort out and refine their knowledge (Chiu and Linn, 2011). We view the first three processes from this perspectives and refer to them as cognitive processes of KI. We aim at coming up with a pedagogy and a learning environment by which learners can improve their skills to execute these cognitive processes of KI (Figure 1.1).

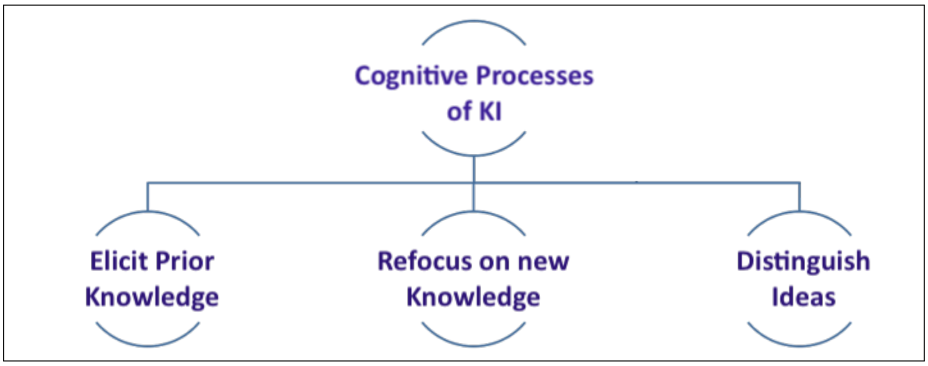

Figure 1.1: KI Cognitive Processes

1.2 Research Objective

The broad research objective of this thesis is: **Designing and evaluating a technology-enhanced learning environment (TELE) to improve learner’s cognitive processes associated with KI**.

The rationale behind targeting the development of a TEL environment is to make our solution freely available online, thus increasing its accessibility and allowing students and teachers anywhere to use and re-purpose it for their own teaching-learning practices. Moreover, since such cognitive skills are not explicitly targeted in the curriculum, our goal is to reach as many students as possible and allow them to improve their KI cognitive processes outside their regular classroom. Additionally, TEL environment facilitates easy logging of the artifacts generated during the learning. This logging can further be used for many useful purposes such as question-answering in a learning-teaching context and qualitative analysis of questions in the current research context.

We adopt **question-posing (QP)** as the key pedagogical idea for devising a solution to our research objective. By QP, we refer to the generation of a new problem or a question by a learner in a given situation (Mishra and Iyer, 2015a). Literature endorses that question-posing can help learners to look at a given knowledge from different perspectives (El Sayed, 2002), it can also help learners to look for the alternatives, bring out the conflicts and gaps, (Pintér, 2012; Dillon, 1982), and can be used in identification and correction of knowledge deficits (Graesser and Person, 1994). King and Rosenshine (1993) reported the direct benefit of QP-based instructional strategy to the improvement of the learner's performance of creating knowledge webs (Linn, 2013). In a nutshell, QP appeared to be an apt pedagogical idea that can help the learners in making their repertoire of knowledge in their mind accessible to them. This brings us to our broad research question.

Broad Research Question (RQ):

"**How to employ question-posing in a Technology Enhanced Learning Environment (TELE) to improve learners' cognitive processes associated with KI in a Data Structures course?**"

To answer the broad research question, we administer a series of design and research activities. The design activities involve coming up with different versions of the pedagogy, across different phases of the research. We call the pedagogy coming out of this thesis as "IKnowIT-pedagogy," where IKnowIT stands for "**I**nquiry-based **K**nowledge **I**ntegration **T**raining," and the corresponding learning environment developed is called as "IKnowIT-environment" or just "IKnowIT." The research activities involve identification and investigation of a list of specific research questions, through different research studies.

Specific RQs:

- **RQ1:** How is question-posing applicable for improving KI?
- **RQ2:** How can training learners on an exploratory question-posing - based learning environment (IKnowIT) enable them to foster the cognitive processes associated with KI?
- **RQ3:** What are the usefulness and usability of IKnowIT-environment as perceived by the learners?

It should be noted that in RQ2 we have used 'exploratory question-posing' instead of 'question-posing.' **Exploratory question-posing (EQP)** is a special type of QP which we identified while answering RQ1. EQP is a type of QP wherein learners pose questions with an aim to explore more knowledge around a given set of knowledge. While answering RQ1, wherein we studied the qualitative nature of learner-generated questions, we found that QP as EQP can be helpful in fostering cognitive processes of KI in the learners. We'll discuss about EQP in more detail in subsequent chapters.

The primary contribution of our thesis is a design of a QP-based pedagogy that improves learners' cognitive processes of KI. Therefore in addition to the research questions, in this thesis, we also have design questions (DQs). The Primary design question answered in this thesis is:
"DQ: What should be the design-features of question-posing based pedagogy to make it capable of fostering the cognitive processes of KI in learners?"
The answer to this DQ and specific DQs (discussed in later Chapters) produced synthesis of design requirements, design artifacts, and pedagogical designs.

1.3 Research Methodology

The primary research objective of this work is to design and evaluate a technology-enhanced learning environment (TELE) to improve learners cognitive processes associated with KI. Catering to the research objective does not just requires designing of a pedagogical solution and evaluation of the solution, but it also requires extraction of the design principles (also known as local learning or instructional theories (Plomp and Nieveen, 2010)) that explain how the pedagogical design ensure the improvement of cognitive processes of KI in learners. For these requirements, we chose design-based (DBR) (Barab and Squire, 2004; Reeves, 2006; Herrington et al., 2007; Kopcha et al., 2015; Collective, 2003) as our overall research design. The pedagogy design, evaluation, and extraction of local learning theories are achieved using two cycles of DBR. Each cycle of a typical DBR has four distinct phases as follows (also shown in Figure 1.2).

1. **Problem analysis:** In this phase, the researcher, through the synthesis of literature and/or empirical studies determines or refines the research problem that needs to be answered

2. **Solution Design:** In this phase, the researcher develops solutions informed by existing design principles and technological innovations.

3. **Evaluation:** In this phase, the researcher performs iterative cycles of testing and refinement of solutions in practice.

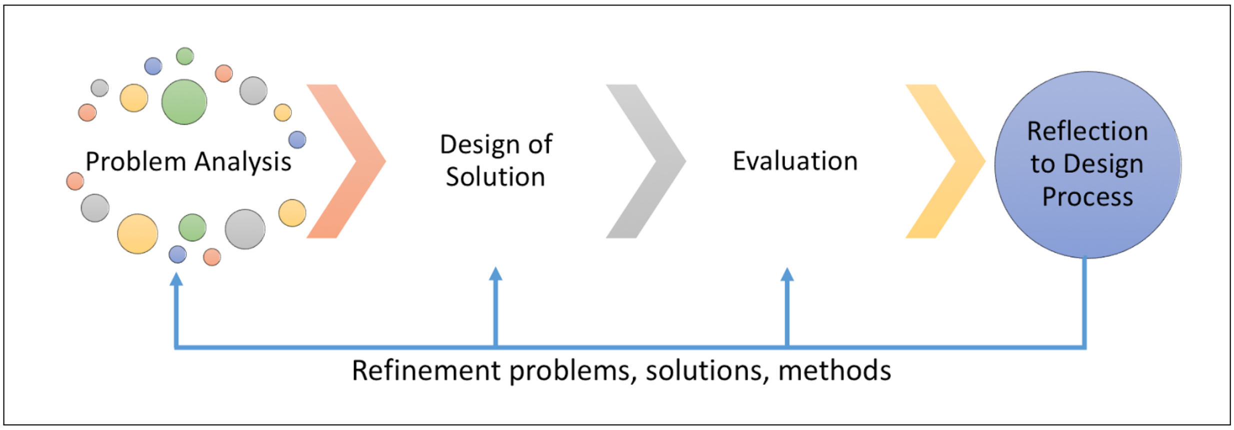

Figure 1.2: Overview of Design Based Research

4. **Reflection:** This phase requires the researcher to perform the reflections, based on the design and evaluation results in the previous phases, to produce "design principles" and enhance solution implementation

In this thesis, we conducted two cycles of DBR. In the first cycle, we came up with initial pedagogical design and performed proof of concept level investigations. We refer to this DBR cycle as **"Cycle 1"**. While in the second DBR cycle, we refined the initial pedagogical design, performed the qualitative and quantitative evaluations of the design, and extracted *"local learning theories"*, and we call this DBR cycle as **"Cycle 2"**. The term "Local learning theories", also known as "local instructional theories (Plomp and Nieveen, 2010; Liljekvist et al., 2017; Gravemeijer and Cobb, 2006), refer to the mechanisms that explain how the learner's interaction with the features of a learning environment leads to learning, (i.e., improvement of cognitive processes associated with KI in the learner, in the case of this thesis).

All the field studies are done in the domain of Data Structures with the second-year undergraduate computer science engineering students.

1.3.1 Research Studies done in this Thesis

In total, we administered seven field studies, four in DBR Cycle 1 and three in the second. In Cycle 1, we answered our first research question which is: *"How is QP applicable for improving KI?"*. The first two studies aimed at investigating if QP, as a cognitive phenomenon is applicable to KI. While the third and fourth studies aim at investigating if QP, as a pedagogical idea applicable for improving learners' KI performances.

Study 1: The first study is an exploratory research that aims at qualitatively analyzing the learner-generated questions and examines how do learners integrate knowledge during exploratory question-posing (EQP). The data analysis methodology used in this study was inductive thematic analysis (Fereday and Muir-Cochrane, 2006).

Study 2: Study 1 resulted in identifying the three frequently-employed EQP strategies (Chapter 5). As a follow up to Study 1, Study 2 is a validation study which aims at validating the findings of Study 1 by answering the question, "Are the three EQP strategies valid within Data Structures course?"

Study 3 & 4: The third and fourth studies are quasi-experimental study used to quantitatively and qualitatively evaluate the effect of a QP based pedagogy, respectively (Chapter 6). Study 3 answers a sub-RQ, "Can Guided Cooperative Questioning based pedagogical intervention (a QP based pedagogy from literature) improve learners' KI performance?" While Study 4 answers the qualitative sub-RQ, "What do the learners perceive about the effects of guided cooperative QP based pedagogical intervention?"

In Cycle 2, we answer our second and third research questions which are: *"How can training learners on an EQP-based learning environment enable them to foster the cognitive processes of KI?"* and *"What are the usefulness and usability of the designed QP-based learning environment as perceived by the learners?"* This research cycle involves our fifth, sixth and seventh research studies.

Study 5: The fifth study aims at iteratively evaluating and evolving the pedagogical design and answer the design question DQ3 and a sub-RQ (RQ2a) together (Chapter 7). The Design question DQ3 is, "What should be the design-features of next sub-version of our pedagogical design (version 2.x) to make it capable of fostering the cognitive processes of KI in learners?" and RQ2a is, "What are the effects of each of the pedagogical features of our learning environment on learners learning process?"

The research method used in Study 5 is based on the principles of educational design research (Plomp and Nieveen, 2010) and grounded theory (Charmaz, 2014), where the pedagogy refinements and "local learning theories" iteratively evolve from an interleaved iterations of data collection, analysis, and implementation (Chapter 7). We call this method **iDEEN**, which stands for "**I**terative **D**esign **E**valuatio**n** and Evolution." In addition to the iterative evaluation and evolution of the pedagogy, Study 5 also provides an overall account of the effect of the pedagogy on the learners' KI performance, as indicated by the improvement in the question-posing quality of the learners (Chapter 10).

Study 6 & 7: The last two studies provide summative evaluations of the final version of our pedagogical design (Chapter 10) with an aim to triangulate the findings from Study 5 (iDEEN study). Wherein, Study 6 has two parts: one quantitative and another qualitative. The quantitative part presents an examination of the effects of the pedagogy on the learners' KI performances, as indicated by their performance in a KI assessment test. While the qualitative part triangulates the findings of the quantitative part by using a qualitative analysis of the instructor's interview done twenty days after the execution of the pedagogical intervention to examine the prolonged effects of the pedagogy on the learners.

In the cases of Study 3, Study 5 and Study 6, we operationalized the KI assessment rubric given by Liu et al. (2008) to quantify the KI performance of the learners. We would see the operationalizations in more detail in the respective chapters.

1.4 Solution

The pedagogy ("IKnowIT-pedagogy") and the corresponding learning environment ("IKnowIT-environment") are the solution to our research problem and primary contributions of this thesis.

1.4.1 IKnowIT-pedagogy

At the end of the two DBR cycles, we obtained a six-phased pedagogy, shown in Figure 1.3.

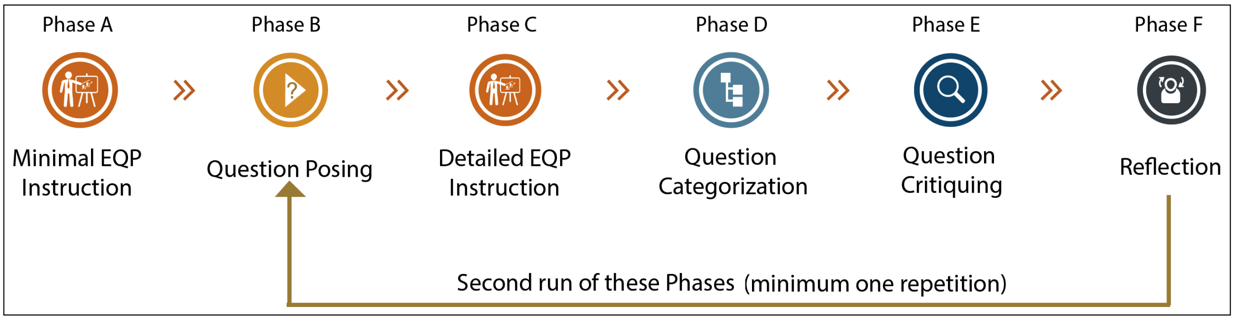

Figure 1.3: IKnowIT-pedagogy

The key pedagogical idea is to make a learner to perform the cognitive activity of question-posing, followed by series of metacognitive activities. The metacognitive activities make the learner reflect on how they perform the QP, what role does their prior knowledge play, what role do the given new knowledge play, how are different knowledge pieces (from prior knowledge and new knowledge) link with each other to give rise to a question, how is question-posing activity beneficial for deeper conceptual understanding, etc. In addition to the six phases, the pedagogy also necessitates at least one more iteration of the IKnowIT phases.

In **Phase A** ('Minimal EQP Instruction'), the learner is made to read minimal information about QP, viz., why should one ask questions, benefits of exploratory questions, the role of clarification questions, etc. In **Phase B** ('QP') the learner is made to watch a video lecture and submit questions, as and when they come in the learner's mind. In **Phase C** ('Detailed EQP Instruction'), the learner is made to read more detailed information about EQP, specifically about different types of EQP strategies. In **Phase D** ('Question Categorization'), a learner is made to analyze the questions that s/he posed in the 'QP' phase to categorize them into applicable EQP strategies. In **Phase E** ('Question Critiquing'), a learner is made to analyze a list of questions and their categorizations that any other learner had generated and categorized before. The last phase, **Phase F** ('Reflection') makes the learner answer a series of reflection questions. These reflection questions are fixed, and shown to every learner who undergoes the complete IKnowIT-pedagogy. The reflection questions are mapped to the goals of making learners to: (i) recognize the role of EQP strategies, (ii) recognize the importance of EQP and EQP-strategies for deeper understanding, (iii) explicitly reflect on their Question-Posing strategy, and (iv) explicitly recognize the plans and regulations that s/he can use for future learning. The details of each phase are provided in Chapter 4.

1.4.2 IKnowIT-Environment

IKnowIT-Environment is a web-based self-learning environment which is an operationalization of the IKnowIT–Pedagogy. Figure 1.4 shows the compilation of the snippets of the main features of the four user interfaces corresponding to the QP, Categorization, Critiquing, and Reflection phases of the pedagogy. In the Figure, the first snippet (1) is from the QP phase, where learners watch a video and pose questions. The second (2) snippet is from the Categorization phase, where the learner analyzes questions generated by her/him. The third snippet (3) is from the Critiquing phase where learner evaluates the questions generated by another the learner and comments. The fourth (4) snippet is corresponding to the Reflection phase where learner needs to answer a series of reflection-questions. Detailed screenshots of the environment is presented in Chapter 8.

In addition to operationalizing the IKnowIT-pedagogy, the learning environment also

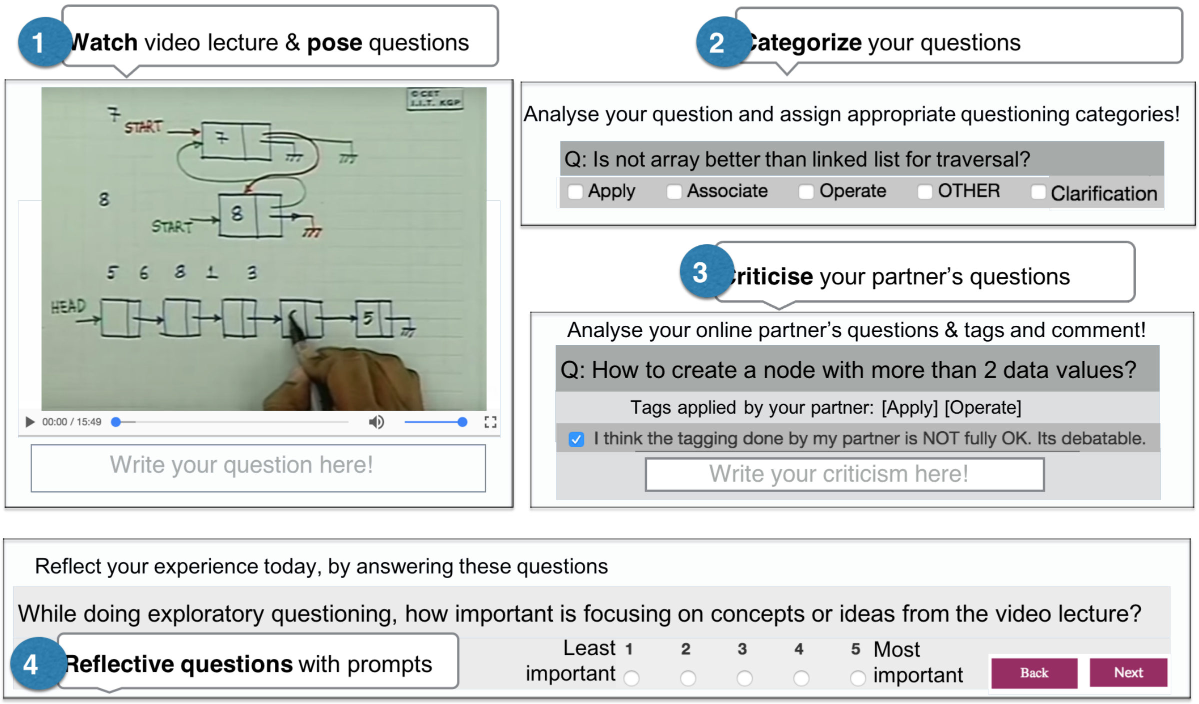

Figure 1.4: Screen Snippets from the various Phases of the IKnowIT-environment

facilitates user maintenance and data logging. This is important because many of the learner's inputs (e.g., learner's submitted questions) are needed to be stored from one phase and may be later retrieved if needed in another phase. Moreover, the logged data helps in further research and evaluation activities.

The environment has been developed using the client-side technologies, including HTML5, Javascript, and CSS, and the server-side technologies PHP and MySQL. The environment can be accessed through an internet browser. All testing and evaluation, in this research, have been done specifically on desktops and laptops, and therefore small handheld devices may not provide the same effect and experience.

1.5 Scope of Thesis

The scope is limited to engineering population as all the samples for the study are taken from the Data Structures course in engineering.

In DBR Cycle 1 of this research (Chapter 5), we identified a list of three EQP strategies. These strategies were identified while researching in the context of Data Structures course. We believe that these strategies may apply to other domains if those domains have similar characteristics as the Data Structures domain. One may attempt to characterize the Data

Structures domain based on the three EQP strategies, which suggest that the concepts within the Data Structures domain are frequently linked by relations of type: one concept *is an application of* another concept, one concept *can be used to implement* another concept, one concept *is contrasting or similar to* another concept, etc. However, formal research is needed to characterize the Data Structures domain in order to recommend any other domain as similar to Data structures For the non-similar domains, the users need to identify the EQP strategies using the method followed in Study 1 of this research.

We have tested if the skill of executing the cognitive processes of KI, learned using one topic, works (transfers) in the case of another topic within Data Structures. This was a medium transfer test, as the transfer (Perkins et al., 1992) is tested between two different topics, and not a near transfer, where the transfer is testedÂăwithin a topic. On another hand, it was not a far transfer test as it is done within a domain.

The pedagogy and learning environment developed in this research are web-based self-learning environment. The implementation is limited to the browser-based learning environment. The pedagogy, however, can be implemented on various other platforms.

1.6 Contribution of Thesis

Our thesis has contributed with following:

1. **Knowledge contribution to theory**

   (a) Empirically shown that EQP can foster the cognitive processes of KI.

   (b) Identified the three EQP strategies: These are the three categories of ways by which a learner relates her/his prior knowledge with given knowledge to come up with an exploratory question in Data Structures domain.

   (c) Identified local learning theories about how does a learner pose questions in the IKnowIT-environment.

   (d) Identified local learning theories about the interplay between the learners' questions and their KI cognitive process in the IKnowIT-environment.

   (e) Identified local learning theories about how the learners foster, recognize and apply cognitive processes of KI in the IKnowIT-environment.

   (f) Identified local learning theories about the role of QP in the IKnowIT-environment.

(g) Identified local learning theories about the role of EQP-strategies in the IKnowIT-environment.

2. **Pedagogy contribution to inform development of other learning environments**

   (a) **IKnowIT-pedagogy:** We have designed a QP-based pedagogy that fosters learners' cognitive processes of KI.

3. **Learning environment contribution**

   (a) **IKnowIT-environment:** We developed a web-based self-learning environment that implements the IKnowIT-pedagogy.

4. **Contribution to education design research community**

   (a) **iDEEN: Iterative Design Evaluation and Evolution method:** We introduce a design research method that is based on the principles of grounded theory inquiry and education design research.

1.7 Structure of Thesis

This thesis is organized in twelve chapters as follows.

Chapter 2 discusses the literature surveyed. It presents the background and related work carried out to get a deeper insight towards the need and solution approach for answering the research objective. It presents the contemporary theories about KI and research related to the pedagogy or learning environment for the goals to affect learner's KI. The chapter also presents research that has used QP as the pedagogical idea for achieving goals similar or nearly-similar to the goals related to promoting KI in the learners.

Chapter 3 presents our overall research design. It provides the overview of the cycles of the design based research employed in this work. It also presents the research questions, hypothesis, and list of the studies corresponding to those research questions. Chapter 4 presents an overview of our solution, i.e. IKnowIT-pedagogy, along with the description of its phases. It also presents our solution approach. Chapter 5 and 6 presents the research work carried out in DBR Cycle 1. Chapter 5 presents the problem analysis and Solution Design phases of DBR Cycle 1. This includes studies 1 and 2. Chapter 6 presents the evaluation and reflection phases of DBR Cycle 1. This includes Study 3 and Study 4.

Chapter 7 and 8, presents the DBR Cycle 2. Chapter 7 presents the problem analysis and the design of the solution. This chapter presents the iDEEN (iterative design Evaluation and Evolution) implementation (Study 5). Chapter 8 presents the evaluation and the reflection phases of the DBR Cycle 2. It includes findings from Study 5, 6 and 7. Chapter 9 presents the local learning theories obtained from the two cycles of this design based research. Chapter 10 presents the description of the final version of IKnowIT-environment. Chapter 11 discusses the answers to the research questions, and claims and generalizations from this work, followed by the limitations. Chapter 12 lists the contributions from this thesis and future research directions coming out of this work.

Chapter 2

Review of Literature

As the area of research is knowledge integration (KI) we started the exploration with the understanding of different conceptions of KI in education research. We carried out systematic domain literature survey which included journal papers, assessment handbooks, relevant websites and conference papers. As shown in Figure 2.1, the literature survey concentrated on the KI construct in education and delved into fundamental questions about the need for fostering KI in the learners. The exploration further concentrated on the related works that have either attempted to foster KI in learners or which can suggest how to foster KI? Since the goal of the research is to improve learner's ability to do better KI as a transferable thinking skill, we also explored the fundamental question that what does it mean to do better KI at the cognitive level. Further exploration was done in the domain of learner-question-posing wherein we surveyed the Question-Posing (QP) literature to examine if the QP is a suitable pedagogical idea that can be used to design a pedagogy for improving KI processes in learners.

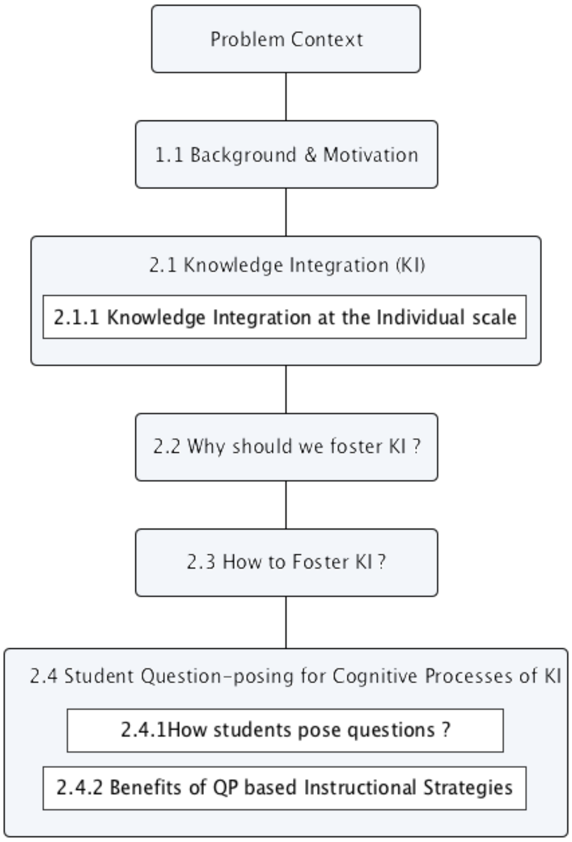

Figure 2.1: Overview of the Literature Review

2.1 Knowledge Integration (KI)

KI construct has been defined at many scales (Kastens and Manduca, 2012). At the individual learner scale, Linn (2000) identifies "linking, connecting, distinguishing, organizing, and structuring" as processes of KI, and "patterns, templates, views, ideas, theories and visualizations" as that which is being integrated. Gobert and Buckley (2000) argued that integrating pieces of information about the structure, function, behavior, and causal mechanisms of a phenomenon lead to the formation of individuals' mental models.

At the scale of a specific learning activity, Kali et al. (2003) described a KI activity as one that learners perform after completing a sequence of knowledge acquisition activities. This requires them to distinguish the elements of their existing knowledge and reintegrate their knowledge into a systems context. At the scale of a course or curriculum (e.g. (Krajcik et al., 2008), KI refers to an approach in which the instructor and/or instructional materials establish and make use of purposeful connections among the portions of the curriculum. At the scale of the entire scientific enterprise, KI encompasses collaborative efforts, such as community knowledge building (Hong and Scardamalia, 2014; Scardamalia and Bereiter, 2006) to bring insights from multiple disciplines to bear on a complex problem. **This thesis deals with KI at the individual learner scale.**

2.1.1 KI at the Individual Scale

Slotta and Linn (2000) presented KI as a theoretical framework of learning and defined it as "a dynamic process where learners build connections between their existing knowledge and the curriculum content." (Slotta and Linn, 2000). Liu et al. (2008) describes KI as the "process of adding, distinguishing, evaluating, and sorting out accounts of phenomena, situations, and abstractions in science." According to Kastens and Manduca (2012) "KI involves pulling together ideas and information into a coherent framework such that new ideas can be linked to already established ideas."

In the context of narrative comprehension, Burris and Brown (2014) describes that the process of KI requires access to stores of generic world knowledge and personal experiences to build narrative mental representations. The researchers describe that the prior knowledge compensates for gaps in narrative coherence or when information is ambiguous, and allows for the generation of inferences connecting prior knowledge to narrative information. KI also allows comprehenders to update mental representations based on personal encounters and understanding. Similarly, Mohd. Rodzi et al. (2015) explicates the implicit nature of KI by identifying its essential processes such as identification, creation, assimilation, and evaluation to identify the core elements necessary for any initiative in KI.

KI refers to the process by which a learner uses theory or evidence to create a linked and coherent argument (Baxter and Glaser, 1998; Nichols and Sugrue, 1999; Shepard, 2000). KI is supported by the constructivist view of learning and is based on extensive research on science instruction (Linn and Eylon, 2006; Linn et al., 2004a). The relation between KI and learning can also be understood from the connectionist theory of cognition. According to the connectionist model of thought, more number of connections among the knowledge components (Fodor and Pylyshyn, 1988) would lead to better learning of the concept. According to Lee et al. (2011), the process of making links among ideas and forming arguments results in a more organized understanding of the concepts.

2.2 Why should we foster KI?

Educators and researchers agree that for deep conceptual understanding, learners need connected ideas not isolated or inert knowledge (Lee et al., 2011). When there is not enough time to get into a topic deeply, then the learners become accustomed to looking at the things superficially (Kastens and Manduca, 2012).

Integrated knowledge makes it possible that groups of ideas can be pulled out, connected and mobilized for solving problems, answering questions, or understanding observations (Kastens and Manduca, 2012). KI is important because deep learning in science requires learners to integrate their ideas from multiple perspectives (Chiu and Linn, 2011; Linn and Eylon, 2006).

KI perspective is not limited to lower cognitive levels (Bloom et al., 1964) of learning of a concept but rather leads to learning at higher cognitive levels. KI enables an additional level of representation of concepts wherein concepts exist in association with other concepts and not in isolation. Enabling this complex representation gives the learner opportunity to access, manipulate and inquire about a complex representation (Kirsh, 2009) thus leads to learning at higher cognitive levels.

Bauer and Jackson (2015) discusses the importance of KI from cognitive semantics perspective. Their cognitive science study using event-related potentials (ERP) show that "separate but related facts integrate to form new information (integration facts)." Memory (ERP) transition from integration facts to well-known facts (prior knowledge) is very rapid. Therefore supporting KI may lead to faster registration of knowledge from working memory to the long-term memory (Ljungberg et al., 2010).

Several lines of research have demonstrated the need for research into supporting or fostering KI. Studies on conceptual change and development found that knowledge fragmentation occurs frequently and in various age groups (diSessa, 2008; Izsak, 2005; Wagner, 2006; Gillespie et al., 2004). For a learner who is new to a topic, the fragmentation occurs more. Slotta and Linn (2000) demonstrated that learners approach the study of heat and temperature with a wide array of loosely connected ideas and language.

Studies on expertise acquisition show that knowledge organization in memory is an important characteristic that distinguishes novices from experts in a domain (Chase and Simon, 1973; Gobet, 1998). Experts understand how the pieces of knowledge are related to each other on a conceptual level, far better than the novices, because experts have more abstract background knowledge. Novices, because of this fragmented organization of knowledge, focus on superficial differences between their observations (Chi et al., 1981).

According to the information processing theory of cognition, the limited capacity of learners' working memory forces a learner to take much time and effort (Ericsson et al., 1993) to build well-integrated knowledge structures in long-term memory. For ease of building of the knowledge structures in working memory, learners need many cycles of loading prior knowledge and new information into their working memory, compare and integrate them, and finally, store the result in long-term memory (Ljungberg et al., 2010). This also shows that an instructional or cognitive scaffold is needed to make the learners perform these processes.

2.3 How to foster KI?

KI can be supported by all the approaches that foster knowledge transfer and generalization because they help learners to see abstract similarities between superficially different contexts (Schneider, 2012). There have been various studies aimed at supporting learners' KI on a given topic. A synthesis of solutions to foster KI is shown in Figure 2.2. Explanation generation has been reported as an effective pedagogy for supporting KI. Several researchers Chang and Linn (2013); Chiu and Linn (2008); Ryoo and Linn (2012) have reported that generating explanations before and after interacting with dynamic visualizations helped learners distinguish among their ideas and promoted KI.

Hoadley and Linn (2000) presented a discussion tool (SpeakEasy) in a KI environment and demonstrated how online, asynchronous peer discussions can be designed to enhance cohesive understanding of science, i.e., achieve more KI. Hoadley and Linn (2000) demonstrated that online debates could model the process of distinguishing ideas by making learners know each others' alternative views thus ultimately leads to better KI.

Schwendimann (2016) described how creating and critiquing concept maps can lead to better KI. The results showed that critiquing is a more time efficient alternative to generating concept maps to improve KI performance.

Zertuche et al. (2012) compares the impact of teacher-designed openers ("brief activities that initiate a class") with the openers designed using recent research emphasizing KI. Two prime results from this study were that the learners make the greatest gains when they revisit key evidence in the technology-enhanced curriculum unit before revision, and engaging learners in

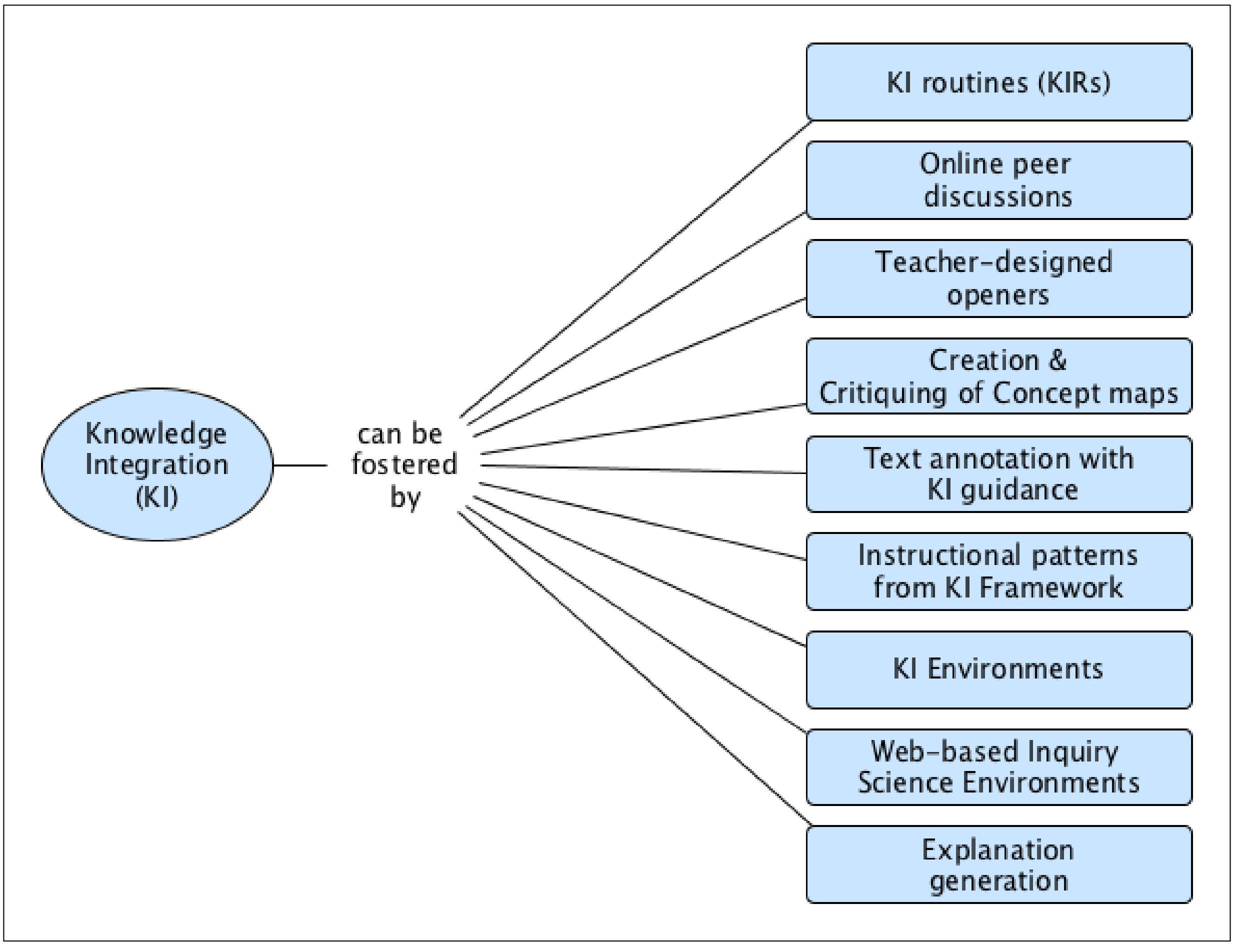

Figure 2.2: Synthesis of Approaches to Foster KI

processes that promote KI during the opener motivate learners to revise their ideas.

Berger et al. (2008) presented a program focused on enhancing KI in high-school physics by repeated implementation of KI routines (KIRs). KIRs are short generic activities that guide the learners to explicitly link between related aspects of physics learning (e.g., between the laboratory work and the related theoretical ideas). The key pedagogical idea behind KIRs is that the learners construct new knowledge, based on their prior knowledge, through active and social learning, and to account for their learning.

Gerard et al. (2016a) explored ways to design guidance for short essays that promote meaningful revision rather than superficial changes. Researchers found that learners who annotated an essay made significantly greater pre to post-test gains and were also better able to use automated guidance on a post-test item than learners who only received KI guidance.

One of seminal work on promoting KI is done under the umbrella of KI framework (Linn and Eylon, 2011). It is a constructivist view that has evolved through empirical studies over more than two decades and was used to align curriculum, assessment, pedagogy, and professional development (Linn, 1995; Linn et al., 2004a; Linn and Eylon, 2006; Quintana et al., 2004). KI framework presents KI principles and KI instructional patterns. KI principles refer to the specific guidelines that promote coherent understanding, whereas, the KI instructional patterns refer to the "sequences of processes that reinforce each other to help learners create coherent views of instructed topics." A large repertoire of KI environments that employ KI framework are KI Environments (KIE) (Bell et al., 1995) and its' second version Web-based Science Enquiry (WISE). These systems focus on the enhancement of learner KI for a broad range of science concepts and inquiry processes (Chiu and Linn, 2011). In WISE, learners engage in a variety of activities (virtual experiments, graphing, modeling) centered on an overarching, contextually relevant inquiry question (Gerard and Linn, 2013). For example, McElhaney et al. (2012) presents an inquiry learning scaffold "idea manager," built using KI framework that promotes coherent understanding of the ideas. Idea manager helps the learner by facilitating them to record their ideas and construct coherent explanations. In another study (Williams and Linn, 2002), researchers have used the KI framework on the WISE platform to create scaffolds for classroom experimentation that enabled fifth-grade learners to increase their understanding of plant growth and development. Lee et al. (2010) used the KI framework to guide the design of inquiry instruction featured in ten inquiry units to successfully facilitate a better understanding of several science topics. All these environments aim at improving learning from KI framework perspective.

According to Linn and Eylon (2006), instructional support for KI is highly important and recommends a four-step approach: elicit prior ideas, acquire additional ideas, develop criteria for the evaluation of their ideas, and sorting out of irrelevant or contradictory ideas from the learners' knowledge base.

2.4 Learner Question-Posing (QP) for Cognitive Processes of KI

On the one hand, it is argued that the KI approach promotes questioning by emphasizing the ability to make links among ideas in the context of constructing arguments based on normative ideas (Lee et al., 2011). On another hand, King (1994b) suggests that questioning can promote connections between the concepts which would lead to improved KI. QP involves learners in the transformation of knowledge and understanding, engages them in constructing knowledge through various processes and enables them to generate new knowledge through self-exploration (Ghasempour and Bakar, 2013). The QP activities foster in learners a sense of ownership of their learning by engaging them in metacognitive strategies (Ghasempour and Bakar, 2013). The cognitive mechanisms associated with QP makes it a plausible solution to the problem of fostering KI.

2.4.1 How Learners Pose Questions?

Graesser and Person (1994) identified four different psychological mechanisms that form the base for asking of questions. The mechanisms (Graesser and Person, 1994) are: (i) Correction of knowledge deficits, (ii) Establishing Common grounds, (iii) Social coordination of actions, and (iv) Conversational Control. In the case of first mechanism of correction of knowledge deficit, one would pose questions to seek knowledge and get answers to what s/he doesn't know. In the second case, two people in conversation use QP as a means to update the mutual knowledge to achieve successful communication. In the case of the third mechanism, questions such as "Can you do X for me?" are used, with a purpose to collaborate in activities involving social coordination and get things done. The fourth questioning mechanism describes the questions that can help in controlling the conversational flow and include greetings, rhetorics, complains, etc. Of these four psychological mechanisms, the first one, i.e., "correction of knowledge deficits," is directly useful for learning and prevalent in academic settings, where learners pose questions 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 QP 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 (El Sayed, 2002). (ii) "What if not" - In this strategy, new questions are posed by negating any data, objects, operations or any other component of another question (Dillon, 1982). (iii) "What if Strategy" - In this strategy, components of a given question is changed to generate new questions (Pintér, 2012). (iv) "Imitation strategy" - In this strategy, the learner generates questions by reproducing the QP strategy demonstrated by examples of questions and their generation processes (Kojima et al., 2009). (v) Cruz Ramirez (2006) proposed a Question-Posing strategy in the mathematics domain, consisting of six non-sequentially dependent steps - searching, selection, transformation, classification, association, and posing.

2.4.2 Benefits of QP-based Instructional Strategies

Figure 2.3 illustrates the QP-based instructional strategies and their benefits, and are further detailed as follows.

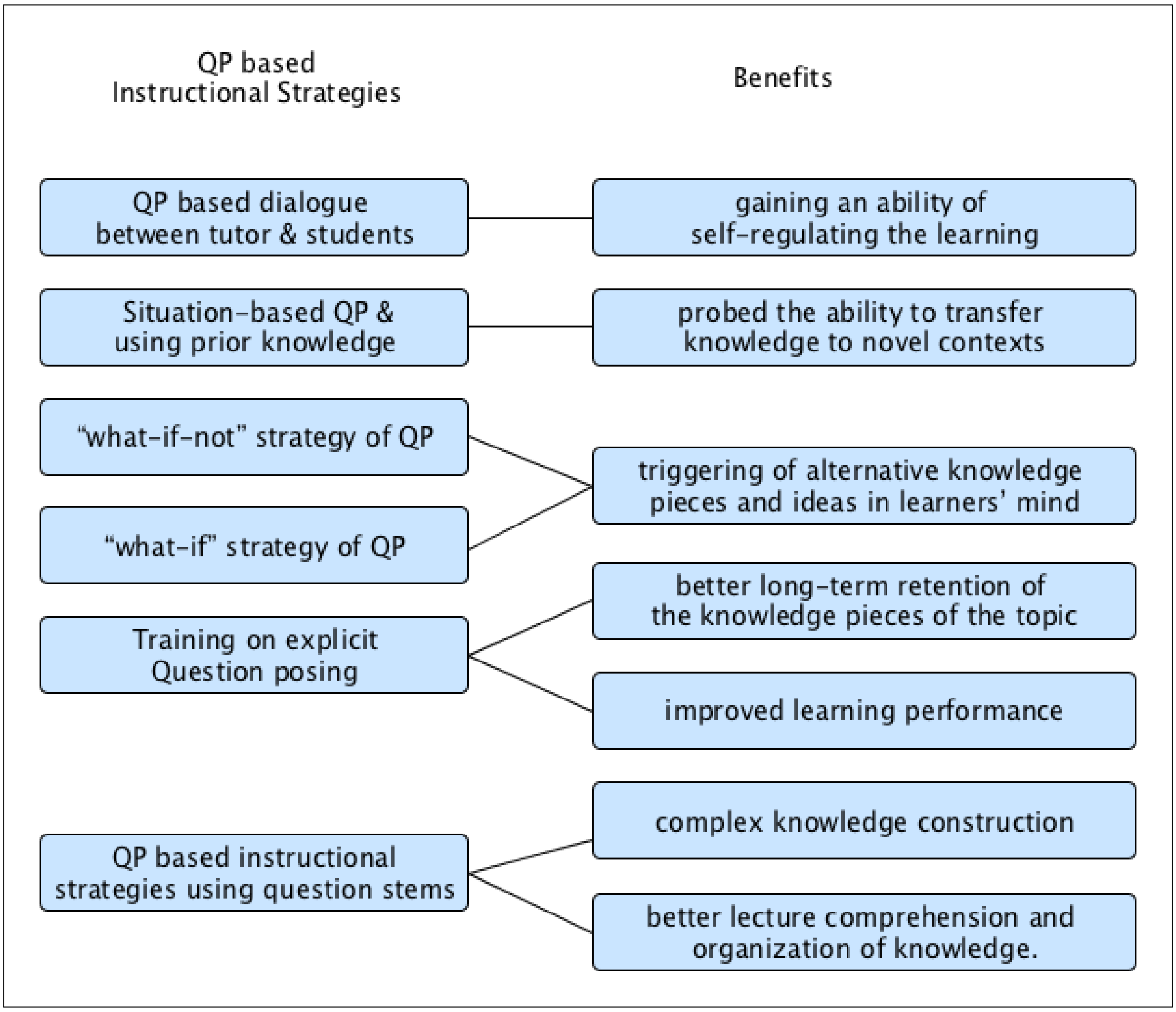

Figure 2.3: Synthesis of Approaches of Benefits of QP

A research by Graesser and Person (1994) has shown that QP-based dialog between tutor and learners in a tutoring session, helped learners in gaining an ability to self-regulate their learning by asking questions when they spot knowledge deficits. In a study (Mestre, 2002) with the undergraduate learners, who were asked to generate questions based on the given situation and their prior knowledge, researchers have shown that QP has successfully probed their ability to transfer their knowledge to novel contexts.

Lavy and Bershadsky (2003) has shown how learner-QP can be used to trigger alternative knowledge pieces and ideas in the learners' mind. The pedagogical idea was to make learners practice the "what-if-not" strategy of QP. In another study with pre-service teachers, the participants were given knowledge on how to generate "what-if-not" questions. It was found that the participants perceived that engaging in this kind of inquiry-based activity enhanced both their mathematical and meta-mathematical knowledge (Lavy and Shriki, 2010). Lavy and Bershadsky (2003) has shown how learner QP of "what-if" type can also be used to trigger alternative knowledge pieces and ideas in the learner's mind.

Learners who were trained on QP demonstrated better retention of the concepts even after a 3-month gap between post-test and intervention (Cankoy and Darbaz, 2010). This demonstrates the effects of QP for better long-term retention of the knowledge pieces of the topic. Cildir and Sezen (2011) have demonstrated that the learning performance of the learners is related to their QP skill; high scorers were found to have high QP skills and low scorers had low QP skill.

King (1994b) has highlighted the effects of student-QP based instructional strategy. The results have shown that the learners trained to ask questions engaged in more complex knowledge construction than those who were not. The study also demonstrated that if the questions are designed to access prior knowledge/experience, then they are more effective in inducing complex knowledge construction and enhancing learning.

In another study by King (1994a), it was found that the learners who generated their own discussion questions specific to the lecture using "thought-provoking generic question stems" outperformed the learners who used discussion questions generated in the same course during the previous semester by other students using identical question stems. This has demonstrated the nuances of the implementations of the QP activities (role of learner control in this case) which may lead to different levels of benefits.

A comparison of three groups of learners was done by King and Rosenshine (1993). The first group generate discussion questions using detailed question stems, the second group generate discussion questions using single word question stems, and the third group do not use question stems. The results show that the first group outperformed the other two groups on the evaluations related to the (a) explanations provided during the discussion, (b) post-test comprehension, and (c) knowledge mapping. Findings indicate that in cooperative discussion contexts structured guidance in asking thought-provoking questions elicits explanations and therefore mediate learning. In another study, King (1993) has again demonstrated the benefit of student-QP using generic questioning prompts. Other studies (King, 1992, 1989) have also demonstrated the positive effects of QP based studies on learners organization of knowledge.

2.5 Our Focus

From the literature survey done, we observed that most of the research in the KI domain focused on designing instructional supports to improve learners' KI performance within a specific topic. While researchers have discussed the improvement in KI ability within a topic, the primary emphasis remains on improving learning performance of a specific topic. However, we consider the improvement of KI as a transferable thinking skills (Murthy et al., 2016) and our research aims at improving learners' thinking skills such that they are enabled to execute the cognitive processes of KI on their own, irrespective of the topic, domain, or whether the learning environment has any instructional support for it or not.

We base our understanding of the cognitive processes of KI on the KI framework Linn (2013); Linn et al. (2004b); Bell et al. (1995). The sequence of processes, referred by the KI patterns (Linn and Eylon, 2011), if seen from the learners thinking skills perspective, can be viewed as (1) Elicit prior knowledge; (2) Refocus on the new knowledge to help distinguish or link ideas; (3) Distinguish ideas; (4) Sort out ideas by promoting, demoting, merging and reorganizing. With these constituent KI processes, we looked into the literature to find other pedagogical ideas that require or that can foster these processes in the learners' mind. We found that student-QP is an apt pedagogical idea that can foster subsets of these KI processes at a cognitive level. We can see from the above literature that QP can be used to make learners explore the repertoire their prior ideas, make learners look for alternatives, and identify conflicts and gaps. These cognitive mechanisms associated with QP seems to be in alignment with the cognitive processes of KI. However, we found that there is a dearth of research that focuses on exploiting student-QP as a way to provide the cognitive scaffold to KI. Our notion of QP involves the generation of new questions around a given semi-structured (Stoyanova and Ellerton, 1996) QP situation, such as a video lecture, a classroom instruction, etc. Semistructured QP situation is such QP situation which does not restrict the posed questions around a specific problem-solving task but demands the questions to be within the scope of a lecture, course or a domain. We want learners to pose such questions which can help them explore or unfold new knowledge around conceptually preceding and/or related given knowledge in a given domain. Therefore we call such QP as **“exploratory question-posing” (EQP)**.

In the initial part of this research, we focus on empirically investigating the suitability of QP for the pedagogical goal of fostering cognitive processes of KI. *Therefore the first research question that this research work answer is, “how is QP applicable for improving KI (RQ1)?”* Subsequently, after obtaining empirical evidence that QP, as a cognitive phenomenon and as a pedagogical idea is applicable to the goal of fostering learners’ cognitive processes of KI, we iteratively evaluate and evolve the pedagogical designs to specifically suit our research goal.

The next chapter discusses the overall research methodology followed in this thesis to address the research objective of fostering the cognitive processes of KI.

Chapter 3

Research Methodology

In this chapter, we present our research methodology; i.e., design based research (DBR). We aligned our choice of the overall research design and research methodology with our broad level research objective. First, we present the characteristics of our research objective to provide the reasons of why the DBR is a suitable methodology for this research. Then we present the details of DBR, followed by the details of the DBR cycles in this research, which included the objectives of each DBR cycle, research studies conducted in each DBR cycle, methods for each research studies, and finally the ethical considerations.

3.1 Characteristics of Research Objective

The research design and overall research methodology were adopted, based on the characteristics of our broad research objective: *"To design and evaluate a technology enhanced learning environment (TELE) to improve learners knowledge integration (KI) ability by enabling them to better perform the cognitive processes associated with KI."* Our research objective is characterized by following requirements:

- **What are we looking for?**
  - Our objective is to come up with a pedagogical design to improve cognitive processes of KI in learners.
  - Our objective is to create and study learning interventions (such as learning processes and learning environments) with the purpose of developing or validating theories about learning processes and how these can be designed.
  - Our objective is to come up with a learning intervention to improve thinking processes associated with KI in the context of second year engineering undergraduates using a web-based technology enhanced self-learning environment.
- **How are we looking to achieve it?**
  - Our research requires working closely with learners as our research objective aims to improve their thinking processes associated with KI.
  - As the learning intervention would depend upon the learning context and settings, our research requires connecting the desired outcomes and the intervention design process with the context and settings.

Considering the above characteristics of our research objective, "design based research" (Collins, 1992; Collective; Wang and Hannafin, 2005) seems to be a suitable research design. Most of the characteristics of DBR matches with the nature of our research objectives. The following section provides the description of DBR and maps its characteristics to the characteristics of our research objectives.

3.2 Design Based Research (DBR)

DBR belongs to a family of educational research known as Educational Design Research (EDR) (Plomp and Nieveen, 2010). EDR is meant to design and develop an intervention (such as programs, teaching-learning strategies, and materials, products and systems) as a solution to a complex educational problem. In addition, EDR serves to advance our knowledge about the characteristics of these interventions and the processes to design and develop them. In other words, EDR helps to design and develop educational interventions (for example, learning processes, learning environments and the like) with the purpose of developing or validating theories. EDR constitutes a family of design-oriented approaches to educational research, including but not limited to DBR (Barab and Squire, 2004), design based implementation research (DBIR) (Penuel et al., 2011) and design and development research (DDR) (Richey and Klein, 2005, 2014).

DBIR caters to the design research intended to address problems of implementation, i.e., designing effective, scalable, and sustainable policies and programs in education (Fishman et al., 2013; Penuel et al., 2011). DBIR problems involve multiple stakeholders at the educational systems level. This is not the case with our research problem, which deals with the cognitive development at the individuals' level, and therefore DBIR does not suit our research requirement.

DDR caters to the design research intended to "the systematic study of designing, developing and evaluating instructional programs, processes and products" (Richey and Klein, 2005). DDR partially suits our requirement, as one of our objectives is to design and develop a learning environment. However, in addition to the learning environment, our research goal also includes designing a pedagogy and contributing to the underlying design principles (or the local learning theories) related to the pedagogy.

DBR has been understood in number of ways. According to Reeves (2006), the DBR is the education design research aimed at "refinement of problems, solutions, methods, and design principles." Wademan (2005) proposed a generic design research model which illustrates that the "successive approximation of practical products" (referred to as 'interventions') works hand-in-hand with the 'successive approximation of theory' (which he also calls 'design principles'). Wang and Hannafin (2005) defines DBR as, "*a systematic and flexible methodology aimed to improve educational practice through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and* *leading to contextually-sensitive design principles and theories.*"

These descriptions suggest that the DBR is a suitable fit for our research requirement. We see that DBR does not just aim at designing, developing and evaluating the pedagogical solutions, but it also aims at identifying underlying design principles or local learning theories (Plomp and Nieveen, 2010; Liljekvist et al., 2017; Gravemeijer and Cobb, 2006). To illustrate it further, we present the prime characteristics of DBR (Wang and Hannafin, 2005) in more details below.

1. DBR is pragmatic, as it refines both theory and practice.
2. It is theory driven and grounded in relevant research, theory, and practice.
3. Design processes are conducted and studied in real-world settings.
4. Designers are involved in the design processes and work together with learners.
5. Design processes are an iterative cycle of analysis, design, implementation, and redesign.
6. Initial plan is usually insufficiently detailed so that designers can make deliberate changes when necessary.
7. Mixed research methods are used to maximize the credibility of research. Methods vary during different phases as new needs and issues emerge, and the focus of the research evolves.
8. The research process, research findings, and changes from the initial plan are documented.
9. Research results are connected with the design process and the setting.
10. The content and depth of generated design principles may vary. Guidance for applying generated principles is needed.

The requirements of our research objectives, i.e., the aim to create a contextually dependent pedagogical design; the purpose to develop or validate theories about learning processes and learning environment; working closely with learners; connecting the outcomes with development processes and the authentic real-world settings, are catered by DBR. Moreover, DBR suggests that the research has to be theory-driven, research may use mixed research methods, it may involve a number of iterative cycles, and initial plan may be partially detailed.

We follow the DBR structure outlined by Reeves (2006), which suggests that a DBR involves several cycles of research activities. Every cycle of the research has four phases of research activities: (i) ‘Problem analysis,’ (ii) ‘Solution Design,’ (iii) ‘Evaluation,’ (iv) ‘Reflection.’ These phases are outlined in Figure 3.1.

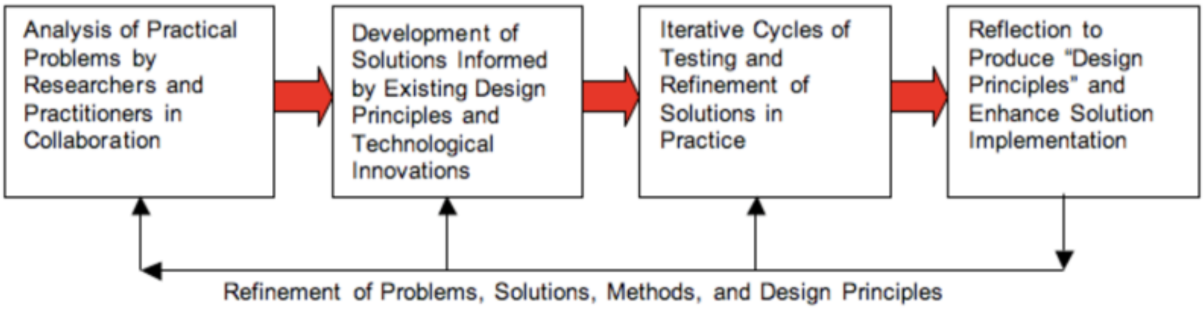

Figure 3.1: DBR Phases (Reeves, 2006). Figure reproduced from Plomp and Nieveen, 2010)

The first phase of a DBR cycle is **“problem analysis’**, wherein a researcher, through the synthesis of literature and/or empirical studies, determines or refine what research problem needs to be answered. In the second phase, **‘Solution Design’**, the researcher develops solutions informed by existing design principles and technological innovations. The third phase of a DBR cycle is the **‘Evaluation’** phase, wherein the researcher performs iterative cycles of testing and refinement of solutions. The last phase of a DBR cycle is about **‘Reflection’**, which requires the researcher to perform the reflections, based on the design and evaluation results in the previous phases, to produce ‘design principles’ and enhance solution implementation.

3.3 DBR Cycles in this Thesis

In this thesis, we have conducted two cycles of DBR to come up with the pedagogical design. We refer to our pedagogical design as “Inquiry-based Knowledge Integration Training (**IKnowIT**) - pedagogy,” (IKnowIT-pedagogy), and the learning environment as IKnowIT-environment. The two cycles of DBR are described below.

DBR Cycle 1

Primary objectives of DBR Cycle 1 were: (i) to investigate if QP is applicable for Knowledge Integration, and (ii) to come up with an initial pedagogical design. The primary contributions of this research cycle are: (i) QP was empirically found applicable for KI, and (ii) initial versions of IKnowIT-pedagogy were created (version 1.0 and 1.1). We refer to this research cycle as **‘Cycle 1.’**

DBR Cycle 2

The objectives of the DBR Cycle 2 were: (i) to refine and finalize the pedagogical design and come up with a working solution; (ii) to evaluate the pedagogical design; and (iii) to extract local learning theories. Primary contributions of this research cycle are: (i) Final version of IKnowIT-pedagogy was created; (ii) IKnowIT-environment was created and finalized; (iii) Local learning theories were extracted; and (iv) Evaluations of the pedagogy and environment were carried out. We refer to this research cycle as **'Cycle 2.'**

3.3.1 Questions Answered in our DBR Cycles

Each of our DBR cycles involved research and design activities to answer three types of inquiry questions, as follows.

1. **Research Questions (RQ):** These set of questions are answered through administering one or more empirical studies. They are present in the "problem analysis," "evaluation" and the "reflection" phases of DBR.

2. **Literature Questions (LQ):** These set of questions are answered through literature analysis. They are present in the problem analysis phases of the DBR.

3. **Design Questions (DQ):** These set of questions are oriented to find specific operationalization of theories or practices to design or develop artifacts or methods, in the "Solution Design phase" of the DBR. They also include synthesizing the design requirements in the 'problem analysis' phase.

The list of these questions corresponding to each DBR cycles, along with the employed method of investigation is shown in Table 3.1. It should be noted that, in DBR, specific research problems that one needs to answer comes out only during the process of research. Therefore, the specific RQs, LQs, or DQs that we see in Table 3.1 were not predetermined by the researcher. Instead, findings of one part of the research, determine the questions to be answered in the later part(s).

Table 3.1: List of RQs and sub-RQs with corresponding Method of Investigation

DBR Phase		**RQ/ DQ/ LQ**	**Method**
DBR Cycle 1			
Problem Analysis (Cycle 1)	**LQ1**	What is KI and what does it mean to improve cognitive processes of KI?	Literature analysis
	LQ2	What are the viable strategies to improve cognitive processes of KI?	Literature analysis
	RQ1	How is QP applicable for improving KI?	
	RQ1a	How do learners integrate knowledge during exploratory QP?	Inductive thematic analysis on the questions generated by learners in QP sessions - Study 1
	RQ1b	Are the exploratory QP strategies 'Apply,' 'Operate' and 'Associate' valid within Data Structures course? *(**Note:** These three strategies came out while answering RQ1a, in Study 1.)*	Content analysis on the questions generated by learners in QP sessions - Study 2
	LQ3	What is a viable QP strategy to start with for designing a QP-based pedagogy for improving cognitive processes of KI?	Literature analysis
Solution Design (Cycle 1)	**DQ1**	What should be the adaptation of the design of 'Guided Cooperative Questioning'-based pedagogy (IKnowIT-pedagogy version 1.0) as a semi-online learning intervention? *(**Note:** 'Guided Cooperative Questioning' was a pedagogy, chosen from literature, while answering LQ3.)*	

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Table 3.1 – *Continued from previous page*

DBR Phase		**RQ/ DQ/ LQ**	**Method**
Evaluat$^{n.}$ & Reflect$^{n.}$ (Cycle 1)	**RQ1c**	Can ‘Guided Cooperative Questioning’-based pedagogical intervention improve learners’ KI performance?	Quantitative analysis of the difference between the experimental and control group performances - Study 3
	RQ1d	What do the learners perceive about the effects of guided cooperative QP based pedagogical intervention?	Content analysis of the focused group interviews - Study 4
DBR Cycle 2			
Problem Analysis (Cycle 2)	**DQ2**	What were the design problems in IKnowIT-pedagogy versions 1.0 and 1.1, which should be addressed in the next version?	Analysis of findings from Cycle 1
Solution Design and Evaluat$^{n.}$ (Cycle 2)	**RQ2**	How can training learners on an exploratory QP - based learning environment (IKnowIT) enable them to foster the cognitive processes associated with KI?	
	DQ3	What should be the design-features of the next subversion of IKnowIT (version 2.x) to make it capable of fostering the cognitive processes of KI in learners?	13 iterations of Iterative Design Evaluation and Evolution (iDEEN) method - Study 5
	RQ2a	What are the effects of each of the pedagogical features of IKnowIT-environment on learner’s learning process?	

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Table 3.1 – *Continued from previous page*

DBR Phase		**RQ/ DQ/ LQ**	**Method**
Solution Design and Evaluat$^{n.}$ (cycle 2) *(Contd ...)*	**RQ2b**	What are the effects of the learners' interaction with the IKnowIT-environment on their improvement of KI quality?	Rubric based analysis of learner generated questions (One group pre-post Analysis) - Study 5 Quantitative analysis of the difference between the experimental and control group performances using KI rubric. - Study 6
Evaluat$^{n.}$ & Reflect$^{n.}$ (cycle 2)	**RQ3**	What are the usefulness and usability of IKnowIT-environment as perceived by the learners?	
	RQ3a	What are the learners' perception of the extent of usefulness of each IKnowIT pedagogical features for their learning?	Usefulness analysis based on the survey with Likert scale - Study 7
	RQ3b	What are the learners' perception about the usefulness of IKnowIT-environment for their understanding of (1) the strategies of exploratory QP; (2) how to use QP to do better KI?	Usefulness analysis based on survey with Likert Scale - Study 7
	RQ3c	What are the learners' perception of the effect of IKnowIT-environment on their KI related abilities?	Usefulness analysis based on the survey with Likert scale - Study 7
	RQ3d	How usable is the IKnowIT-environment?	System usability score based on SUS survey (Brooke et al., 1996; Bangor et al., 2009) - Study 7

The two DBR cycles executed in this research are shown in **Figure 3.2**. In 'Problem Analysis' phase of Cycle 1 we answered two sub-RQs (RQ1a and RQ1b) and three literature questions (LQ1, LQ2, and LQ3). In 'Solution Design' phase we answered DQ1. In 'Evaluation and Reflection' phases we answered two sub-RQs (RQ1c and RQ1d).

In Cycle 2, we answered one design question (DQ2) in the 'problem analysis' phase. It should be noted that in Cycle 2 there were 13 interleaved iterations of 'Solution Design' and 'Evaluation' phases. We refer to these iterations as 'iDEEN' iterations where iDEEN stands for "**I**terative **D**esign **E**valuation and **E**volutio**n**." The iDEEN method discussed in Chapter 7 is based on the principles of educational design research (Plomp and Nieveen, 2010) and grounded theory (Charmaz, 2014) where the pedagogy design and 'local learning theories' iteratively evolve from an interleaved iteration of data collection, analysis and implementation. Through these iterations we answered one research question (RQ2a) and one design question (DQ3). In the remaining part of the 'Evaluation' and 'reflection' phases of Cycle 2, we answered sub-RQs: RQ2b, RQ3a, RQ3b, RQ3c, and RQ3d.

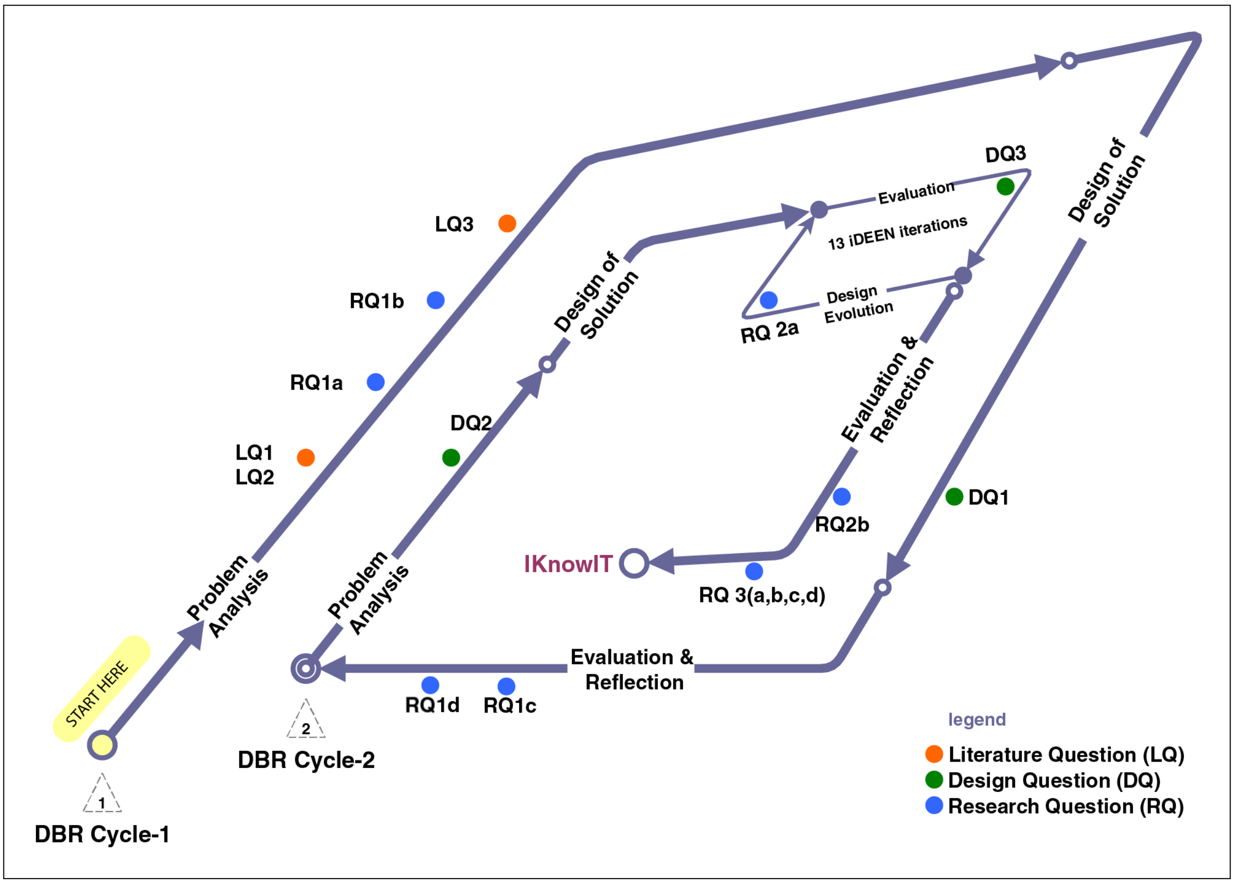


Figure 3.2: The Two DBR Cycles

3.3.2 Research Designs of the Studies within the DBR Cycles

In a research project, often more than one research design needs to be applied (Plomp and Nieveen, 2010). While DBR is the overarching research design, within the cycles of DBR we used several different research designs. The decision of the choice of research designs at any point within the DBR cycle is determined by the nature of the RQ or sub-RQ that has to be answered. The nature of RQ determines the type of research functions which in turn informs the choice of the research design. This logical sequence is shown in Figure 3.3.

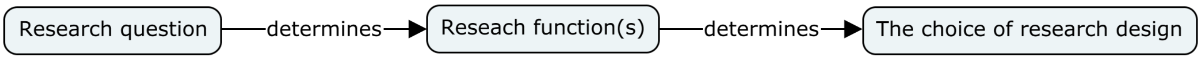


Figure 3.3: The Logical Sequence of Choosing a Study Design

Table 3.2 shows a compiled list of research functions and research designs used in this research. The research functions are compiled from Plomp and Nieveen (2010); Strauss and Corbin (1997); Glaser (2017).

Table 3.2: Mapping of Research Design and Research Functions

Research Functions	**Research Designs**
To determine the effectiveness of an intervention	Evaluation research
To describe and explain mechanisms of learning	Grounded theory
To design and develop interventions in practical context informed by theories and to explain learning theories	Design research
To describe, compare and evaluate	Survey
To explain and compare	Experiments
To describe	Inductive thematic analysis

3.3.3 Answering Research Questions

RQ1: How is QP applicable for improving KI?

This RQ determines if QP is a viable pedagogical idea which affects learner's cognitive processes of KI. We answered this RQ at two levels: firstly by examining if QP as a cognitive activity can be related to the cognitive processes of KI; and secondly by examining the proof of concept, if QP as a pedagogical idea is effective for improving learners' KI performance. We answered two sets of sub-RQs to address these two levels, respectively.

The first set of sub-RQs includes **RQ1a** and **RQ1b** as listed in Table 3.1. These sub-RQs primarily examine the nature of cognitive processes involved when a learner poses any question. To answer RQ1a we administered **Study 1** which involved inductive thematic analysis of the learner-generated questions. Study 1 resulted in the identification of the three EQP strategies by which learners connect their prior knowledge and given new knowledge to come up with questions. The result of Study 1 led us to RQ1b wherein we did a validation study (**Study 2**) to confirm if the results of Study 1 are prominent enough in the Data Structures domain.

The second set of sub-RQs includes **RQ1c** and **RQ1d** as listed in Table 3.1. Before answering these sub-RQs, we identified a QP-based pedagogy from literature (LQ3) and then designed an initial QP-based pedagogy by adapting from the identified pedagogy (DQ1). First, we quantitatively tested its effectiveness in improving learners' KI performance (**Study 3**) and answered RQ1c. Then we refined the pedagogy based on the observations from Study 1 and qualitatively tested its effects on the improvement of KI (**Study 4**) to answer RQ1d.

RQ2: How can training learners on an EQP-based learning environment (IKnowIT) enable them to foster the cognitive processes associated with KI?

To answer this RQ we were required to come up with a pedagogical design which can foster the cognitive processes of KI in the learners. We were also required to extract the local learning theories that explain how the training using the EQP-based pedagogical design affects the fostering of cognitive processes of KI. Lastly, we needed to triangulate these qualitative findings about the fostering of cognitive processes of KI with the quantitative measurements of the effects of the training on the learners' KI performance.

To fulfill these requirements we administered **Study 5** wherein we performed an iterative interleaved evaluation (**RQ2a**) and evolution (DQ3) of the pedagogical design. Detailed interview data was collected and analyzed using a research design based on the principles of grounded theory and education design research. This analysis led to the evolution of the final IKnowIT-pedagogy, the operationalization of the pedagogy as a learning environment (IKnowIT-environment) and extraction of local learning theory (answer to the **RQ2a**). Quantitative analysis of the learner-generated questions in Study-5 and the quantitative analysis of the learners' responses to KI assessment items in **Study 6** were used to triangulate the effects of the evolved pedagogy (**RQ2b**).

RQ3: What are the usefulness and usability of IKnowIT-environment as perceived by the learners?

After we completed the design and development of the IKnowIT-pedagogy and environment we administered **Study 7**. Study 7 involved usefulness and usability survey questionnaires that the learners answered after completing a session on the IKnowIT-environment. RQ3 was answered by answering the sub-RQs: **RQ3a**, **RQ3b**, **RQ3c**, and **RQ3d**, as listed in Table 3.1. First three sub-RQs evaluate the usefulness of the IKnowIT-environment while the last evaluates the usability.

3.4 Ethical Considerations

The following issues were taken into consideration while finalizing the research methods and data analysis techniques:

- **Consideration of ethical issues:**
  As the research studies involved human participants, the detailed guidelines were prepared for ethical consideration based on Cohen et al. (2000). These guidelines primarily include:
  - Preparing procedures and documentation for taking informed consent from the participants: Participants were given a consent form before every research study. They were well-informed about the objective and the procedure of the study. They were offered clarification by the researcher in case they had any queries. After informing the above details the participants were asked for their consent. They were free to discontinue the study at any point of time. The participants were assured that participation in the study would have no bearing on their grades and academic performance.
  - The anonymity of all the participants was maintained throughout and all the data was collected, preprocessed and stored for this appropriately.
    Consent information given to the learner before interviews is shown in Appendix I.
  - Permission for publication: The necessary permissions for publication were sought from the participants.

- **Deciding constraints on the research:**

  As the research studies involved undergraduate learners from engineering colleges it was important to synchronize the research studies with their academic calendars. This was even more important because of the fact that our research required those participants who have already undergone a course on the introductory programming and have not yet completed their Data Structures course. This laid down a constraint to recruit the participants who recently started their second year undergraduate engineering.

  The necessary permissions and consent from the concerned authorities for conducting research studies were obtained in advance. Various details related to actual execution of studies were discussed with the course instructors of the participants. These involved availability of computers, working local area network, internet, video player software, working audio jacks and earphones, server, number of learners to be recruited for the study, requirement of supporting staff, etc. Student participation was voluntary and they were provided with (workshop) participation certificates for attending the sessions.

3.5 Summary

In this chapter, the rationale behind choosing DBR as research design was presented along with the details of the two DBR cycles. Cycle 1 is detailed in chapters 5 and 6 while Cycle 2 is presented in chapters 7 to 10. The specific research designs of various individual studies are described in the respective chapters. In the next chapter we present an overview of our solution.

Chapter 4

Solution Overview

In this chapter we present our solution, i.e. the pedagogy developed through design based research (DBR). In the first section we present our solution rationale, then, in the second section, we describe our pedagogy.

4.1 Rationale for Our Approach

We used questioning as a means to foster learners' cognitive processes of knowledge integration (KI). From a cognitive science perspective, while a person tries to pose a question concepts in the memory are explored (Chapter 5). In this view, questions are the 'indicators' of exploration. The integration of concepts (KI) is caused by (if anything) the exploration process, which comes before and after the questioning. 'Before', when learner is posing a question, and 'after', when s/he searches for its answer. Our key pedagogical idea is to make learner to pose exploratory questions, which in turn ensures that the learner performs the cognitive processes of KI. This is followed by making the learner do metacognitive reflections to make sure that s/he can recognize the processes that were executed and their importance. The details of these mechanisms explaining how the IKnowIT-pedagogy achieves it's objective is presented in the "local learning theory" (Chapter 9).

4.2 IKnowIT-pedagogy

4.2.1 Instructional Goals

With a broad objective of designing a pedagogy to improve cognitive processes of KI in learners, and with the key pedagogical idea to use learner-question-posing (QP) as a cognitive tool, the learning objectives (LO)s for the pedagogy to be designed are listed as follows:

- **LO1:** Student should be able to pose exploratory questions and learn about exploratory question-posing (EQP) strategies using topic 1 (e.g. "Tree - Data Structures").
- **LO2:** Student should be able to recognize the execution of the cognitive processes of KI, which were executed when s/he was posing exploratory questions in the topic 1.
- **LO3:** Student should be able to pose exploratory questions by using EQP Strategy Prompts in topic 2 (e.g. "Graph - Data Structures").
- **LO4:** Student should be able to recognize the execution of the cognitive processes of KI, which were executed while she was posing exploratory questions in the topic 2 ("Graph - Data Structures") topic.
- **LO5:** Student should be able to recognize how the cognitive processes of KI contribute to deeper conceptual understanding in the topic 2 ("Graph - Data Structures" topic).
- **LO6:** Student should be able to recognize the execution of cognitive processes of KI with EQP in some topic from a farther domain. (Out of the scope of this thesis)
- **LO7:** Student should be able to recognize how the cognitive processes of KI contribute to better KI and deeper conceptual understanding in some topic from a farther domain. (Out of the scope of this thesis)

We conjecture that if learners follow the above path of LOs, then they can improve their cognitive processes of KI. However, the actual learning path is extracted as local learning theories in the later part of this thesis, and is presented in Chapter 9.

4.2.2 IKnowIT-pedagogy Phases

We executed two cycles of design based research (DBR) to achieve our objective of designing pedagogy and developing corresponding technology-enhanced learning (TEL) environment. Across these two research cycles and various studies, we came up with total nine intermediate versions of the pedagogy. In the final version of the pedagogy (at the end of the DBR Cycle 2), there are a total of six phases as shown in Figure 4.1. Each phase corresponds to a learning activity. The pedagogy is operationalized using a web-based TEL environment. We call the learning environment as **I**nquiry-based **K**nowledge **I**ntegration **T**raining (IKnowIT) - environment or **"IKnowIT-environment"** and we refer to the pedagogy as **"IKnowIT-pedagogy."**

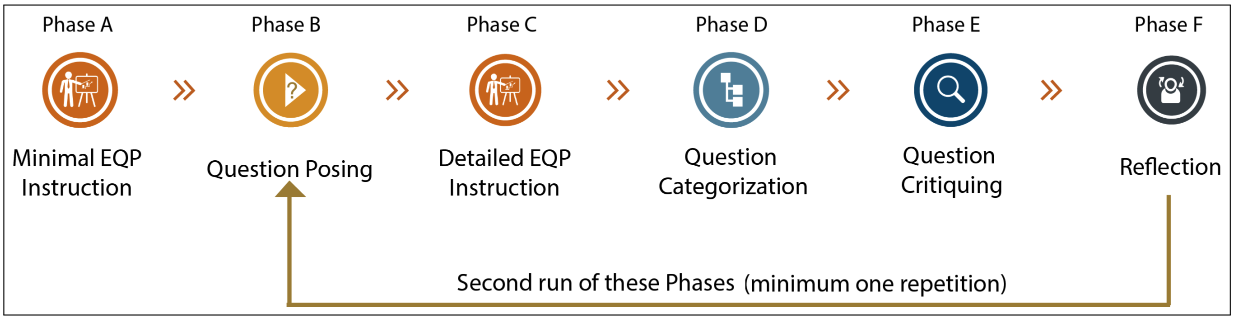


Figure 4.1: Inquiry-based Knowledge Integration Training (IKnowIT) - Pedagogy

The IKnowIT-pedagogy has three parts which are as follows:

1. **Learning Context Preparation**

   In this part of the pedagogy, a learner gets an introduction to the session objectives along with minimal information about QP and EQP followed by seeding of a knowledge context (by watching a video lecture on a topic) thereby creating her/his own learning artifacts (by posing questions while watching the video lecture).

2. **Higher Order Cognitive Engagements with the Learning Artifacts (higher order thinking activities)**

   In this part, the learner performs higher order thinking activities of analyzing and evaluating the learning artifacts (posed-questions) created in the first part to develop an understanding about the EQP strategies and the KI processes that are executed when one poses exploratory questions.

3. **Meta-cognitive reflections about learning**
   In this part the learner goes through a series of reflection questions which aim at recognition of the cognitive processes of KI, recognition of the importance of QP for KI, explicating the importance of KI for deeper conceptual understanding, and recognition of plan and regulation that one can use for future learning.

In addition to the above three parts, the IKnowIT - pedagogy also puts forward **a necessary repetition** of all the three parts at least once with different knowledge context. This is done to ensure that the learner can experience and recognize the applicability of the concepts that s/he learned and the reflections that s/he did in the first three parts. All of the six phases of the IKnowIT-pedagogy are described in subsequent subsections.

4.2.3 Phase A: Minimal EQP Instruction

In this phase of the pedagogy, the learner goes through a reading material which is interleaved with some reflection quizzes. We call these reading materials as 'Learning Dialogue' (LeD). The LeD in this phase contains an introduction to the IKnowIT session, a primer instruction on QP and introductions to the concepts of "clarification and exploratory" questions and their importance. The objective of this phase are as follows:

1. To motivate learners towards the IKnowIT activities.
2. To motivate learners towards EQP without overloading them with the details of the EQP.

4.2.4 Phase B: Question-Posing

In this phase, the learner poses questions around a given QP situation (Stoyanova and Ellerton, 1996). The QP situation consists of a video lecture (almost 15 minutes long) on a topic from Data Structures. According to Stoyanova and Ellerton (1996), this QP situation is a semi-structured one, as it allows learners with a freedom to think of any questions they want but around a specified topic. Learners are asked by IKnowIT-environment to "pose questions as soon as they pop up in their mind."

4.2.5 Phase C: Detailed EQP Instruction

In this phase of the pedagogy, the learner goes through another learning dialogue that again contains text readings and some interleaved reflection quizzes. Unlike Phase A which has minimal details, the learning dialog in Phase C contains detailed information about EQP while including an introduction to the three most frequently-observed EQP strategies in Data Structures (identified in Cycle 1 (Chapter 5)). These strategies are: (1) Apply, (2) Operate and (3) Associate. These are the different strategies by which a learner integrates different knowledge pieces from the given new knowledge (video lecture) and/or from her/his prior knowledge while posing exploratory questions. The description of these strategies is given in Chapter 5. The primary purpose of these questioning strategies is to provide the learner with a lens to further analyze and diagnose their already generated questions (in phase B). We found that the details of these three broad strategies were also used as the generic questioning prompts by the learners in further cycles of IKnowIT.

The first three phases (A, B and C) are meant for preparing a learning context. In Phase A and phase C, the learner gets primed about QP and EQP details. In phase B, the learner poses questions, which would further be used as learning artifacts in the next phase (D).

4.2.6 Phase D: Question Categorization

Here, the learner performs analysis level activity on the self-generated learning artifacts (questions). In this phase, the IKnowIT provides the list of the questions posed by the learner in Phase B and s/he is required to tag each of her/his question with the questioning strategies ('Apply,' 'Associate," 'Operate' and "Other"). This requires the learner to apply the descriptions of these strategies and analyze the questions, which in turn it makes the learner look deeply into questions and identify how the knowledge pieces from given knowledge and/or prior knowledge are actually integrated in each question.

4.2.7 Phase E: Question Critiquing

In this phase, IKnowIT system provides the learner with the list of questions generated and categorizations labeled by another learner. The learner is required to evaluate if the questions and their labeled category(ies) are correct or not. After evaluating s/he is required to comment on the reason that why the category(ies) is correct or not correct.

This phase makes the learner analyze and evaluate the learning artifacts generated by someone else. It further provides an opportunity for the learners to understand the role of different knowledge pieces (from the given and/or prior knowledge) and the role of their integration in the question formation.

4.2.8 Phase F: Reflection

In this phase, the learner answers eight reflection questions which include six objective questions (either Multiple Choice Questions, Likert Scale Question, or True False Questions) and two open response questions. These reflection questions make the learner perform metacognitive reflection upon the KI processes that they carried out while posing questions and their importance to their learning. The reflection questions are designed to achieve following learning objectives:

1. Student should be able to recognize that the given set of EQP strategies are not generalizable, there can be more strategies.
2. Student should be able to recognize that KI processes and the exploratory questions are important for better learning.
3. Student should be able to recognize that KI processes and EQP are intertwined.
   - Student should be able to recognize that it is important to focus on the concepts or ideas from the video lecture (new knowledge).
   - Student should be able to recognize that, one needs to recall her/his prior knowledge while doing EQP.
   - Student should be able to recognize that, one needs to relate her/his prior knowledge and new knowledge (video lecture) while exploring the topic.
4. Student should be able to recognize the processes of "distinguishing among ideas" (identifying conflicts, gaps, etc.) that help in finally coming up with questions.
5. Student should be able to recognize the plans and regulations that s/he can use for future learning.

4.3 Summary

In this chapter, we have seen an overview of the IKnowIT-pedagogy and our solution approach. The implementation of the pedagogy in the form of a web-based learning environment is presented in Chapter 8. The detailed local learning theory that explains the mechanisms about how the learner's interactions with the pedagogical features lead to the improvement of her/his cognitive processes of KI, is empirically extracted in Cycle 2 of this design based research and presented in Chapter 9. In the next two chapters, we present the account of DBR Cycle 1, as outlined in Figure 4.2.

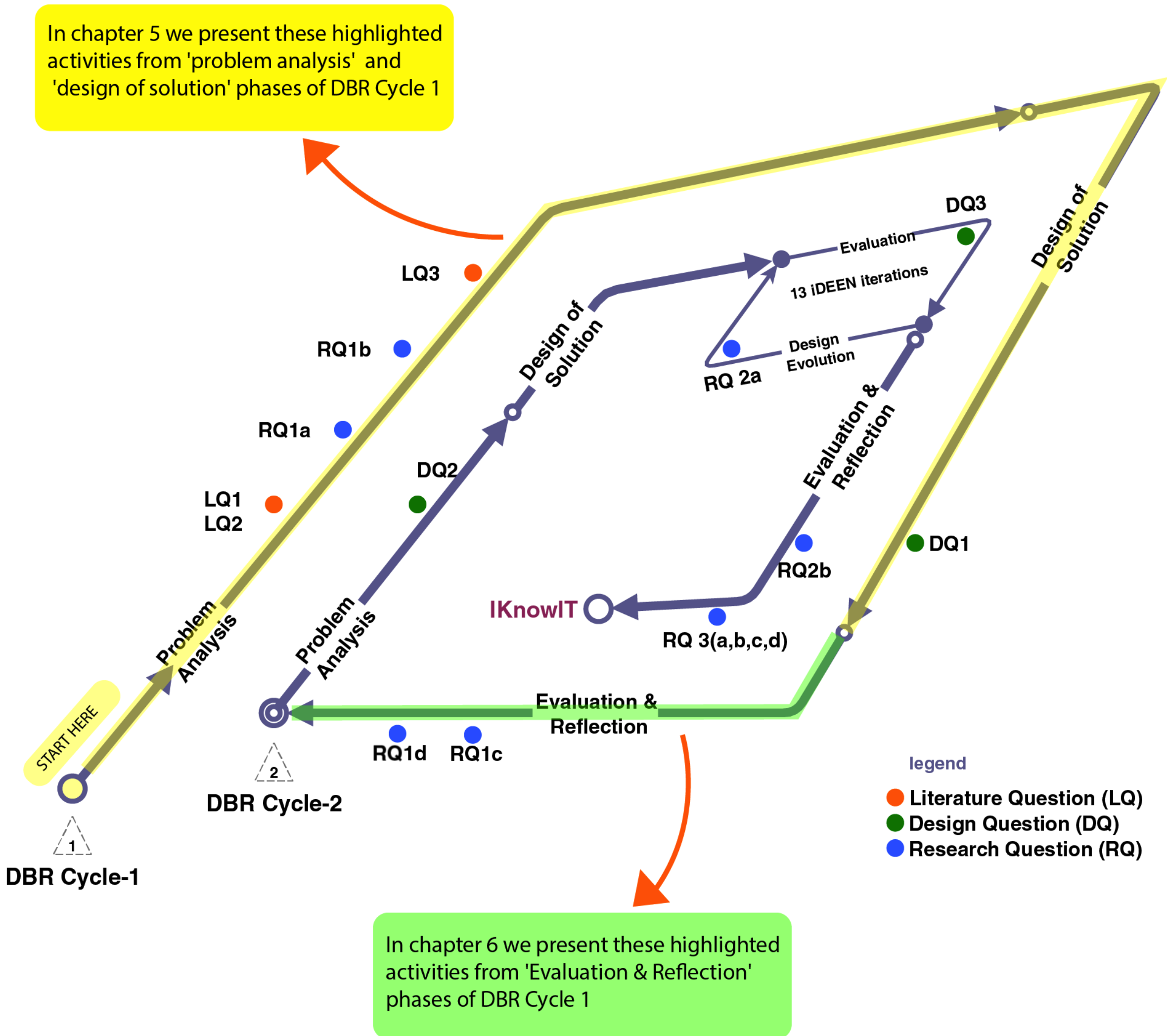


Figure 4.2: Thesis Organization – Locating Chapter 5 and Chapter 6 in the DBR Cycles

Chapter 5

Cycle 1: Problem Analysis and Initial Solution Design

In this chapter we present the details of (i) Problem Analysis and (ii) Solution Design phases of Cycle 1 of DBR. In the problem analysis phase, we identify and define our research problem using the findings from the literature and empirical studies. In the solution design phase we present the first pedagogical design meant for improving learners' cognitive processes of knowledge integration (KI).

5.1 Problem Analysis

The first level of problem analysis phase of DBR Cycle 1 has been achieved by synthesizing answers to the literature questions (LQ1 and LQ2). Next level of problem analysis is done by administering empirical examinations to our first research question (RQ1). We start by revisiting our discussions from our literature synthesis chapter (Chapter 2) to report the answers to these LQs.

- **LQ1: What is KI and what does it mean to improve cognitive processes of KI?**
- **LQ2: What are the viable strategies to improve cognitive processes of KI?**

As presented in Chapter 2, KI is seen at many levels kastens2012fostering - at an individual level, at the level of learning activity and at the level of entire knowledge building community. We address the KI at an individual level and aim to foster learners' KI processes at the cognitive level. We base our understanding of KI on the KI framework (Linn, 2013; Bell et al., 1995) that suggests essential sequences of processes that reinforce each other to help learners create coherent views of instructed topics. These processes (Figure 5.1) from cognitive skills perspective can be viewed as:

1. The learner elicits her/his prior knowledge
2. The learner refocuses on the new knowledge to help distinguish or link ideas with the prior knowledge
3. The learner distinguishes among ideas - by identifying conflicts, gaps, inconsistencies while relating new ideas

We limit our scope to **these three processes**. The goal of "improving cognitive processes of KI" has the following **learning objectives:**

1. Learner should be able to identify the cognitive processes of KI.
2. Learner should be able to recognize the importance of why these processes to her/his learning.
3. Learner should be able to know how to execute the cognitive processes of KI.
4. Learner should be able to execute the cognitive processes of KI.

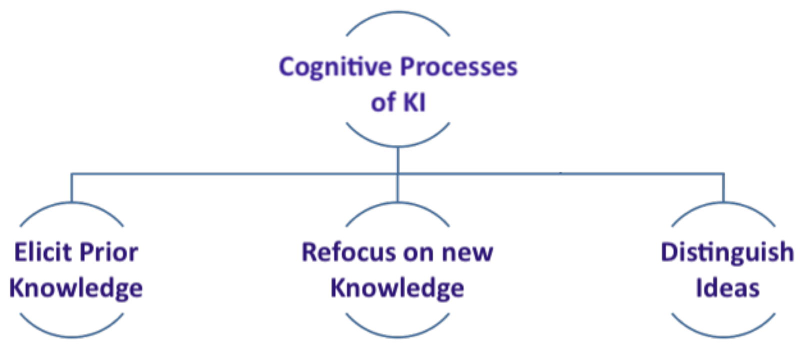


Figure 5.1: Cognitive Processes of KI

We aim at coming up with a pedagogy and a learning environment by which learners can improve their skills to execute these cognitive processes of KI (Figure 5.1). In order to identify the viable pedagogical strategies to improve the cognitive processes of KI, we characterize our requirement as follows. The pedagogical strategy should be such that it makes the learner to execute the cognitive processes of KI.

After referring many strategies such as self-explanation, note taking, concept maps, using instructional supports, etc. (Schneider, 2012), we settled with Question-Posing (QP) as the literature suggests that QP can foster all of the above-needed processes of knowledge integration. QP can be used for the correction of knowledge deficits (Graesser and Person, 1994). It can be used to look at a given knowledge from different perspectives (El Sayed, 2002). It can trigger cognitive processes such as searching, selection, transformation, classification, and association (Cruz Ramirez, 2006). It can be used to Figure out alternatives (Dillon, 1982; Pintér, 2012). Moreover, QP makes the conflict and doubts visible and accessible, by articulating them in the form of a question. Once the doubts or conflict are visible, it forms the first criteria for them getting them getting sorted out.

Motivated by the literature, we empirically investigate further “if Question-Posing is applicable for improving cognitive processes of KI” thus leading to our first field study.

5.1.1 Study 1 - Exploratory Question-Posing (EQP) and KI

To examine the applicability of QP for KI, we administered an inductive qualitative study, in which we analyzed the questions posed by the learners in several Data Structures classes. We investigate the mechanisms of how learners pose questions and examine if those mechanisms are aligned or related to the cognitive processes of KI. The broad research question that this study aims to answer is as follows.

- **RQ1: How is QP applicable for improving KI?**

To answer this question, we conducted exploratory qualitative studies to examine how learners' QP can facilitate KI. These qualitative studies resulted in the identification of the three frequently-employed exploratory Question-Posing (EQP) strategies by which learners integrate knowledge pieces from prior knowledge and new knowledge to come up with exploratory questions.

5.1.1.1 Sample

Total 90 learners: 60 from a 2nd-year undergraduate Data Structures (DS) class and 35 from 3rd year undergraduates in Artificial Intelligence (AI) class.

5.1.1.2 Implementation

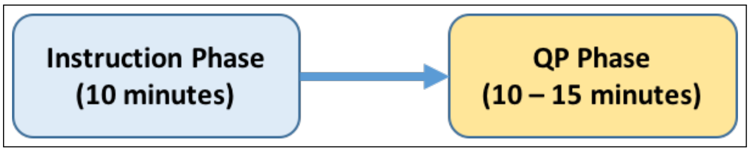


Figure 5.2: Study 1 Implementation: QP Session

We administered a QP session (as shown in Figure 5.2) in a 4th-semester engineering classroom of 60 learners. The session required the learners to pose questions in a semi-structured QP situation (Stoyanova and Ellerton, 1996). Semi-structured QP situation allows learners with a freedom to think of any questions they want BUT around a specified topic. The QP session included an instruction phase, which was executed for 10 minutes, and a QP phase which was executed for 10 - 15 minutes. In the instruction phase, the course instructor delivered a seed instruction (a small lecture) on Data Structures topics. Topics covered in the seed instruction were *"Node Structure"* and *"Linking two nodes."* The learning objective of the seed instruction was: *"By the end of the seed instruction, the learner should be able to define, declare, construct, and access node data structure and linkages between them using Java programming language."* The QP phase continued for 10 - 15 minutes. Learners were told to write their questions on paper slips and submit to the teaching assistants (TAs). We collected all the generated questions, and after discarding the redundant and irrelevant questions, we were left with a corpus of 56 distinct questions.

The AI session was similar to the DS session. We administered two QP sessions in a 7th-semester engineering classroom of 35 learners in the AI course. The instruction phases were of 15 minutes in each session. 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, learners 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 learner should be able to identify the attributes of intelligence present in the learning agents."* The QP phases in both sessions continued for 10 minutes. Here also learners wrote their questions on paper slips and submitted to the TAs. Learners were explicitly told about the types (clarification and exploratory) of questions, similar to the Data Structures sessions. We collected a corpus of total 48 distinct questions, 25 in the first session and 23 in the second session (corpus 2).

5.1.1.3 Data Sources

The data collected were the learners' generated questions in the QP sessions as described in the previous section. There were total 104 questions, 56 from the first corpus and 48 from the second.

5.1.1.4 Analysis Overview

We employed inductive thematic analysis (Fereday and Muir-Cochrane, 2006). Thematic analysis allows researchers to move from a broad reading of the data toward discovering patterns. It involves pinpointing, examining the data to come up with patterns or "themes" within data (Braun and Clarke, 2006). In the study, our broad purpose was to identify some patterns that can inform the mechanism of if and how learners' QP is applicable to the KI processes. The challenge of this analysis was that we didn't know what exact pattern to look for. For example, in the following question, posed by a learner after attending the lecture on *Linked list*, we knew only a few facts about it.

> *"Why Linked list when array is solving the purpose, and the Linked list* [node] *is using twice the memory?"*

We knew, (i) the content of the lecture that learner has attended; (ii) the content of her/his question that s/he has generated, and (iii) an initial analysis objective to guide our analysis. The initial analysis objective was to examine: *"how do learners pose questions as evident from the text of the questions submitted by them?"*

We performed a total of three rounds of thematic analysis to get three layers of findings. In the first round of analysis we observed that learners' QP has two distinct purposes, viz., learners ask questions either for clarification or for exploration. This made us look again into the data with a new analysis objective: *"How do learners pose exploratory questions as evident from the text of the questions submitted by them?"* In the second round of analysis, we found that learners try to relate their prior ideas/knowledge and new knowledge from the lecture when coming up with the questions. This further gave us a new analysis objective: *"Is there any pattern to which learners relate their prior knowledge and the new knowledge?"* This formed our third round of analysis. In the third round, we found that the exploratory questions have three broad patterns by which learners relate their prior knowledge and new knowledge that results in the identification and articulation of a question. The details of this analysis and findings are presented in the following subsections.

First round: In this round, we observed that the learners pose two types of questions in their class: (1) Clarification questions and (2) Exploratory Questions. Clarification questions aim at making the teacher to explicitly repeat what has already been lectured. Exploratory questions aim at making the teacher answer with some knowledge that has not been already lectured.

Second round: In this round, we performed detailed inductive qualitative analysis of the question corpus and found that there are two types of knowledge (or concepts) apparent in any question: (i) The knowledge delivered explicitly in the video lecture, we call it 'new' (or 'given') knowledge (NK); and (ii) The knowledge not delivered explicitly in the video lecture. We call it 'prior' knowledge (PK). There were few questions, which aimed at explicit reiteration of the content of the video lecture and did not have any prior knowledge, we call them clarification questions (Mishra and Iyer, 2015b). All other questions, which lead to the unfolding of a new concept, are called exploratory questions. We also found that every exploratory question exhibited certain patterns of associations between the prior and the given knowledge. With this information, we performed a second set of inductive qualitative analysis explained below, to answer our research question (RQ1a):

- **RQ1a: How do learners integrate knowledge during exploratory QP?**

Third round: In this round, we performed the detailed inductive thematic analysis of the same corpus to answer RQ1a. We carried out open coding and axial coding (Strauss et al., 1990) separately for each of the question sets (DS and AI questions). This helped in testing if the results of the axial coding are valid across the Computer Applications domains (DS and AI). This qualitative study has been reported in detail in (Mishra and Iyer, 2015b). At the end of the analysis, there were seven evident strategies by which learners integrate their prior knowledge and the given knowledge to come up with exploratory questions. These seven strategies were further grouped into three classes of the core exploratory questioning strategies, referred to as: (1) Employ, (2) Operate, and (3) Associate.

In the subsections below we explain the two coding procedures (Charmaz, 2014; Clarke, 2005; Strauss and Corbin, 1998) - open coding and axial coding, and present the incidents, the strategies and the core strategies emerged as the results of the third round of analysis.

5.1.1.5 Analysis and Results: Open coding to generate incidents

The goal of the open coding was to explore the question data and identify incidents (Figure 5.3), i.e., units of analysis to code for meanings, feelings, actions, events and so on (Charmaz, 2014; Clarke, 2005; Strauss and Corbin, 1998). We started reviewing the question set (Corpus 1) with the focus question *"How do learners arrive at questions in our semi-structured QP situation?"* We adopted the method of constant comparison (Charmaz, 2014; Clarke, 2005; Strauss and Corbin, 1998), 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. In order to ensure that we do not get biased to any of the possible answer to the focus question, we did not predefine any rubric or predetermine any concepts to aid the qualitative analysis of the data.

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 QP, and coded the potential incident(s). For example, the question (from 2nd QP session in AI) - *"Can we use the 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 concept from given knowledge.'* After some iterations of constant comparison, these two incidents were modified to *'Use of concept(s) from prior knowledge to develop a richer understanding of the given knowledge.'*

The final list of identified incidents is shown in Figure 5.3.

<table>
<tr><th colspan="2">Common incidents identified in the DS and AI problem sets</th></tr>
<tr><td colspan="2">
• Identifying an application of a knowledge component(s) in the seed from real life. (S1)
• Use of concept(s) from prior knowledge to develop a richer understanding about the seed knowledge. (S3)
• Variation on some attribute of the seed knowledge. (S6)
• Using prior procedural knowledge, create an operation that can be done on the seed concepts. (S7)
• Using prior knowledge about an operation transform the state of the seed concept(s). (S7)
• Clarifying a concept in the seed knowledge. (S8)
• Requesting reiteration of a concept from previous lectures. (S8)
</td></tr>
<tr><th>Additional incidents identified in the DS problem set</th><th>Additional incidents identified in the AI problem set</th></tr>
<tr><td>
• Identifying an application of a knowledge component(s) in the seed from the same domain. (S1)
• Identifying an application of a knowledge component(s) in the seed from other domain. (S1)
• Reorganize components of NK to create a new structure of the NK. (S2)
• Comparing the NK procedural knowledge with prior procedural knowledge. (S4)
• Comparing NK with prior knowledge from other domain. (S4)
• Associating prior knowledge from same domain with NK. (S5)
• Creating a procedure using prior knowledge to perform a target operation on the seed. (S7)
• Resolving a conflict about the seed knowledge. (S8)
</td><td>
• Examining how to apply NK in a known context. (S1)
• Use of alternate conceptions from prior knowledge to develop a richer understanding about the seed knowledge. (S3)
• Comparing NK with prior knowledge from real life. (S4)
• Making an analogy between prior knowledge and seed knowledge. (S5)
• Associating NK with prior knowledge from other domain. (S5)
• Associating experiences from real world with the seed. (S5)
</td></tr>
</table>

Figure 5.3: List of different incidents identified in the DS and AI question set after open coding. Strategies are given in parenthesis. NK refers to new knowledge

In the end, there were a total 15 of different incidents identified for the Data Structures question set, and 13 different incidents in the Artificial Intelligence question set, as shown in Figure 5.3.

5.1.1.6 Analysis and Results: Axial coding to generate QP Strategies

Axial coding, as stated by Strauss and Corbin (1998) 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 (Fitzgerald et al., 2005), which was operationalized using a series of meetings between researchers. The researchers continued working together in this manner to group related incidents until consensus was reached. In some cases, incidents seem to be relevant in more than one category. For example, *"Comparing the given procedural knowledge with some prior procedural knowledge."* This incident fits 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 QP Strategies, as these categories reflect different ways in which learners arrived at a question in the semi-structured QP situation.

The axial coding of the incidents obtained from the open coding revealed eight (S1 - S8) different QP strategies. It was evident that learners make use of **given** (and/or **prior**) knowledge in various ways to arrive at questions. In the subsequent paragraphs, we describe all these eight categories with examples. The examples used in the descriptions come from the question-set collected from Data Structures QP-session.

Strategy 1 (S1): Apply

In this strategy, the learner employs the concept(s) from the given 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. Following example questions demonstrate this strategy:

- *"Can trees be made using nodes?"*
  Here application ('tree') comes from the same domain, i.e., Data Structures, and the concept 'node' comes from the given lecture in the instruction phase.

- *"Can we create groups?"*
  Here application ('groups') comes from a different domain, i.e., Discrete Mathematics. Learner questions if the concepts from the given knowledge (lecture), can be used to create another concept, coming from prior knowledge fo another domain.

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

Strategy 2 (S2): Organize

In this strategy, learner poses a question to unfold an arrangement of the given knowledge by organizing multiple instances of the concept from given knowledge to obtain a structural arrangement (which comes from prior experience). Following example question demonstrates this strategy:

- *"Is cyclic list of nodes possible?"*
  Here multiple instances of the concept ('node') from given knowledge (lecture), i.e., a large number of nodes are proposed to be organized in a cyclic manner to unfold a variant of the given knowledge (i.e., 'circular Linked list'). The idea of cyclic arrangement comes from the prior knowledge of the learner.

Strategy 3 (S3): Probe

In this strategy, learners pose a question to associate prior knowledge to the given knowledge with an objective to add more understanding to the latter. Here prior knowledge is <u>not</u> the prior known application, as in S1. These associations use prior knowledge as a basis to make a richer inquiry into the given knowledge. Prior knowledge could be the name of a property, an attribute, or a component of the given knowledge. Following example question demonstrates this strategy:

- *"address* [pointer] *'next' is relative or direct?"*
  Here concepts from prior knowledge ('relative/direct addressing') have been used to make a richer understanding of the construct 'next,' which is a part of given knowledge.

Strategy 4 (S4): Compare

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

- *"What is the difference between chain of nodes vs. array?"*
  In this question, the prior knowledge ('array') is contrasted with a concept from given knowledge ('chain of nodes').

Strategy 5 (S5): Connect

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

- *"Can we use the neural network and fuzzy logic to create an agent?"*
  In this question, the prior concept of 'neural network and fuzzy logic' is connected with the context ('agent') of given knowledge.

Strategy 6 (S6): Vary

In this strategy, the objective of the question is to modify/vary component(s), attribute(s), or part(s) of the given knowledge to unfold the variants of the concepts from given knowledge. These questions may or may not give rise to some application of the given knowledge, but applications are not explicitly identified as in S1. Following example question demonstrates this strategy:

- *"Can we have 'previous' node in addition to 'next'?*
  In this question, the learner asks if instead of having just one reference to another node can there be more than one reference. This idea of 'having two reference variables' comes from the learner's prior conceptions, as it was not introduced in the lecture. Through this question a variant of 'singly-linking of node,' i.e., the concept of 'doubly Linked list' is set to be explored by the learner.

Strategy 7 (S7): Implement

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

- *"How to perform inheritance from a node possible to give multi-nodes"?*
  Here the operation inheritance has been explicitly identified, and the question is about how to implement that operation on the concept from given knowledge ('nodes'). Operation 'inheritance' comes from prior knowledge, and 'node' comes from the given knowledge (lecture).

Strategy 8 (S8): Clarify

The analysis revealed that learners ask a question to clarify their doubts. All the questions which need a reiteration of the content that has explicitly been taught in the given lecture are categorized under this strategy. It should be noted that Clarify questions do not unfold any new knowledge. Following example question demonstrates this strategy:

- *"What is the use of ' **.**this' [pointer] method?"*
  The use of ' **.**this' operator was explicitly taught in the given lecture.

Other observations from an examination of the incidents and categories

1. Learners use a range of QP strategies.
2. Learners use different types of prior knowledge during QP.
3. Learners use prior knowledge from same and/or different domains.
4. A learner 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 'storyline' that emerges out of linkages between categories from axial coding. In our case, our research objectives are fulfilled with axial coding.

5.1.1.7 Analysis and Results: Further grouping of the QP strategies

Figure 5.4 shows the core-strategies and their underlying subcategories. We can see that the two broad purposes of QP are: (i) **Exploration** of unknown knowledge; and (ii) **Clarification:** of the points that have already been said in a lecture. The seven exploratory QP can further be grouped into three broad EQP strategies:

1. **Employ (Apply)**, where the concepts from given knowledge are used to create some goal 'application' or 'arrangement.' In the learning design, we use the term 'Apply' instead of 'Employ.'

   For example in a lecture on 'graph Data Structures' a learner asks a question like: *"Can I create social network using graph?"*

2. **Operate**, where the QP aims at exploring the operation(s) required for achieving a goal state or modification related to the concepts from given knowledge.

   For example in a lecture on 'graph Data Structures' a learner asks a question like: *"How can I search a value from the set of values stored in graph data structure?"*

3. **Associate**, where concepts from given and prior knowledge interact with each other to give more insight into either the given knowledge or about some new knowledge, or about both.

   For example in a lecture on 'graph Data Structures' a learner asks a question like: *"How bad is the graph data structure, when we compare it to the tree data structure?"*

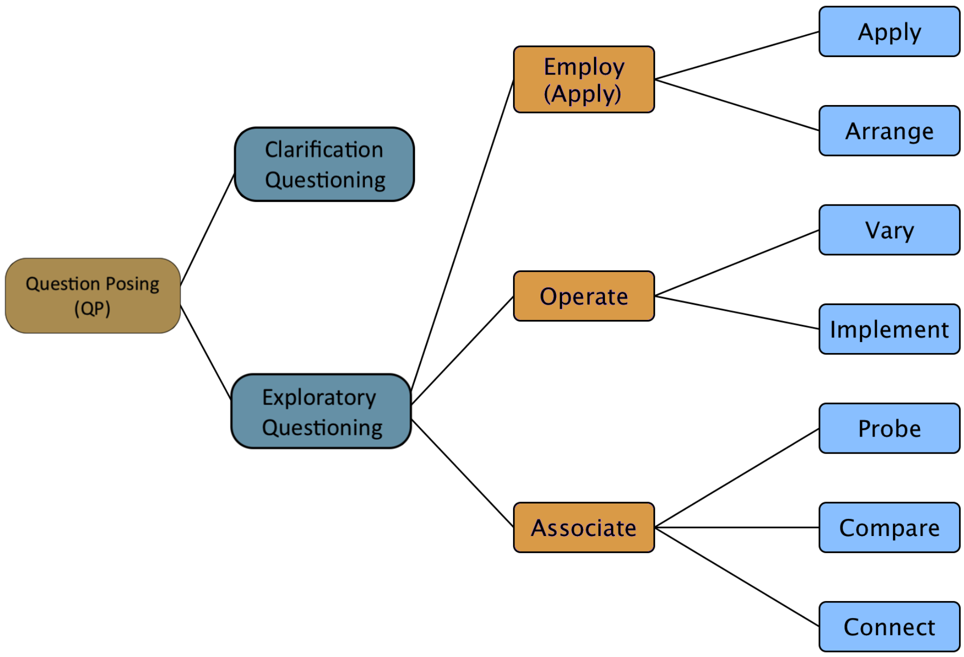


Figure 5.4: Hierarchy of Identified EQP Strategies

Note: In this thesis, we refer to these QP strategies as "Exploratory question-posing (EQP) strategies" or "EQP prompts." We have used these strategies as the questioning prompts in our QP based pedagogy. These strategies are domain (Data Structures) specific and have been extracted from the question-artifacts generated by the undergraduate learners, which means that they are the suitable abstractions of the thought processes of the undergraduate learners when they pose exploratory questions. Therefore they are expected to work well for the undergraduate learners participating in any QP activity in the Data Structures domain.

5.1.2 Study 2 - Validation of the EQP Strategies

This study was conducted to answer our next research question, i.e.

- **RQ1b. Are the EQP strategies 'Apply,' 'Operate' and 'Associate' valid within Data Structures course?**

The implementation of this study was similar to that in Study 1 (see Figure 5.2). We administered a QP - session in another second-year CS engineering undergraduate Data Structures class with 38 learners.

Since our objective was to validate the existing EQP strategies, we did a content analysis (Best and Kahn, 2016) of the collected questions and tested if any question can be categorized as per the descriptions of one or more of the three EQP strategies. Out of 112 questions collected, we found that 85% of the relevant questions were of the exploratory questioning type, out of which 87% of the questions fell into either Employ, Associate, or Operate categories. Distributions of the questioning strategies are shown in Figure 5.5. Moreover, out of total 93 exploratory questions, 18 fell in 'Employ,' 28 fell in 'Operate,' 31 fell in 'Associate' categories, while 16 did not fall any of the three EQP categories.

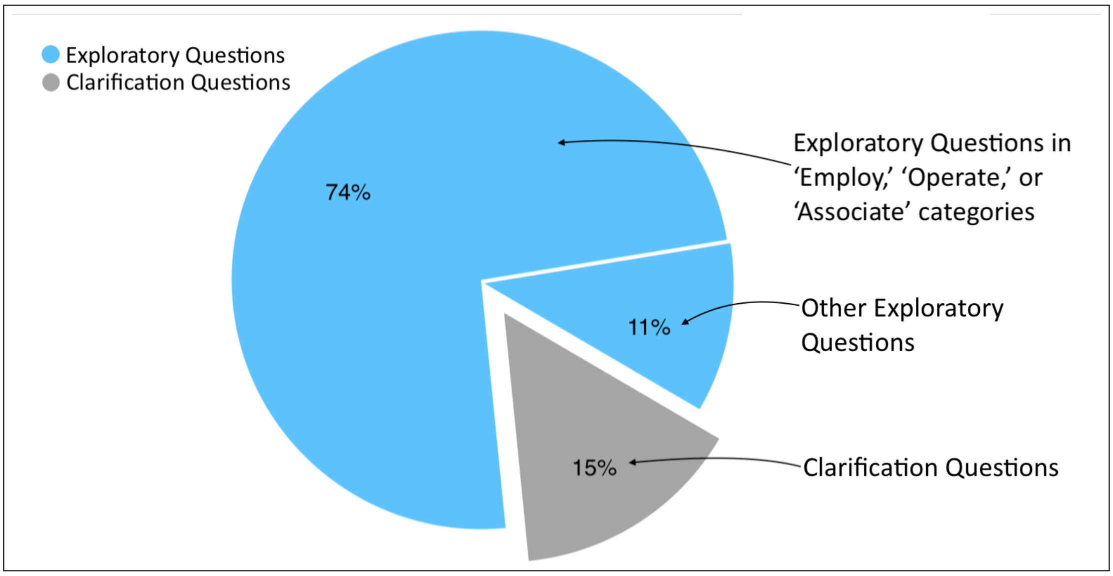


Figure 5.5: Prominence of EQP and EQP-Strategies.

5.1.3 QP-based Instructional Strategies for KI

Study 1 has empirically established that while posing exploratory questions, learners deal with their prior knowledge, given new knowledge, and perform their integrations at the cognitive level in broad three patterns, which we identify as EQP strategies. Therefore, this has shown that QP as a cognitive process is applicable for KI. This makes QP as an applicable pedagogical idea for addressing learning objective related to KI.

To proceed further, we examine the applicability of QP, as a pedagogical idea for improving the cognitive processes of KI. For this, we start with answering the following literature questions (LQ).

- **LQ3. What is a viable QP strategy to start with for designing a QP-based pedagogy for improving cognitive processes of KI?**

To answer this question, we looked into the literature to Figure out candidate QP based pedagogy that suits our purpose. We found that "guided cooperative questioning" (GCQ) pedagogy, proposed by King and Rosenshine (1993) suits our purpose. King and Rosenshine (1993) demonstrated the effectiveness of this three-phased QP pedagogy on the construct of 'knowledge construction,' which is very close to the perspective of knowledge web' (Linn et al., 2004c) and therefore closer to the construct of KI. The GCQ pedagogy is shown in Figure 5.6. All other QP based pedagogies were targeting relatively distant construct, such as comprehension (King, 1989), problem solving (Pintér, 2012; Cankoy and Darbaz, 2010), and self regulation (Graesser and Person, 1994).

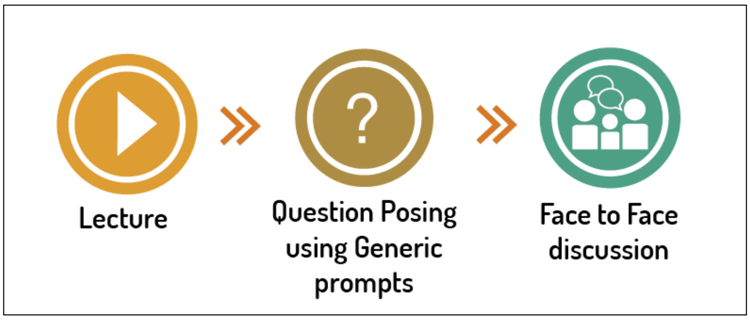


Figure 5.6: Guided Cooperative Questioning by King and Rosenshine (1993)

With GCQ as a choice for our basic design, we move further to the designing of the first version of IKnowIT-pedagogy (version 1.0) and answer our first design question (DQ). From here on we would call the first version of the IKnowIT-pedagogy as 'IKnowIT-pedagogy version 1.0.' We answer following DQ in the next section.

- **DQ1: What should be the adaptation of the design of GCQ based pedagogy (IKnowIT-pedagogy version 1.0) as a semi-online learning intervention?**

5.2 Solution Design

In the problem analysis phase, we analyzed literature, administered two empirical studies to examine the 'applicability' of QP for KI improvement. Till now, we answered RQ1 and we can claim that QP makes the learner trigger the cognitive processes of KI. The next level of examination of the 'applicability' would be to use QP as a pedagogical idea and evaluate its effects on improvement of the indicators of KI. Therefore, in the Solution Design phase of DBR Cycle 1, we first answer design question (DQ1) to obtain an initial QP-based pedagogy, using which the empirical studies can be carried out.

5.2.1 IKnowIT-pedagogy Version 1.0

We adapted GCQ pedagogy (King and Rosenshine, 1993) to suit the following distinctions:

1. We used video lecture instead of classroom face-to-face lecture.
2. Instead of the generic QP prompts, as used by King and Rosenshine (1993); we used the seven Data Structures specific EQP strategies, which we obtained in Study 1 as QP prompts.

Figure 5.7 shows the pedagogical design. This was the very first version of the IKnowIT-pedagogy. However, it is not semi-online, as required by the DQ1, and we limit this adaptation of GCQ just to partly computer-based implementation. When we compare GCQ pedagogy (Figure 5.6) with the IKnowIT-pedagogy version 1.0 Figure (5.7). We can see that the face-to-face lecture in the GCQ is replaced by video lecture. The QP activity has been split into two parts. In the first part learners read information on QP, and in the second part, they perform the QP task. The face-to-face discussion activity remains the same. In the following paragraphs, we describe each of the four phases of the IKnowIT-pedagogy version 1.0.

Phase 1: Video lecture

The first phase involved watching 17 minutes long video lecture on "Linked list." Learners were allowed to seek the video back and forth and watch the video as many times as they want, within the stipulated maximum time.

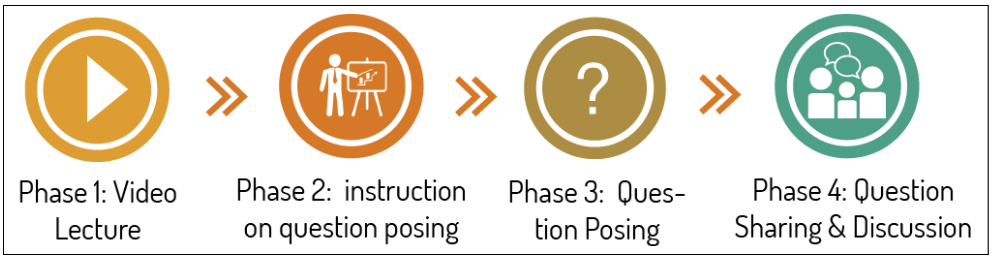


Figure 5.7: IKnowIT-pedagogy Version 1.0

Phases 2: Instruction on Question-Posing

In Phase 2, learners read slides on different questioning types (clarification and exploratory), and different EQP strategies ('Apply,' 'Operate' and 'Associate') identified in Study 1. This phase was added to make sure that the learners are informed about the usefulness of QP and get familiar with the three EQP strategies. Informing the learners about the usefulness of the QP is needed to encourage them to take part in the QP activity. Familiarizing the learners with the three strategies is important because we expect the learners to use the strategies, while they do QP (next phase).

Phases 3: Question-Posing

In Phase 3, learners are asked to pose questions around the content of the video lecture they watched in phase 1. Learners are allowed to refer to the slides containing the instruction on QP and the video lecture, during the QP activity.

Phases 4: Question sharing and discussion

This phase is similar to that described in the guided cooperative questioning. Here the learners share their questions with their peers and then discuss them face to face. In this version of IKnowIT, there was no specific script and control to what learners were discussing.

5.3 Summary

In this chapter, we presented the first two phases of DBR Cycle 1. The research done in these two phases is not just crucial for answering the research question (RQ1) related to the applicability of QP for KI improvement, but it has also contributed with the extraction of important learning and design artifacts. The learning artifacts that came out of ' the problem analysis' phase of DBR Cycle 1 are the three EQP strategies. These EQP strategies can be used in the QP-based pedagogies for Data Structures undergraduate learners, as the questioning prompts. The design artifact came out of 'Solution Design' phase is the first version of the QP-based pedagogy (i.e., IKnowIT-pedagogy version 1.0). In the next chapter, we present the other two phases of Cycle 1. The next chapter starts with the evaluation of the first version of IKnowIT-pedagogy version 1.0.

Chapter 6

Cycle 1: Evaluation and Reflection

In this chapter, we present the evaluation phase and reflection phase of Cycle 1 in design based research (DBR). We start with the evaluation phase and present the field studies done to evaluate the first pedagogical design. In the reflection phase, we present our reflections on the design process which includes how Cycle 1 informs about the design principles to be followed in Cycle 2.

6.1 Evaluation

In this phase of Cycle 1, we conducted the field studies to evaluate the pedagogical design. We start by reporting Study 3 which evaluates the first version of IKnowIT-pedagogy (version 1.0), shown in the previous chapter (Figure 5.7).

6.1.1 Study 3 - Quantitative Evaluation of Initial Pedagogy

This study aims at quantitatively evaluating the applicability of question-posing (QP) for knowledge integration (KI) by measuring the effect of Guided Cooperative Questioning (GCQ) based IKnowIT-pedagogy (version 1.0) on learners' KI performance. This study answers the following research question:

- **RQ1c: Can guided cooperative QP based pedagogical intervention improve learners' KI performance?**

6.1.1.1 Study Design and Implementation

The study design was two group control study. Figure 6.1 shows the timeline and activities of the experimental and control groups. The descriptions of the activities performed by the experimental group are as follows.

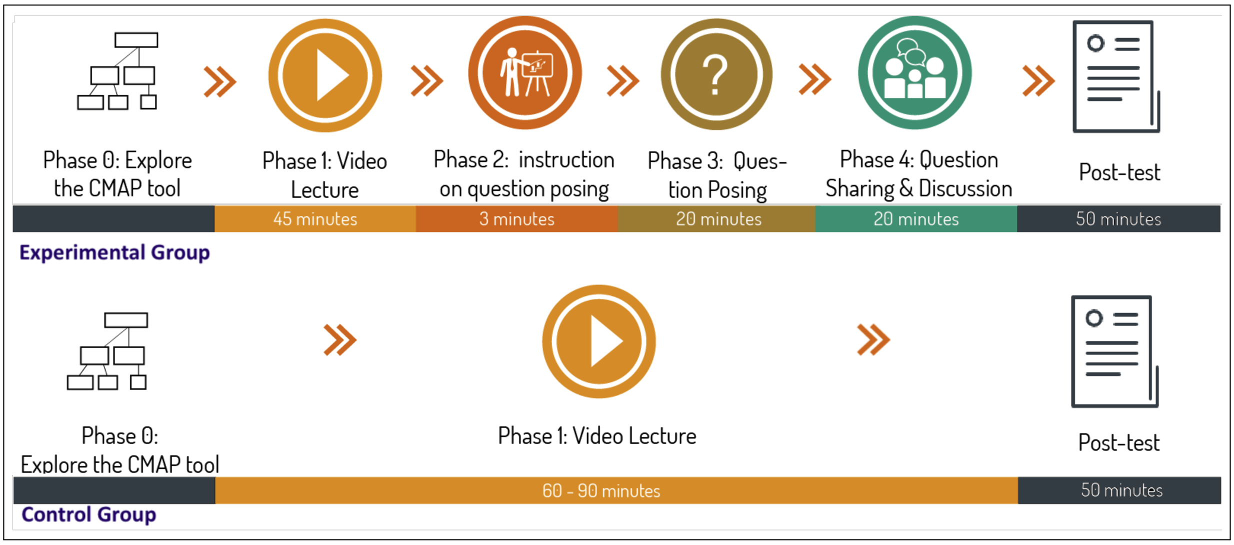


Figure 6.1: Study 3 - Design

- **Exploration of CMap tool**
  In the start, learners were given a 1 minute and 26 seconds long video on how to make a simple concept map (CMap). This was important because the assessment was completely based on concept mapping and learners had no prior exposure to either to CMAP tool or CMaps. We used CMaping as an assessment technique for KI (Schwendimann, 2016).

- **Phases 1, 2, 3 and 4 (IKnowIT-pedagogy Version 1.0)**
  Phase 1 was about watching a 17 minutes long video lecture on "Linked list." Learners

were given total 45 minutes to complete this activity. They were allowed to seek forward and backward in the video and watch it as many times they wanted. This activity was implemented using traditional video players on a desktop computer. In the phases 2, 3 and 4 learners did the following activities respectively: (1) They read slides on different questioning types (clarification and exploratory), and different questioning prompts (the three main EQP strategies, including the seven EQP (sub-)strategies obtained from Study 1); (2) They posed questions around the content of the video; and (3) They shared their questions and then discussed face to face.

- **post-test**
  In the post-test, learners were given a list of the keywords from the video lecture they watched and were told to create CMaps to reflect what they learned in the "Linked list" video. The CMaps submitted in the post-test were used to assess KI performances of the learners.

The control group learners, as shown in Figure 6.1 got double the time to watch the same video lecture. Double time was given to make sure that the learners in the control group engage with the content of the video lecture for an equal length of time. We can see in Figure 6.1 that the control group is allowed to watch the video for maximum 90 minutes, and the total time given to the experimental group (for Phases 1 to 4) was 88 minutes. Control group learners were not made to do any QP or discussion activities. The video was 16 minutes in length, and both experimental and control groups were given the same video.

6.1.1.2 Sample

We recruited 24 second semester Computer Science undergraduate engineering learners. Learners were equally distributed to the control and experimental groups using random sampling.

6.1.1.3 Data Collection and Analysis

The primary data collected were the maps generated by the learners as a post-test activity. The researcher also maintained an observation journal which aimed at logging the observed difficulties that learners face during the session.

The standard (Lee et al., 2011; Liu et al., 2008) rubric shown in Figure 6.2, for assessing the KI construct, was adapted for evaluating CMaps. This rubric originally gives solution on how to analyze texts responses generated by learners to assess their KI performance.

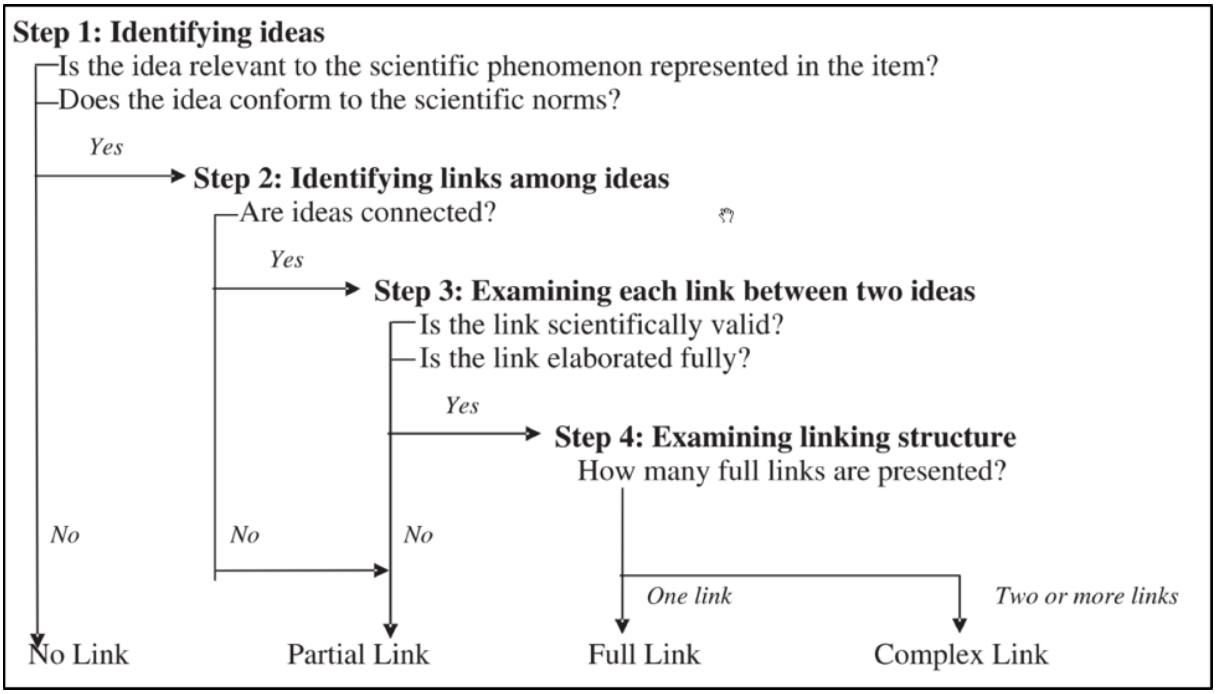


Figure 6.2: Four Step KI Scoring Scheme (Liu et al., 2008). Figure reproduced from (Liu et al., 2008)

To understand how this rubric was used to evaluate the CMaps created by the learners, we first need to understand the basic structure of CMap (Schwendimann, 2016). Figure 6.3 shows a CMap generated by a learner. We can see that a CMap looks like a connected graph where nodes represent different concepts and the links between two nodes represent the relationship between the concepts. Moreover, as shown in the next Figure 6.4, two concepts connected with one link is known as one triplet. Each triplet can have further extensions. It should be noted that, in the third case shown in Figure 6.4, "more than one extensions" are possible in two ways: first when one triplet extends the main triplet; and second when the two nodes parallelly (as sibling branches) extend the main triplet.

The four-ordered levels of KI performances (see Figure 6.2) given by Liu et al. (2008), viz., Score 0 for 'No Link,' Score 1 for 'Partial Link,' Score 2 for 'Full Link,' Score 3 for 'Complex Link' were mapped to the four criterion in a CMap, as follows:

- When there is no valid or relevant triplet in a CMap, we tagged the CMap as 'No Link.'
- Count of all valid triplets was considered to be the count of 'Partial Links.'
- Count of all valid triplets with one extension was considered to be the count of 'Full Links.'

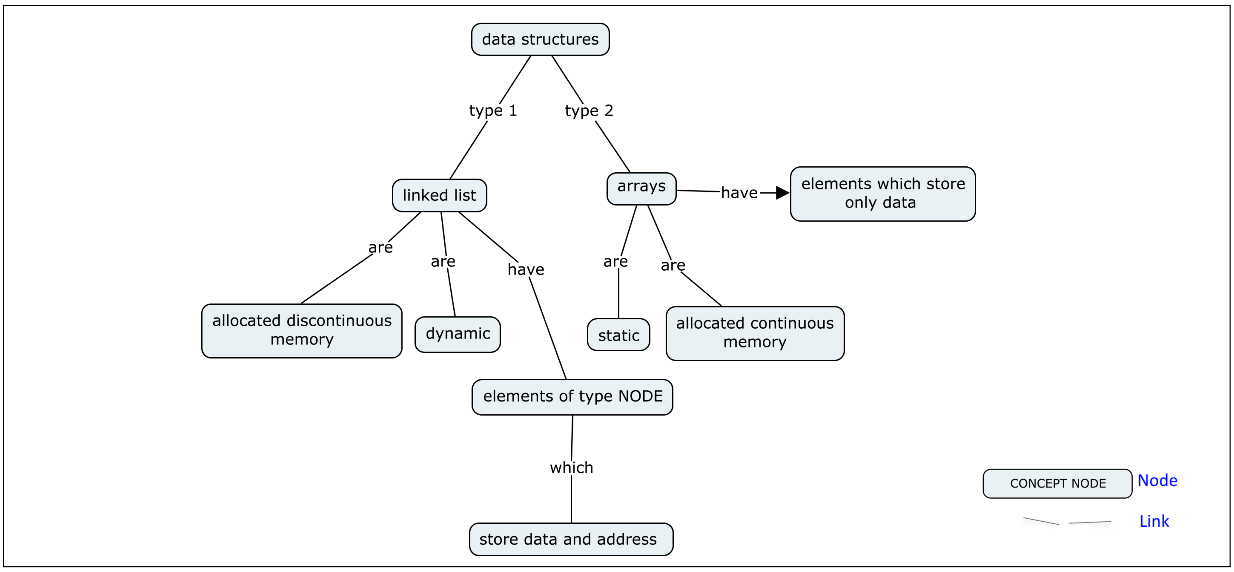


Figure 6.3: Example CMap, Generated by a Learner on the Topic Linked list

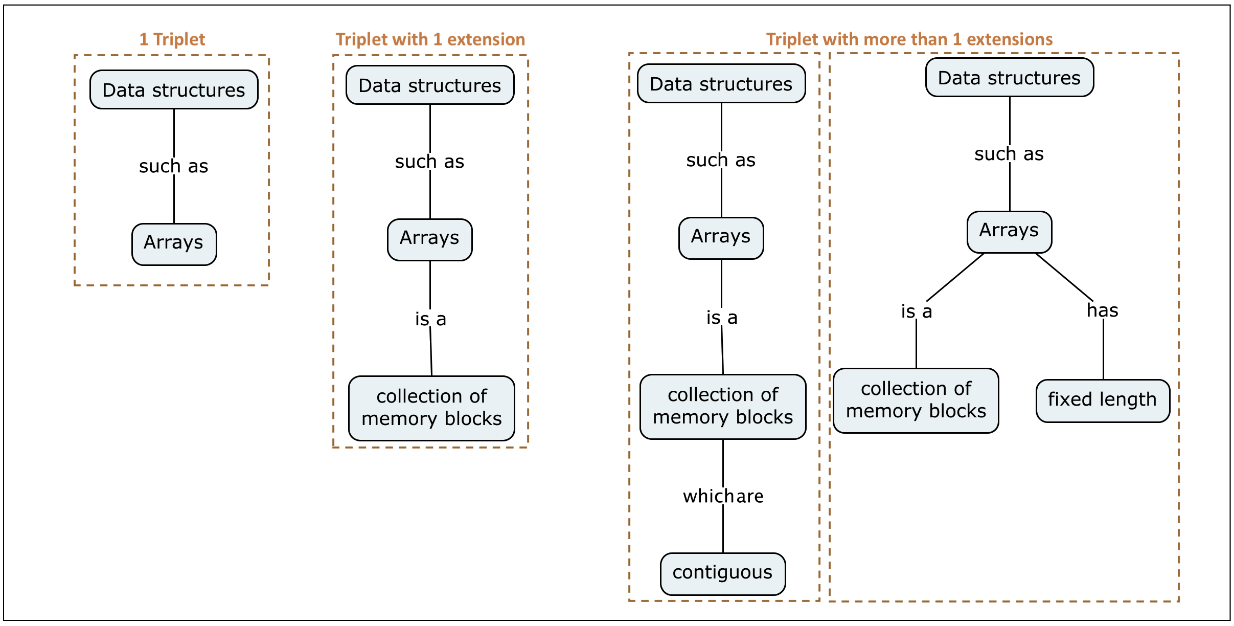


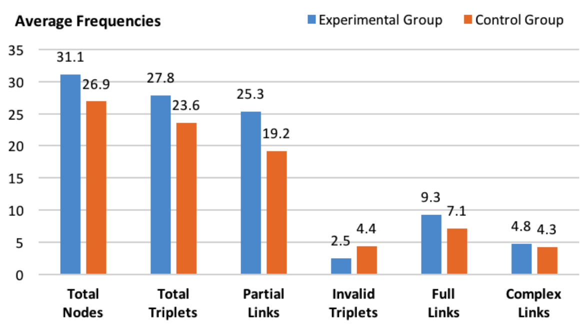
Figure 6.4: Examples of Triplets and their Extensions

- Count of all valid triplets with more than one extensions was considered to be the count of 'Complex Links.'

The variables which were evaluated in any CMap, as the indicators of the level of KI performances achieved by the learners were: (1) count of triplets, (2) count of partial links (valid triplets), (3) count of full links (partial links having extension by at least one node), (3) count of complex links (full links having extension by more than one node).

6.1.1.4 Results

For each learner-generated CMap, we extracted the counts of ‘partial links,’ ‘full links,’ ‘complex links,’ along with the counts of ‘nodes’, ‘triplets’, and ‘invalid-triplets’. Except for the count of the ‘invalid triplets,’ more the value of the count of any criterion, better is the KI performance. We did a comparison of the two groups on each of these criteria, as shown in the bar graph (Figure 6.5). We see that the experimental group has performed better than the control group in all the criterion. We also see that the experimental group has generated less ‘invalid triplets,’ than the control group, which is also a desirable trend. Though the differences between the two groups performances were statistically not significant, the result gives a trend that the QP group scored higher than the control group. This positive trend was further corroborated by the qualitative feedback collected in Study 4 of this DBR cycle.



	Total Nodes	Total Triplets	Valid Triplets	Invalid Triplets	Full Links	Complex Links
Mann Whitney U	50.5	42	40	41.5	61.5	72
Z	-1.24	-1.74	-1.85	-1.79	-0.61	0
P (2-tailed)	0.213	0.082	0.064	0.073	0.541	1
Test Statistics, $N^{experimental}=N^{control}=12$						

Figure 6.5: Result from Study 3

From the researcher’s observation log, we found that most of the experimental group learners, who were supposed to use the Data Structures specific EQP-prompts, did not use them. All of them read the details of the EQP prompts but didn’t refer back to them during questioning. This prompted us to collect formative feedback from the learners after post-test. The learners’ feedback confirmed that they rarely used questioning prompts while posing questions, and it was daunting for the learners to follow a new set of questioning prompts. For example, one learner said, *“they [EQP strategies] were new to me... Questions I could generate without them, anyways.”*

6.1.2 Study 4 - Qualitative Evaluation of Initial Pedagogy

This study was primarily administered to qualitatively investigate if the positive effects of the QP-based activities, as observed in Study 3, can be corroborated. In this study, we collected qualitative data to further examine the applicability of QP for KI (RQ1) by answering the following sub-research question:

- **RQ1d: What do the learners perceive about the effects of guided cooperative QP based pedagogical intervention?**

6.1.2.1 Implementation

The observation in Study 3 was that the learners were not using the QP prompts to generate questions. Moreover, we also wanted to move towards a semi-online-based operationalization of the pedagogy (as mentioned in DQ1). These issues prompted us to update the pedagogical design, as shown in Figure 6.6, from version 1.0 to version 1.1, for Study 4.

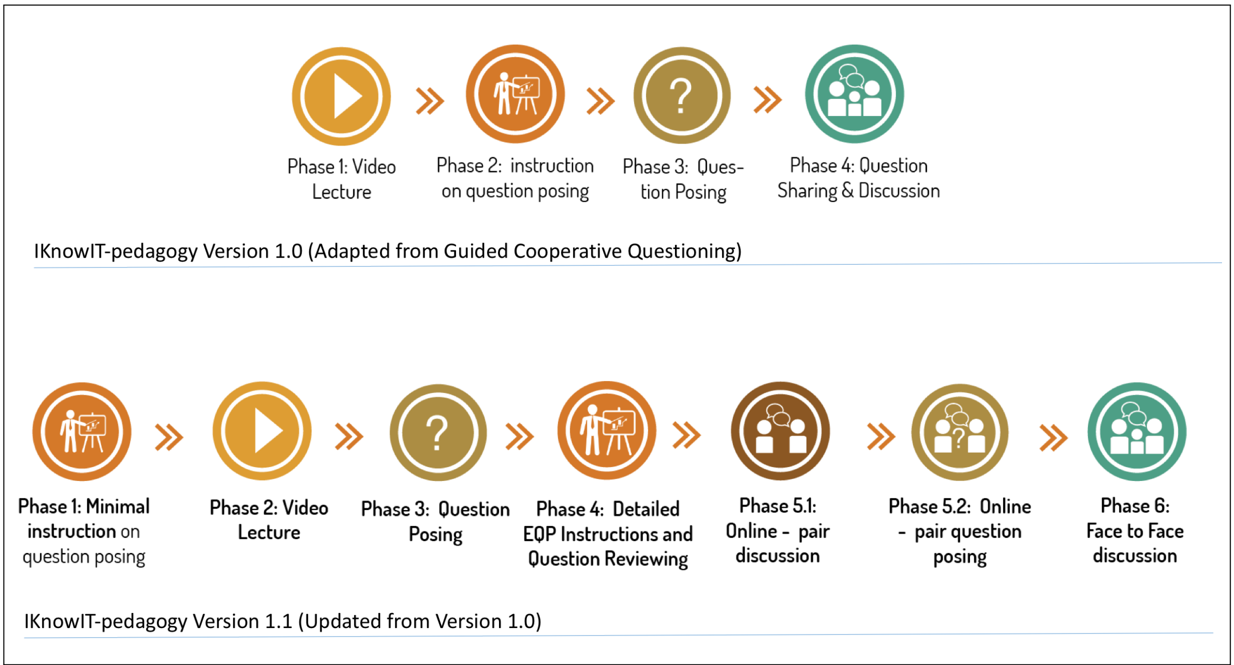


Figure 6.6: Updating the IKnowIT-pedagogy, from Version 1.0 to Version 1.1

We made the following changes in the pedagogical design (Version 1.1) corresponding to the following issues.

1. **Issue:** The EQP prompts were daunting because they were new to the learners.

(a) **Action 1:** The reading slides about the question prompt was chunked (Baker, 2010) into two parts. The first part (Phase 1, Version 1.1, Figure 6.6) had very minimum information about QP, i.e., introduction to the concepts of clarification and exploratory questions. We conjectured that giving a small introductory information to the learner before the QP activity should make the activity less daunting.

The second part of the reading (Phase 4, Version 1.1, Figure 6.6) contained information about the EQP strategies and how can learners use them as question prompts. Moreover, Phase 4 further pushed the learners' engagement with the EQP strategies, by making them to analyze their posed questions using the EQP strategies descriptions, and find out if any of their questions fall in any of the EQP categories.

(b) **Action 2:** Additional discussion activity was added (Phase 5.1, Version 1.1, Figure 6.6). This discussion was done with an online peer over internet browser-based text chat. For the online chat activity, our conjecture was that discussion with a pair may help in understanding the EQP prompts more clearly (Smith et al., 2009). However, the other discussion activity remains the same (Phase 6, Version 1.1, Figure 6.6), as in Phase 4 of the Version 1.0.

(c) **Action 3:** QP activity was done twice. One after the minimal QP instruction (phase 2, Version 1.1, Figure 6.6) when learners did not read anything about the question-prompts.

The other QP activity was done after the learners have supposedly assimilated a lot of details about the question prompts (Phase 5.2,, Version 1.1, Figure 6.6). It was done in pairs, with a conjecture that EQP prompts may not daunt learners if they work in pair (King, 2002).

2. **Issue:** Needed to convert most of the system online.

   (a) **Action:** The activities of reading slides, pair discussion and collaborative questioning were done online (Phase 4, Phase 5.1, and Phase 5.2, Version 1.1, Figure 6.6). In addition to the goal of addressing the first issue, these changes also acted as a pilot run for online implementation.

Following is the description of the phases in the updated IKnowIT-pedagogy version 1.1 (Figure 6.6).

Phase 1: Minimal instruction on QP: Learners were given minimal instruction on clarification and exploratory questioning by the workshop instructor for 5 minutes. This minimal instruction aimed at informing learners of the learning objective of the sessions and sensitizing them to QP.

Phase 2: Video Lecture: Learners watch a 15 minutes long video lecture on “Introduction to Linked list” individually. They were told that they can play, pause, seek backwards-forward the video whenever they want. They were given total 25 minutes to watch the video. Learners were free to take notes on text-editors whenever they want.

Phase 3: Question-Posing: Learners were asked to generate questions (for next 10 minutes) around the content of the video lecture. They were told that they can generate any number of questions, and they should try to generate good quality exploratory questions.

Phase 4: Detailed Instruction on EQP & Question reviewing: Learners were given a prompt sheet which contained a list of exploratory questioning strategies with examples. They were asked to review and tag their generated questions with the EQP strategy categories listed in the prompt sheet. Learners were also informed that one question can have more than one category and the list is not exhaustive, so they are free to use “other” tag if none of the category matches. Maximum time allocated for this phase was 5-7 minutes.

Phase 5.1: Online - Pair Discussion: The learners were randomly paired and were asked to initiate an online group chat (using Google hangout for text chat). Every chat pair was asked to add a moderator to their chat session. The learners were told to follow the moderators' instructions while discussing through online-chat. They were also told that “the moderator would not be reading their posts and discussions; moderators job would just be to make the learners aware of what is the next discussion objective/ activity, and when not to post anything on the chat. This activity continued for 15-20 minutes.

Following is the list of activities (moderator's instructions) showing the script of the online discussion task which was implemented with the help of the moderator.

1. *Copy your questions with their question categories and post it on the chat. (Post “Done!” when you have finished posting)*

2. *Read all the questions posted by your partner and check if your partners have categorized their questions correctly. (Don't post anything before you have read.)*
3. *Both of you - please chose one question which you feel is not categorized properly by your partner. (don't post anything)*
4. *Participant one - let your partner know which question you have chosen and give reasons why do you think that the category is not correct. Both of you discuss debate and conclude the category of the chosen question. (Post "done" when you are done with it).*
5. *Participant Two - Now you tell which question have you chosen and give reasons why do you think that the category is not correct.*
6. *Now again chose one more question which you feel is not categorized properly by your partner. (Don't post anything).*
7. *Both of you discuss and finalize the category of the chosen question. (Post "done" when you are done with it).*
8. *If you want to discuss any other question you can discuss. Go ahead. You have some more minutes.*

Phase 5.2: Online - Pair Question-Posing

In the same chat session, the moderator gave following instruction: *"Participant 1 and 2, now your group needs to together generate one good quality exploratory question around the same video content. You both try to ensure that the quality of the exploratory question is good."*

Once or twice, in the mid of the chat session, the moderator posted the prompt that *"They have to make sure that they read each other's' post carefully while discussion."* This activity continued for 5-10 minutes."

Phase 6: Face-to-Face Discussion: In this phase, learners shared the questions generated by their pair on an online shared canvas, i.e. Padlet (DeWitt et al., 2015). The instructor projected the Padlet wall and discussed the questions and their answers. Time allocated for this phase was 10 minutes.

6.1.2.2 Study Design

The study design was a single group control study. Learners performed the activities described before (version 1.1, Figure 6.6).

6.1.2.3 Sample

We recruited 15 second-semester computer science engineering undergraduates from a Mumbai University engineering college. The implementation was done in two batches of seven and eight students in each batch respectively.

6.1.2.4 Data Collection and Analysis

Semi-structured focused group (Gill et al., 2008; Cohen et al., 2013) interview was conducted with both experimental and control group learners. The focus questions of the interview were:

- How was the session beneficial?
- How was the online pair and discussion phase beneficial?
- What was frustrating in the workshop, and how could it be improved?

The interview was qualitatively analyzed and we report the results from the analysis below.

6.1.2.5 Results

Following are the extracts from the focused group interviews:

- **Learners views on what they perceived about QP after the workshop:**
  - Learning "how to question" would help in understanding the concepts better.
  - *"We can think about a topic in different ways and therefore can learn more concepts at the same time."*
  - QP can bring learners out of passive learning.
- **Learners perceptions of what they learned from the session:**
  - Learned how to pose questions.
    * *"I learn how to pose different kinds of questions and how to improvise on QP."*

- Learners learn how to deeply look into any concept
  * Quote 1: *"It made us to explore more into the topics and making better questions of each things...."*
  * Quote 2: *"It made us to learn the thinking process... given a concept, how to deeply look into it...."*
  * Quote 3: *"Workshop helped in given any data, video, lecture, how to assimilate it and extract important things out of it."*
- Learners learn how to phrase questions properly and communicate them correctly to the teacher.

6.2 Reflection to Design

In this DBR cycle, we qualitatively analyzed how is the QP applicable to KI. The findings in Chapter 5 shows that posing exploratory question requires learners to integrate knowledge components. Through the inductive qualitative research we have identified three broad categories of exploratory QP. The categories demonstrate that while coming up with exploratory questions learners execute the processes associated with knowledge integration cognitively, i.e. learners elicit their prior known ideas, learners connect the new ideas with their prior ideas and they distinguish among the ideas.

In the two studies (3 and 4), we have adapted and administered the guided cooperative questioning King and Rosenshine (1993) with the EQP categories as the questioning prompts. These qualitative and quantitative studies have provided a proof of concept that making learners do QP based activities can affect their performance positively. Study 3 provided quantitative trend (although statistically not significant) that questioning, as a pedagogical idea, can affect KI. The qualitative feedbacks corroborated this trend. The feedback in Study 4, such as, "[intervention made them] to think in different ways," "...made us explore more..." etc., are desirable from the KI indicators (Linn and Eylon, 2011).

In addition to these proof of concepts, the observation and the interview data also provides specifications for further pedagogy refinement. The important feedback for the pedagogical design are as follows:

1. QP is a non-traditional task for the learners, and therefore daunting so it is needed that the learning environment should provide a primer about QP before making learners to

actually pose questions.

2. Learners do not necessarily use the prompts to generate questions. It was observed that the long list of questioning prompts could be counterproductive.
3. It would be desirable to make learners to understand the EQP strategies such that they can use them in their further EQP processes.
4. The discussion phase activity cannot be administered online without a collaboration script.

6.3 Summary

This chapter completes Cycle 1 of DBR. This DBR cycle contributed to the identification of EQP strategies, provided empirical proof of concept that QP is applicable for KI and generated the initial version (1.1) of pedagogical design of the IKnowIT-pedagogy. In the next DBR cycle, we do a careful evolution and evaluation of the features of IKnowIT. In the next four chapters, we report DBR Cycle 2. Chapter distribution for DBR Cycle 2 is outlined in Figure 6.7.

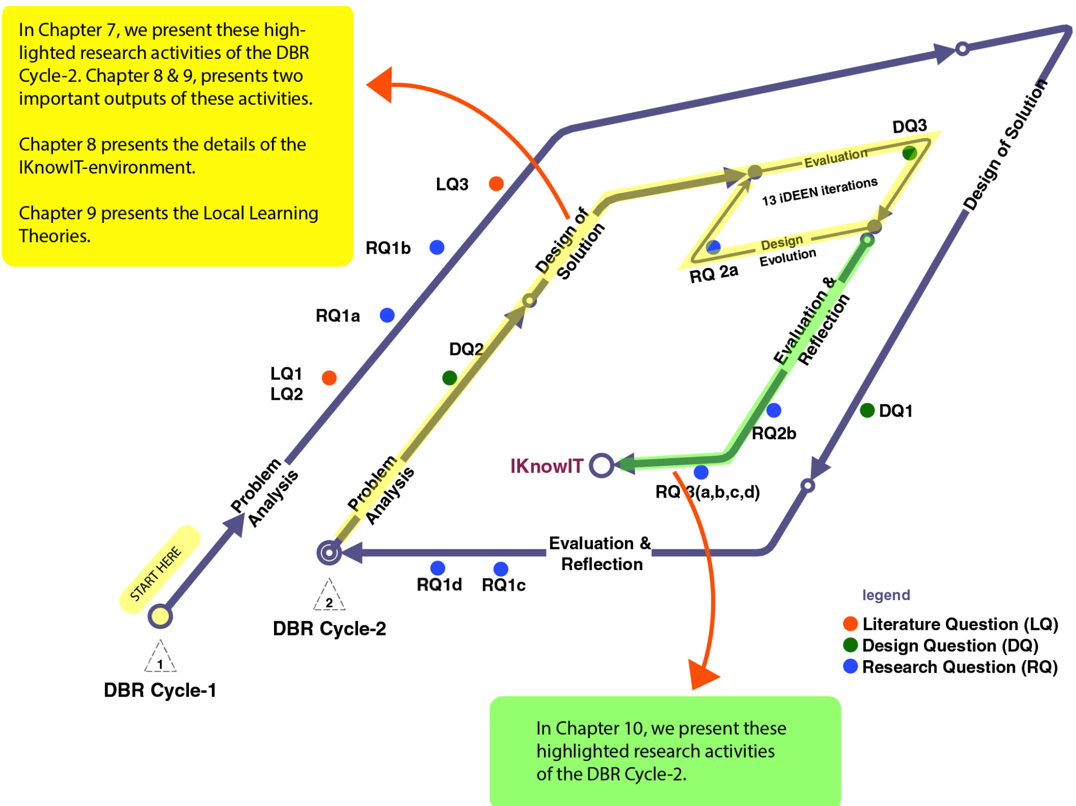


Figure 6.7: Thesis Organization – Locating Chapters 7, 8, 9, and 10 in the DBR Cycles

Chapter 7

Cycle 2: Solution Design and Evaluation Iterations

In this chapter, we present the first part of Cycle 2 of the design based research (DBR). This chapter includes the Problem Analysis phase, the Solution Design and the Evaluation phases of DBR Cycle 2. In the Problem Analysis, we use the findings from DBR Cycle 1 and the literature to further refine our research problem. In the Solution Design and Evaluation phases, we present the thirteen iterations of design evaluation and evolution, which lead to seven versions of the pedagogical design. The evaluation done in these thirteen iterations are the in-depth qualitative examinations of the role of each pedagogical design features present in the seven versions of the pedagogical design. It should be noted that in DBR Cycle 1, we did not implement the versions of the IKnowIT-pedagogy as any web-based learning environment. The development of the web-based IKnowIT-environment starts in DBR Cycle 2.

7.1 Problem Analysis

In this problem analysis phase of DBR Cycle 2, we analyze the reflections from DBR Cycle 1 and answer the following design question.

- **DQ2: What were the design problems in IKnowIT-pedagogy version 1, which should be addressed in the next version?**

The following design problems were identified based on the analysis of findings and reflections in DBR Cycle 1.

1. Learners do not necessarily use the exploratory question-posing (EQP) prompts to generate questions, as they are new to them.
2. Specific EQP prompts are too many and therefore daunting for the learner.
3. Design should ensure that learners understand the EQP strategies such that they can use them in their further EQP processes.
4. The discussion phase activity which was moderated by a moderator needs to be made completely online. Therefore there is a need for a collaboration script for online adaptation.
5. Question-Posing (QP)is a non-traditional task for the learners, and therefore daunting. The primer about QP should be such that it can sensitize learners with the importance of the QP activity.

These problems are addressed in the next version of IKnowIT-pedagogy (2.0), Figure 7.1, described in the section 7.2.1.

Overall, DBR Cycle 1 has shown that QP is applicable to the objective of fostering the cognitive processes of KI. More specifically, DBR Cycle 1 views EQP as a form of QP that engages the learners with the cognitive processes of KI, as EQP requires the learners to use their prior knowledge and given new knowledge, and makes them attempt to link these knowledge pieces and articulate the gaps, inconsistencies, and conflicts that they feel while linking in the form of questions. This brings us to our primary research question (RQ) that has been answered in DBR Cycle 2.

- **RQ2. How can training learners in an EQP-based learning environment (IKnowIT) enable them to foster the cognitive processes associated with KI?**

With the objective to address above synthesized problems and answer this research question, we progress to the subsequent phases of this DBR cycle.

7.2 Solution Design and Evaluation (Study 5) iDEEN: Iterative Design Evaluation and Evolution

The Solution Design and Evaluation phases of DBR Cycle 2 are intertwined, as we have operationalized them using interleaved iterations of evaluations and refinement of the IKnowIT pedagogical design. In this section, we present the **Study 5**, wherein we executed such evolution and refinement iterations. We refer to the method used in this study as **I**terative **D**esign **E**valuation and **E**volutio**n** (**iDEEN**), as it involves iterative evaluations and refinements of the designs. The method is described in the section 7.2.2. In this thesis, we also refer to Study 5 as the **"iDEEN Study"**. The iDEEN study is a qualitative study that focused on evolving the pedagogy and extracting the pedagogical design principles. The iDEEN study addressed the following design question (DQ) and research question (RQ):

1. **DQ3:** What should be the design features of the next versions of IKnowIT-pedagogy to make it capable of fostering the cognitive processes of KI in learners?
2. **RQ2a:** What are the effects of each of the pedagogical features of IKnowIT learning environment on learners learning process?

These design and research questions together would help in answering the second research question(**RQ2.**) of this thesis, i.e., "How can training learners on an EQP-based learning environment (IKnowIT) enable them to foster the cognitive processes associated with KI?"

The first iteration of the design evolution process starts with an initial pedagogy, designed using the learnings from DBR Cycle 1. Each iteration involves qualitative evaluation of pedagogical design followed by the upgradation of the design, informed by the findings in the evaluation. Therefore, the design and evaluation phases of DBR Cycle 2 are interleaved and reported together.

We start reporting Study 5 by reporting the details of the updated pedagogical design (IKnowIT-pedagogy version 2.0), which will be used as the "initial design" for the iterative design evolution process.

7.2.1 IKnowIT-pedagogy Version 2.0 (Initial Pedagogical Design)

Although our pedagogical design is based on the 'Guided cooperative questioning' (GCQ) pedagogy, there is a difference between the objective of GCQ with that of our objective. GCQ aims at improving the learning within a topic, while we aim at fostering the cognitive processes of KI as transferable skills across topics. In line with this distinction, GCQ pedagogy explicitly involved the use of QP prompts during the QP session, whereas, we wanted our learners to be able to use these prompts even after the QP-session. Therefore we focused more on making the learners learn these EQP prompts (strategies), with a conjecture that they would be able to use them when they pose questions next time after coming out of the training session.

Since both EQP prompts and QP activity are new as well as tedious for learners, in the IKnowIT-pedagogy version 1.1 we attempted to make the learners practice first with the EQP prompts (strategies) and then perform a collaborative EQP activity. Moreover, our focus is more on making the learners use the EQP activity, even outside the training session (as a skill) so it was important to ascertain that the learners learn the EQP strategies. We, accordingly updated the IKnowIT-pedagogy version 1.1 to version 2.0. The updated pedagogical design (version 2.0) is shown in Figure 7.1.

Figure 7.1: IKnowIT-pedagogy Version 2.0. Initial Learning Design for the iDEEN Study

The only differences between version 1.1 and version 2.0 were as follows:

- To keep most of the design features on-line, Face-to-face discussions were removed.
- Instead of using the long list of seven specific EQP strategies, only three broad EQP strategies ('Apply,' 'Operate,' and 'Associate'), were used.
- To ensure that learners engage more with the questioning prompts (strategies), the question reviewing activity was broken into two activities, which were:

- **Categorization**, which ensures learner's cognitive engagement with the questioning strategies of the analysis level (Conklin, 2005). In the categorization activity a learner is required to categorize (tag) their questions with correct category of the EQP strategy.
- **Critiquing**, which ensures cognitive engagement of evaluating level (Conklin, 2005) with the questioning strategies. In the Critiquing activity, a learner is asked to evaluate the questions-categorization pairs generated by their online-partner and Critique their correctness.

7.2.2 iDEEN Study: Design and Implementation

The research method followed in this iterative evaluation and evolution is primarily based on grounded theory (GT) research (Charmaz, 2014) and educational design research (EDR) (Plomp and Nieveen, 2010) methodologies. In a GT based investigation, the data-collection and analysis processes are interleaved. In every iteration of data collection, researcher refines, scopes, or extends their focus of investigations. This adaptation of the GT was aimed at refining the pedagogical design of IKnowIT by iteratively extracting the mechanisms of how the pedagogy and the constituent pedagogical features support or hinder learning. These theoretical yields about how learner's interactions with the learning environment lead to learning are often referred as 'design principles,' or 'local instructional theories' in EDR (Van den Akker, 1999; Reeves, 2006; Wademan, 2005). This adaptation of the GT research methodology was done in accordance with the principles and the objectives from EDR (Plomp and Nieveen, 2010), viz.: The research aims at designing an intervention in the real world settings; It involves iterations of design, development, evaluation, and refinement; The focus of iterations is to understand the learning processes and then to inform the design refinements; It is, utility oriented, i.e., merit and usefulness of any design feature for the learners is measured in real world context; each design evaluation and evolution iteration contribute to theory; The process requires working together with the real users in the real settings.

It should be noted that the distinction between a pure GT methodology and iDEEN method is that the former aims at extracting theories, mechanisms or stories about an educational issue; while the later is specifically focused on extracting design recommendations, and theories, mechanisms or stories about how the pedagogical design features lead to the attainment of learning objectives. We believe the specific steps that we followed would be useful for other similar research related to design and development of technology-enhanced learning environments (TELE). Hence in this thesis we encapsulated them into a new method that we call iterative design evaluation and evolution (iDEEN) method. Following were the set of steps executed in this iDEEN study (Study 5), also represented in Figure 7.2.

1. Learner interacted with the learning environment and performed all activities as prescribed in it.
2. The researcher interviewed the learner(s): Interviews were done in between (sometimes) and after the completion of the interactions. In addition to the interview data, researcher's observation notes were also maintained.
3. The interviews were transcribed and analyzed to extract and/or refine the local theories that explain the mechanisms of the effects of different pedagogical features.
4. The pedagogical features were tweaked, retained or dropped from IKnowIT as informed by the results of the analysis.
5. The learning environment was updated to incorporate the updates in the pedagogical design. This created an updated context for the next iteration of iDEEN data collection such that steps 1 onward can be repeated.
6. Steps 1 through 5 were iterated again and again until we got saturations about the mechanisms underlying the effects of different features of pedagogical design, all the necessary features are either updated, retained, or included in the learning design, and all unproductive or counterproductive features were dropped from the learning design.

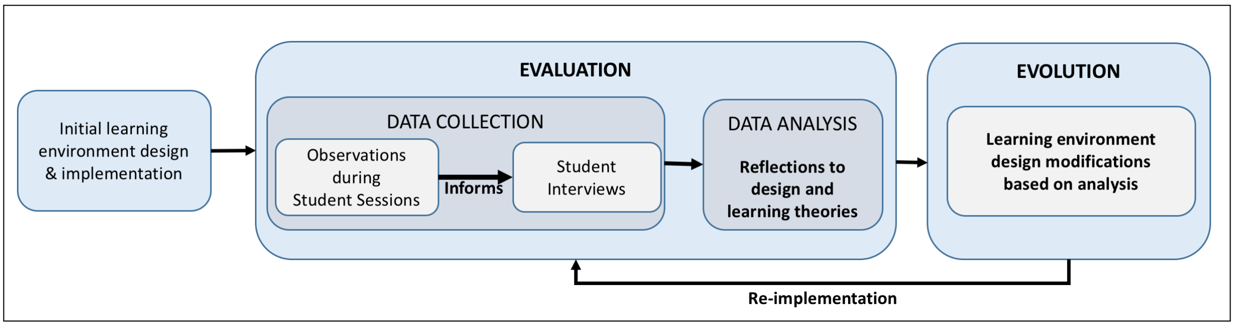


Figure 7.2: iDEEN: Iterative Design Evaluation and Evolution.

Steps 1, 2 & 3 together form the "*evaluation*" part of the iDEEN method and steps 4 & 5 form the "*evolution*" part. The evaluation and evolution iterations continued as described in step 5. The data collection and analysis processes are discussed further in the subsequent subsections.

Every iDEEN iteration made the learner perform activities as per the IKnowIT-environment. In each full session of an iDEEN iteration, learners were made to perform QP activities twice - one at the beginning stage of the IKnowIT-pedagogy, and another after all prescribed phases were executed. Each QP activity required the learners to watch a given lecture-videos on a Data Structures topic and pose questions around them. The list of the topics and the iDEEN iterations is given in Table 7.1. The first QP activity is the initial part of the pedagogy, as shown in Figure 7.1, whereas second QP activity, in the initial few iterations of iDEEN was administered as a post-test activity. However, in later iDEEN iterations, the second QP activity became a part of the pedagogy itself. Total 13 iterations of iDEEN were administered with maximum 2 learners interviewed per iteration.

7.2.3 iDEEN Study: Sample

Recruitment was done through a presentation in undergraduate Computer Science classes. Students were asked to volunteer for a workshop by the host University. The host University has a high reputation (Hewner and Mishra, 2016) in the region and learners have high regards for such workshops. The presentation was followed by a survey that determined if a learner has formally done a course on "Introduction to Programming" and have not yet completed a formal course on "Data Structures." There were 23 CS engineering undergraduates, who had recently completed the first year at the university satisfied the criteria and volunteered. Out of the total 23 learners, 15 were males, and 7 were females. None of these learners had attended any course on Data Structures before. The list of learner counts and gender distribution per iterations is given in Table 7.1.

Table 7.1: List of iDEEN Iterations, Sample and Interviews

Iterations (IT)	**Participant Counts**	**Gender(s) M:Male, F:Female**	**Video Lecture Context (Video 1, Video 2)**	**Interview Counts**
IT1	1	M	Linked list, Tree	2
IT2	2	FM	Linked list, Tree	2

Continued on next page

Table 7.1 – *Continued from previous page*

Iterations (IT)	Participant Counts	Gender(s) M:Male, F:Female	Video Lecture Context (Video 1, Video 2)	Interview Counts
IT3	2	MM	Linked list, Graph	2
IT4	2	FM	Linked list, Graph	1
IT5	2	MM	Tree, Graph	2
IT6	2	FM	Tree, Graph	2
IT7	2	FM	Tree, Graph	2
IT8	2	FM	Tree, Graph	2
IT9	2	FM	Tree, Graph	2
IT10	1	MM	Tree, Graph	2
IT11	2	M	Tree, Graph	2
IT12	2	FF	Tree, Graph	2
IT13	1	M	Tree, Graph	2

7.2.4 iDEEN Study: Data Collection

There were three types of data collected in this study: (i) Researcher's Observation Log; (ii) Interviews; and (iii) the questions generated by the learners during the session. They are discussed in the subsequent paragraphs.

7.2.4.1 Interview Data

Interviews were semi-structured (Cohen et al., 2013; Cohen and Crabtree, 2006) and primarily exploratory. The broad objective for the interviewer was to probe the learners about how one or many learning design feature(s) lead to the accomplishment of IKnowIT learning objectives. In all of the iDEEN iterations, we administered two interviews, except IT4 (see Table 7.1), where we conducted one. The first interview was administered once the learner completed all the activities of the IKnowIT-pedagogy once, while the second interview was administered at the end of the whole session. Table 7.1 shows the list of iDEEN iterations, interview, and samples.

Having the sample size of two learners, not only helped in extracting a broader range of information but also offered additional opportunity to seek clarifications by making the learners confront when needed. For example,, there were several instances when one learner was able to reflect on her/his thought processes only after getting triggered by the response given by the other learner. These benefits are similar to the benefits of the focus group interviews (Morgan, 1996). Moreover, having the sample size of two also didn't compromise with the advantages of the individual interviews, such as the ease of steering and control, the possibility of avoiding the peer pressure to give similar answers to the interviewer's questions, exploring into more depth (Morgan, 1996). All of the questions were directed to both the learners one by one, and the interviewer encouraged the learners to observe each other's response to see if they had anything to add or contest, according to their personal experiences in the IKnowIT session. However, in the cases of IT1, IT10 and IT13, there were only one learner in each iterations and hence he/she was interviewed alone.

Interview Method: At a broad level, the goals of the learner interviews were:

1. To determine if a pedagogical feature needs to be tweaked, dropped or added, and why.
2. To determine the role of each pedagogical feature.
3. To figure out how does each phase of the IKnowIT-pedagogy affects learners' improvement of cognitive processes of KI.

Interviews generally took between thirty five to sixty minutes. Initially, the interviews followed the protocol given in the interview guideline shown in Appendix II. Moreover, the researcher's observation notes also informed the interview questions. For example, when one learner took significantly more or less time for any pedagogical task, it was logged, and the interviewer asked both learners about reasons of why did one take more or less time for the same task than the other. In the start, the interviews appeared to be more like a question and answer format similar to those given in the guideline. With further experience, the interviews tended to flow more smoothly, for example, by going back and forth between the questions, or by making the two learners to comment on each others' responses, or by connecting the responses of the two questions and asking the learner to reflect on them, or by providing conditions like, "what if a feature is removed?" to elicit deeper responses, etc.

The interviewing process was challenging, as sometimes the learners outrightly and strongly give binary responses or provide very broad answers. For example, for the question, *"What was the role of the 'Categorization' activity,"* a learner replied *"no, there was no apparent role, I can't see any,"* then the interviewer insisted the learner to think more, and waited for the response. If this strategy was not fruitful, only then the interviewer used more directed questions, For example: *"What was the benefit of the categorization activity?"* When the learner could not respond anything, even after that, only then did the interviewer provide a more specific direction by saying, "*Did it help you in knowing the categories better, [if yes] how?*" This was followed by discussing the used specific direction and then in the end by again asking, *"if there were any other specific benefits of that activity?"* It was always desirable that the response comes naturally and we don't direct (or prime) the learner towards any direction of response. When the interviewer was completely sure that the learner would not be able to elicit on her/his own further, only then was s/he given a slight hint, i.e., direction. In any case, the interviewer did not use his prior conceptions to lead the conversation. It was more like, first, make as much attempt as possible to elicit everything from the learner without giving any hint, and scaffold the learner with slightly specific direction if and only if the learner is not at all able to elicit beyond a given point.

In the cases of two learners, the interviewer ensured that both get enough personal time to elicit their honest responses without getting biased because of each others' responses. Moreover, the interviewer would often ask the learners to substantiate their responses with instances from their experiences in the IKnowIT session. This allowed the interviewer to extract more concrete stories.

To scaffold learners in reflecting on their learning processes in more depth, the interviewer would often ask the learner to walk-through the processes that s/he followed during a pedagogical activity (by retrospectively thinking aloud). Moreover, to support the recall of the learning experience, often the interviewer would show the artifacts which a learner had generated during the pedagogical activities, and the corresponding user interface in the learning environment. To help to elicit the effects of the overall IKnowIT session, the interviewer would even ask the learner to comment on, *"how did they see themselves different than their classmates who did not do the IKnowIT session."*

In the first few iterations of iDEEN, we focused on high-level constructs like questions, deep conceptual understanding, KI, benefits and disadvantages of different pedagogical features, etc. As we progressed with different iterations, we evolved our focus towards deeper constructs such as "benefits of EQP prompts," "role of Video length," "relation between QP and deep learning or KI," "exploring the concepts," etc.

Overall, it was found that allowing learners to tell their own stories about their experiences about the IKnowIT session could allow the interviewer to elicit a good understanding of their learning processes and the effects of the pedagogical features. An illustrative interview questionnaire is shown in Appendix III.

7.2.4.2 Researcher's Observation

All implementations of IKnowIT were controlled by the researcher as the moderator. The role of the moderator was primarily to observe and maintain logs of following.

1. Keep a log of time, when a learner starts any pedagogical phase and when s/he ends.
2. Technological errors that learners face and report in any version of the IKnowIT-environment implementation. For example, e.g. "Problem in loading peers' questions (in the Critiquing activity)," or, network errors, etc.
3. Issues in user interface (UI) that the learner faced. For example, if any learner cannot comprehend and follow the instructions in an activity of IKnowIT.
4. The support or help that was given to learners to address the technological or UI issues.
5. If a learner is doing on-task or off-task activities (Kothiyal et al., 2013), at any point in the IKnowIT session.
6. Queries/demands that a learner made to the moderator about the learning environment, in addition to technology features and other operational issues, such as the language used in the learning environment.
7. The environmental factors, if any, that can act as confounding variables in our research.

7.2.4.3 Questions Generated by the Learners in the QP Activities

There were two QP activities during which learners were required to pose questions. As mentioned before, the first QP activity was part of the initial pedagogy, whereas the second QP activity, in the initial few iterations of iDEEN was administered as a post-test activity. Initially, the objective of having two QP activities (post-test) was to compare the qualities of the questions posed in the first QP activity (administered in the start of the IKnowIT session) with the qualities of the questions generated after the IKnowIT session. This had provided a post vs. pre effect evaluation of the effects of the IKnowIT sessions.

7.2.5 iDEEN Study: Analysis

The goals of the iDEEN study were: (i) to refine or evolve the pedagogical design, and (ii) to extract the local learning theories (LLTs), that explain the mechanisms of how the learner's interaction with various features of the pedagogy lead to learning. After every iteration of data collection, the audio recordings of the interviews were transcribed. The interview transcription, along with the researcher's observation logs were then qualitatively analyzed. At the end of the analysis we deduce decisions about what modifications should be done in the pedagogy or the learning environment before the next iDEEN iterations, and which decisions should be kept for further examinations in the follow-up iDEEN iterations. As far as LLTs are concerned, the analysis of the interview transcripts leads to either revision of the previously extracted LLTs and/or addition of new theories to the set of LLTs. In this subsection, we would describe the theoretical lens used while we analyzed the transcripts. Then we would illustrate the analysis process in detail by explaining the different levels of qualitative codings.

7.2.5.1 Theoretical Lens

While analyzing the interviews for understanding and extracting LLTs, we used theoretical lenses of EQP (Mishra and Iyer, 2015b) and KI framework (Linn and Eylon, 2011). By EQP theoretical lens, we refer to the findings of DBR Cycle 1; i.e., when learners pose exploratory questions they use their prior knowledge and new knowledge, try to link different ideas in different patterns (as reflected by the three EQP strategies), and articulate the conflicts, gaps, and/or inconsistencies in the form of questions. By "using EQP as a theoretical lens," we mean that while analyzing the data we primarily looked at it from the perspective of these characteristics of EQP. We tried to understand the roles and processes induced via the 'QP' and other pedagogical activities in light of these characteristics. On the other hand, the KI framework provides us the characteristic cognitive processes of knowledge integration. Therefore the KI framework, as a theoretical lens made us look at the data to continuously keep an eye on whether the learning processes are leading to triggering or fostering of the cognitive processes of KI. Overall, the 'EQP' theoretical lens helped us in gazing the process of learning, and the "KI framework," as a theoretical lens helped us in keeping track if (and how) the processes are leading to our research objective.

7.2.5.2 Analysis Process

The learning theories and design decisions were induced by a systematic line-by-line analysis of interview transcripts. The presence of the researcher's observation logs during the analysis helped the researcher develop a better understanding of the context and operational conditions. The analysis process was based on the approach outlined by Charmaz (2014) which has three steps. In the first step, the researcher develops the 'initial codes' from the unit of analysis of data (line or a group of lines). These initial codes describe what is being expressed in each unit of analysis. In the second step, the researcher selects focused codes, by synthesizing collected initial codes that explain larger segments of the data. In the final step, categories are abstracted from the focus codes which are used to build the tentative theory. The explanatory power of this theory is tested with segments from other parts of the data. There are several techniques to help the researcher attempt to develop the categories in this larger theory: axial coding (Corbin et al., 2008), theoretical coding (Charmaz, 2014), and situational maps (Clarke, 2005). An illustrative example of a situational map created and used during the analysis is shown in Appendix VI. The iDEEN process involves iteration of the above steps until saturation is reached. The researcher can claim saturation when new interviews do not significantly elaborate the existing theories (LLTs) and do not generate new design decisions.

Illustrative Example: Following is an excerpt from the interview which illustrates the above discussed coding processes.

> "***Learner2:*** *...I am from IT background, so my question would be about application [an EQP strategy]...' I would be more interested so that I can use it...' '...different background would lead to different point of view...*
> ***Learner1:*** *If prior knowledge is different then conflict would also be accordingly different. If my prior knowledge is shallow then I would perhaps not rely on the new one [knowledge]. If my prior knowledge is deep then I would get conflict more.*
> ***Interviewer:*** *So do you think that people always associate with prior knowledge?*
> ***Both learners:*** *yes sir*"

In the initial pass this interview excerpt was coded as "quality of prior knowledge determines the quality of questions." In later analysis it was incorporated into a larger focused code of "Role of learner's prior knowledge (PK) and given new knowledge (NK)." After a few iterations, a second pass was done and codes were reorganized. We recognized commonalities between this quote and other QP factors. All these ideas became part of the larger category, i.e. "Factors leading to question quality," which is a key part of our LLT related to QP in IKnowIT.

Note that in a typical grounded theory research, in every iteration, the interview questions and the research focus are informed by the analysis of the data collected in the previous iterations. In this iDEEN, the focus of investigation in each iteration of data collection (interview) does not get modified only due to updating the interview questions, but it may also get updated due to the modification in the design itself. Each design updates may contribute to the updating of the data collection context in the next iteration. This is the other reason why we call this research design as *"Iterative Design Evaluation and Evolution"* method. The magnitudes of the design modifications were either very small or, if they were big, then the researcher made sure that the results from the data analysis soundly informed the modification.

7.2.5.3 Checks to Ensure Validity

A common risk that can happen in qualitative research, despite best intentions, is misinterpretation and bias. This is because of the difference in backgrounds and assumptions between participants and researchers. To address this (Lincoln and Guba, 1985), the coding and analysis were reviewed by two researchers and other possible interpretations were considered. Often this included returning to the original data and re-coding until both researchers were in agreement.

7.2.6 iDEEN Study: Results

iDEEN Study has produced three types of outcomes. First of which is the pedagogical design (IKnowIT-pedagogy), second is the learning environment (IKnowIT-environment), and the third one is the set of local learning theories. In this chapter, we report the pedagogical design related results of the iDEEN study. Other results are reported in the next two chapters.

It took us total 13 iterations of iDEEN to achieve a desirable saturations about the mechanisms underlying the effects of different features of pedagogical designs, and when the design features were no longer needed to be refined further. We also discuss crucial observations, decisions and interview findings from each of the iterations (IT1 through IT13) which lead to major evolutions in the pedagogical design. Table 7.2 shows the list and descriptions of the various learning design features present in any iDEEN iteration. Figure 7.3 shows the different iterations of the iDEEN. IT1 through IT13 are the different data collection contexts in the thirteen iterations; in other words, they correspond to different sub-versions of the pedagogical design for IKnowIT.

Table 7.2: Pedagogical Design Features Explored and Evaluated in the iDEEN study

Pedagogical Design Features
Minimal EQP Instruction Learner reads a primer instruction about QP, clarification questions, exploratory questions and their importance.
Question-Posing (with Video Lecture 1) In few initial iterations of iDEEN, learners watched video on “Introduction to Linked list,” while in later iteration “Introduction to Trees” was used as the video lecture. The videos were almost 15 minutes long, and learners get a total 45 minutes to watch the video and pose questions about the videos.
Detailed EQP Instruction Learners read detailed content about EQP including three broad strategies of EQP. The details of these three broad strategies (‘Apply,’ ‘Associate,” and ‘Operate’) are treated as the generic questioning prompts for Data Structures. Further lower levels of EQP strategies (‘Apply,’ ‘Arrange,’ ‘Probe,’ ‘Compare,’ ‘Connect,’ ‘Vary’ and ‘Implement’) are not detailed and not used in the design since in DBR Cycle 1, it was found that a long list of questioning prompts become daunting for the learners to comprehend and then use, when given for the first time.
Question Categorization The system provides the list of the questions posed by the learner and s/he is required to tag each of her/his question with the questioning strategies (‘Apply,’ ‘Associate,’ ‘Operate,’ ‘Other’ and ‘Clarify’)
Question Critiquing (critiquing partner’s questions) The system provides the list of questions posed and categorized by another learner and s/he is required to evaluate if the questions and the tagged category(ies) are correct or not. If the learner finds any inconsistency after evaluating, s/he is required to comment with her/his feedback.
Online discuss over text-chat

Continued on next page

Table 7.2 – *Continued from previous page*

The learner is paired with an online partner, the one whose questions and categorizations were evaluated and critiqued by the learner in the previous activity. Both the learners are asked to chat and discuss with an objective to confront and resolve their differences about the questions.
Reflections activities Learners are required to answer several Likert scale questions and several multiple choice questions to reflect upon the processes and their importance which they learned from the previous activities.
Video Lecture 2 Learners are required to watch a video on another topic and pose questions. With ‘Linked list’ being the topic in video lecture 1, ‘Introduction to Trees’ was the topic in video lecture 2; and with ‘Tree’ being the topic in video lecture 1, ‘Introduction to Graphs’ was the topic in video lecture 2.

7.2.6.1 Design Evolutions in each Iterations

Figure 7.3 shows the thirteen iterations of iDEEN. The green color denotes the features which were retained till the final version of IKnowIT-pedagogy. The check marks denote that a pedagogical feature is included in an iDEEN iteration, whereas the cross marks denote otherwise. The hyphen marks (‘--’) denote that a feature has not been included till a given iDEEN iteration. It can be seen that from 9th iteration (IT9) onwards, there were no or minor changes in the pedagogical design. We would discuss the evolution of the IKnowIT-pedagogy across each iteration of the iDEEN study one by one.

First Iteration (IT1): The first iteration (IT1) was administered with a single learner. IKnowIT-pedagogy (version 2.0) was used as the learning design. Because of the absence of any other partner, the ‘Online pair-discuss’ activity was not performed; and in the ‘Critiquing’ activity learner was given the questions generated and categorized by another learner from a past study, which were already there in the database. Major design change informed from the analysis of the interviews was to club ‘Video watching’ and ‘QP’ as a single activity.

In IT1, the learner was interviewed twice, one after the Critiquing activity and then at the end. In the end, the learner reported that the first interview itself was very important. It made

Pedagogical Design Features	**IT1**	**IT2**	**IT3**	**IT4**	**IT5**	**IT6**	**IT7**	**IT8**	**IT9**	**IT10**	**IT11**	**IT12**	**IT13**
Participant Count	1	2	2	2	2	2	2	2	2	2	1	2	1
Minimal EQP Instructions – Reading (Post watching Video)	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Minimal EQP Instructions – Reading (Before watching Video)	--	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Video Lecture & QP (Separate)	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Video Lecture & QP (Merged)	--	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Detailed EQP Instructions – Reading (EQP strategies in data structures	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Categorize own questions (Using set of EQP strategies in data structures)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Criticize online-partner's questions (and categories	✓#	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓#	✓#	✓#
Discuss over text chat	--	✓	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗	✗
Strategy classification	--	--	--	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗
Reflection Task – Guided Socratic Reflection (Face to face)	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Reflection Task – Using Reflection Questions (Integrated to the environment)	--	--	--	✓^	✓^	✓^	✓^	✓	✓	✓	✓	✓	✓
Video 2 (as a posttest)	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Video 2 & QP (as a part of pedagogy)	--	--	--	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Categorize & Criticize for Video 2 Questions	--	--	--	--	✓	✓	✓	✓	✓	✓	✓	✓	✓
Reflection Task 2 (Same questions with slight variation the format)	--	--	--	--	--	--	--	--	✓	✓	✓	✓	✓
IKnowIT-pedagogy Version 2.x	v2.0	v2.1	v2.1	v2.2	v2.3	v2.4	v2.3	v2.5	v2.6	v2.6	v2.6	v2.6	v2.6

✗ : Feature NOT included in an iDEEN iteration
✓ : Feature included in an iDEEN iteration
-- : Feature NOT conceived till an iDEEN iteration
Green Blocks: Feature retained till the end of grounded theory
#: Criticize online partner's question (Canned Partner - Questions were take from previous studies)
*: KI Strategy classification – Visual
^: Google form–based implementation of the Reflection Task

Figure 7.3: Sub-versions of IKnowIT Learning Design Evolved in Different Iterations of iDEEN (IT1 - IT13)

him understand and reflect the whole process, what he did, and the importance of the process. That is why in Figure 7.3 the first interview is being referred to as 'Guided Socratic Reflection.'

Second Iteration (IT2): Before the next iteration (IT2), QP was clubbed with the video watching activity. This also led to changing the order of the "minimal QP instruction" to the start of the pedagogy, because "minimal QP instruction" is supposed to give a primer information about QP, clarification questions, exploratory questions and their importance. In IT2, since there were 2 learners, therefore, we included the "Online Discussion" activity. But this activity was discouraging. It was observed that when one learner was typing his/her chat, the other learner was busy with off-task activities such as fiddling with his mobile phone. Moreover, this was turning out to be time-consuming and counterproductive and was aborted after 5 minutes of chat. Similar observations were made when we attempted the chat activity again in other three iterations (IT3, IT6, and IT9). In this iteration too, the learners reported the benefits of "face-to-face guided reflection."

Third Iteration (IT3): IT3 was similar to IT2, and it corroborated findings of IT2. In this iteration also, the chat activity was not successful. It was observed that one learner was less participating which lead to further disengagement. Learners took 8 minutes to discuss one question, and it was very difficult for the moderator to control and script the discussion. The chat activity was not included in the next two iterations. Similar to last two iterations (IT1 and IT2), in IT3 also learners reported benefits of "face-to-face guided reflection." This compelled us to create and include a Google form based reflection quizzes for the next iteration. From the IT3 interviews, it was also found that the post-test activity of QP with a new video, gave the learner an improved experience of QP and video watching. This made us include this QP activity as a part of the pedagogy, instead of just using it as a post-test. This change was adopted for the next iteration.

Fourth Iteration (IT4): As per the recommendations from the previous interview analysis, for IT4 we included a repetition of the "video lecture and QP" as a part of IKnowIT pedagogical design. The analysis of the interviews from previous and the current iteration (IT4), it was also found that in addition to the repetition of the activity of "video lecture and QP," learners are also of the view that repeating the "Categorize" and "Critiquing" activities 'may' be more helpful for them. Therefore, in IT5 we included the repetition of "Categorize" and "Critiquing" activities also. Learners reported positive effects of these repetitions across all the future IT iterations.

Fifth to Eighth Iterations (IT5 - IT8): From IT5 to IT8 similar learning design was used. The major difference in the design in IT8 was that the reflection activity was embedded in the IKnowIT environment itself, and feedbacks were added to the reflection questions. In IT6 and IT8, we again attempted the chatting activity which again came out to be discouraging.

Ninth and Tenth Iterations (IT9 - IT10): In IT9 and onwards we included the repetition of the reflection activity also. Therefore, by this iteration set of activities were: (1) Minimal EQP Instruction, (2) Video lecture 1 and QP, (3) Detailed EQP Instruction, (4) Categorize, (5) Critiquing, (6) Reflect, (7-onward) Video 2 and repeat of QP, categorize and reflect activities.

Eleventh to Thirteenth Iterations (IT11 - IT13): The only variation in the version of IKnowIT-pedagogy used from IT11 onward was in the Critiquing phase, where, instead of using questions generated by a synchronously connected online peer, system used questions generated by some other learner from some previous IKnowIT session. This means that, these three iterations have examined if IKnowIT can use a "dummy-partner," with "canned-questions," instead of real online partner generating question synchronously.

Overall, these three iterations further established the saturation of design changes. In the next section, we see the final version of the IKnowIT pedagogical design.

7.2.6.2 IKnowIT-pedagogy Final Version

We see that by the end of the thirteen iDEEN iterations we have reached saturation of pedagogical design changes. The major design changes, as compared to DBR Cycle 1, that iDEEN implementation has led to are as follows:

- The QP-activity has been pushed before the introduction of the EQP prompts; i.e., the first QP-activity happens without any question-prompts.
- Watching of the lecture-video and QP-activities have been merged.
- Reflection activities have been added at the end of all activities.
- One repetition of all IKnowIT phases is found to be benefiting and necessary.
- The collaboration activities, such as discussion (face to face and online) and collaborative QP have been dropped.

Figure 7.4 shows the final version of the pedagogical design. This is the final design output of the 13 iDEEN iterations. The details of the implementation are presented in Chapter 8. The final version of the IKnowIT-pedagogy, as already described in Chapter 4, contains six phases of different pedagogical activities. These include: (i) Minimal EQP Instruction; (ii) QP; (iii) Detailed EQP Instruction; (iv) Question Categorization; (v) Question Critiquing; and (vi) Reflection. In addition to these six phases, the IKnowIT-pedagogy also recommends that the learner should undergo at least two runs of the IKnowIT pedagogical activities.

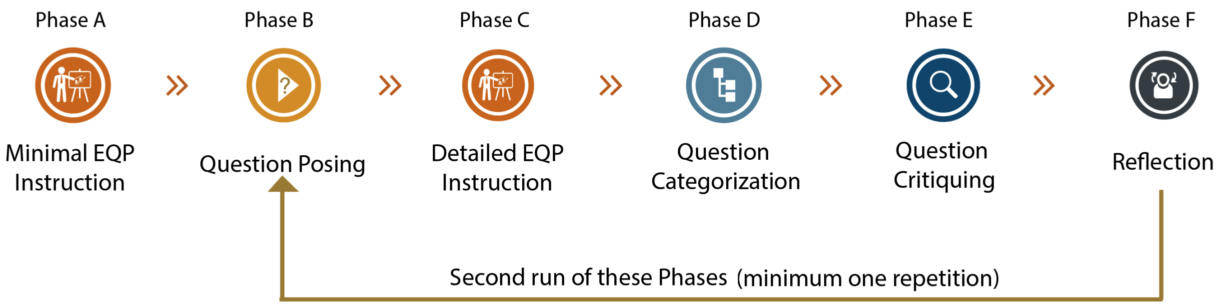


Figure 7.4: Inquiry-based Knowledge Integration Training (IKnowIT) - Pedagogy

7.3 Summary

In this chapter, we presented the problem analysis, and the intertwined solution design and evaluation phases of DBR Cycle 2. We presented the iterative design evaluation and evolution method, iDEEN, and have shown how the thirteen iterations of iDEEN led to the final version of the IKnowIT-pedagogy. The iDEEN results have three aspects, first is concerning the pedagogical design, second is related to the learning environment, and the third is the underlying local learning theories which explain how the learner's interaction with different elements of the pedagogical design lead to the learning objective of the design. This chapter presented only the pedagogical design aspect. Details of the learning environment are presented in Chapter 8, while the local learning theory aspect is presented in Chapter 9.

It should be noted that out of the three types of data collected in Study 5 (iDEEN Study), we used only interview and the observation data in the iDEEN analysis. The third data type, i.e., the questions generated by the learners are used to further examine the change in learners' KI skill. The analysis of this data and the corresponding results are presented in Chapter 10.

Chapter 8

Cycle 2: Final Learning Environment

In the previous chapter, we saw the first outcome of the iDEEN study in the form of IKnowIT pedagogy. In this chapter we present the operationalization of the IKnowIT-pedagogy as a web-based self-learning environment (IKnowIT-environment), which is the second outcome of the iDEEN study process.

8.1 IKnowIT User Interface

Each of the six phases of the IKnowIT pedagogy has been implemented and integrated into the form of a web-based learning application. In this section, we describe each phase of the IKnowIT-pedagogy, with its primary role, as derived from the iDEEN study. We also describe the corresponding user-interface operationalization of each phase.

8.1.1 Phase A: Minimal EQP Instruction

Role: The objective of the "Minimal EQP Instruction" phase was to give the learner an introduction about the IKnowIT session, and a primer on question-posing (QP) such that s/he can attempt to pose exploratory questions in the next phase (QP) of the IKnowIT-pedagogy. The data in iDEEN study has shown that the learners got primed with the two broad QP types (clarification and exploratory) which initiated them to pose questions and reflect on the nature of the questions which were coming to them while watching the video in the QP phase.

Operationalization

The contents of the "Minimal EQP Instruction" are delivered using a Learning Dialogue (LeD) which is built using text and image based learning contents, interleaved with reflection-quizzes. The reflection quizzes enable a dialogue between the learning environment and the learner and help in breaking the monotony. Figure 8.1 presents the screenshot of one page-slide of the LeD. We can see that the page slide contains a multiple choice question. The LeD is composed of many such questions embedded with the reading content, to make sure that the learner's reading task doesn't become monotonous.

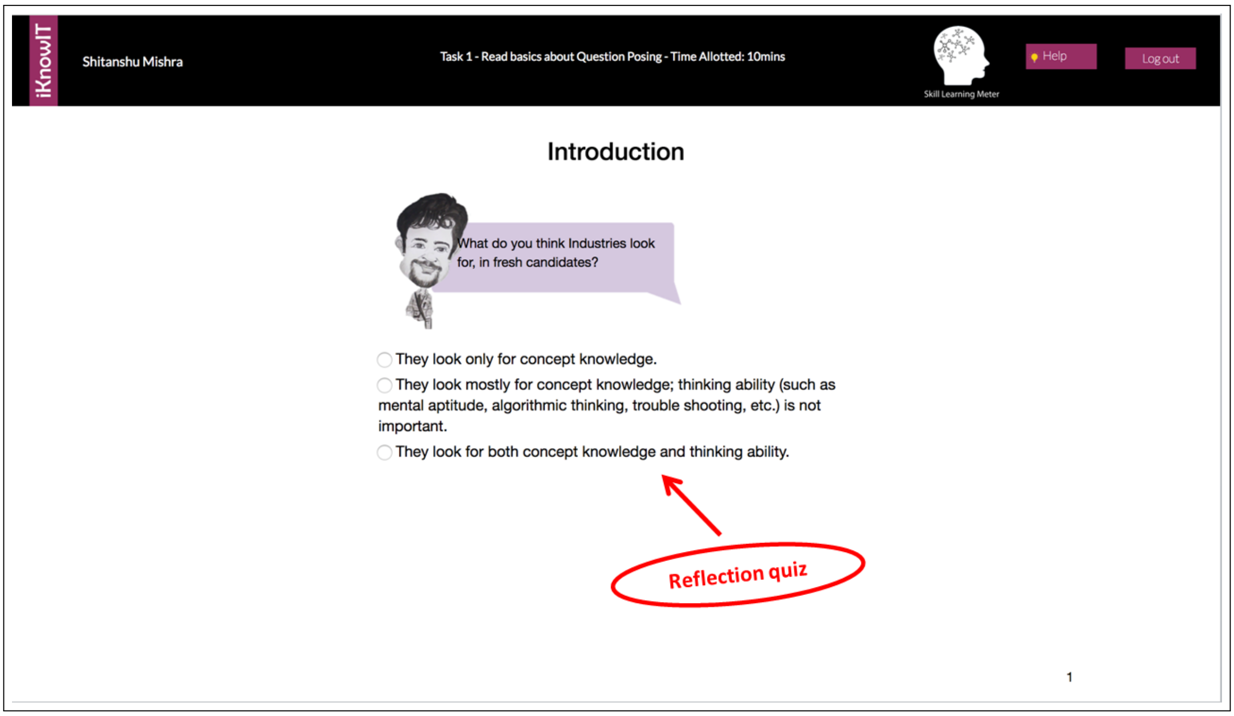


Figure 8.1: IKnowIT Phase A: Minimal QP Instruction (Learning Dialogue 1)

8.1.2 Phase B: Question-Posing

Role: The objective of the QP phase was to generate learning artifacts (questions) and give them an experience of how they naturally pose questions. The data in iDEEN study has shown that the video successfully provided semi-structured QP situation, wherein the learners got context around which they generated and submitted questions. These questions were used by the learners to perform subsequent phases of the IKnowIT-pedagogy.

Operationalization

QP phase requires a QP environment (Figure 8.2) which requires two essential pedagogical features: (1) QP situation (Stoyanova and Ellerton, 1996) and (2) Question authoring tool. The QP situation is the learning content (text or multimedia) around which the learner is required to pose questions. In the case of IKnowIT-environment, we are using video lectures as the QP situations. A text box with a submit button is used to implement the question authoring tool. The question authoring tool and the QP situation are integrated such that the moment a learner clicks the authoring tool to type a question, the video pauses, and resumes only after the learner submits a question or clicks out of the authoring tool. In addition to the QP situation and authoring tool, the QP environment also contains a log area showing the lists of the previous questions submitted by the learner.

There were specific features in the QP environment, which came out to be crucial for the IKnowIT-pedagogy. These are as follows:

1. ***Instruction in the QP activity saying, "Submit a question as soon as it arises in your mind"***
   In order to make sure that the learners submit most of the questions that come to their mind, this instruction was included alongside the question authoring tool. We would see the detailed mechanism related to this in the next Chapter 9.

2. ***Video auto-pause-resume feature, while in the question authoring mode***
   This feature facilitates the automatic pausing of the video when a learner clicks inside the question authoring box, and automatic resuming of the video when the learner clicks the question submit button, or clicks outside the questioning authoring box. This ensured the ease of switching between video watching and QP authoring and avoiding extraneous need to manually pause-play, which reduces cognitive-load.

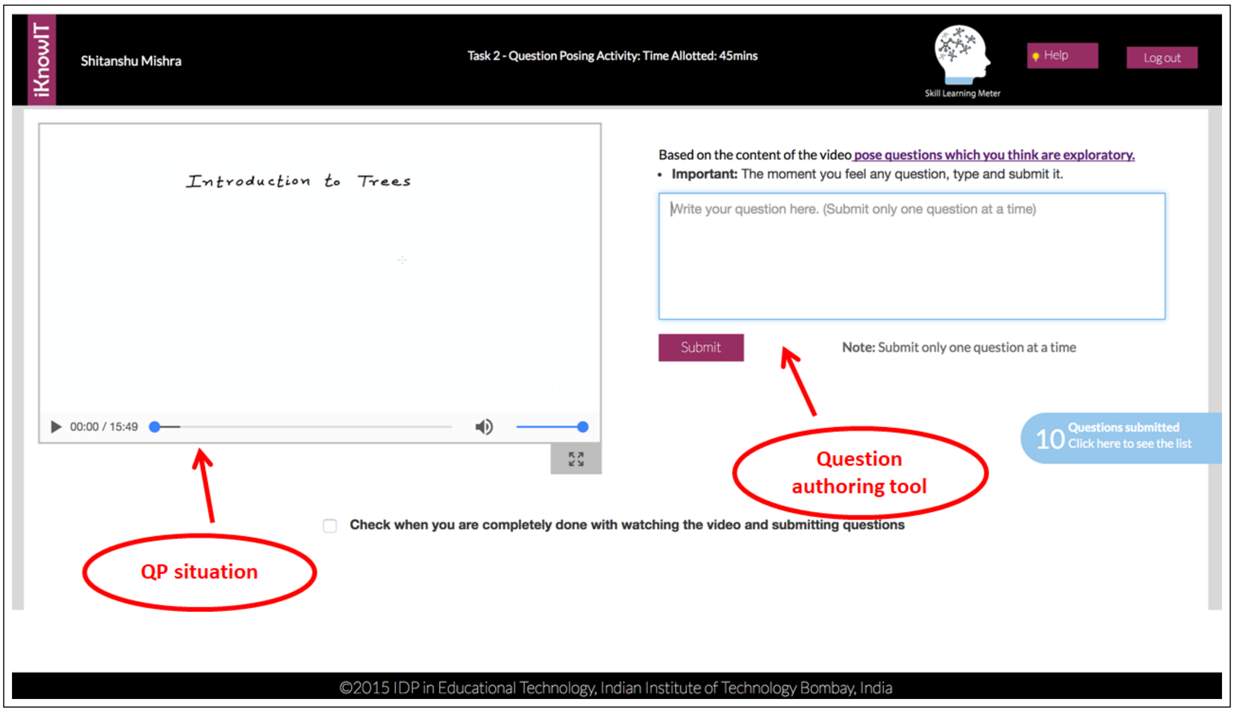


Figure 8.2: IKnowIT Phase B: Question-Posing

3. ***Auto-background dimming during QP task***

   When a learner clicks on the question authoring box, all other screen content except the question authoring box dims off. The rationale behind this feature is to make sure that the learner does a focused question articulation, without any distraction.

4. ***Choice of length of the video (15-16 minutes)***

   The data in iDEEN study has shown that our choice of 15-16 minutes video length is needed to give learner enough opportunity to practice EQP, as perceived by the learners. Moreover, the learners also reported not to have got bored or tired of watching the 16 minutes long video, because of their cognitive engagement with the QP activity.

5. ***Choice of the content of the video, "Introductions to: A. Linked list, B. Tree, C. Graph"***

   The data in iDEEN study has shown that, for better engagement in the activities (QP), the topic of the video should neither be very easy nor be too complex. Moreover, the topic should be vast enough to increase the chance of application of exploratory question-posing (EQP) and knowledge integration (KI) concepts. For better reflections on "how can EQP and KI lead to better understanding," the first video (used in the first run of the IKnowIT-pedagogy) should have some possibility to be related to the second video (used in the second run of the IKnowIT-pedagogy). This increases the possibility for the learners to self-demonstrate the mechanisms of "eliciting prior knowledge (PK), refocusing on given new knowledge (NK) and relating NK with PK."

8.1.3 Phase C: Detailed EQP Instruction

Role: This phase is similar to Phase A, but contains detailed information about three EQP strategies ('Apply,' 'Operate,' and 'Associate') with examples. The contents of this learning dialogue aim to achieve following learning objectives: (i) learner should be able to revisit the distinction between clarification and exploratory questions; and (ii) learner should be able to describe the three EQP strategies.

The initial rationale for making the learners learn about the EQP strategies came from literature, which suggests that the use of QP templates in guided cooperative questioning leads to better knowledge connections (King and Rosenshine, 1993). The data in iDEEN study has shown that making the learners understand the three EQP strategies is important for the IKnowIT-pedagogy in many ways, which are as follows:

(i) EQP strategies give directions about what to look for, about a given knowledge.
(ii) They helped in reflecting on the nature of questions that come to mind.
(iii) EQP strategies also helped in avoiding non-coherent or assorted exploration. Therefore, it avoids confusion.

Operationalization

The operationalization is similar to Phase A (Figure 8.3). This phase also contains the LeD with text and image reading contents, interleaved with reflection quizzes.

8.1.4 Phase D: Question Categorization

Role: Initially, the objective of the 'Categorization' phase was to make a learner use her/his understanding of the EQP strategies to categorize (analyze) their prior questions. This cognitive engagement with the three EQP strategies at analyze level (Krathwohl, 2002), aimed at further strengthening learners' understanding of the three EQP strategies. However, the data in iDEEN study has shown an additional and more important role of the categorization activity. We found that it makes learners get an insight into their own questions and reflect on their questioning process.

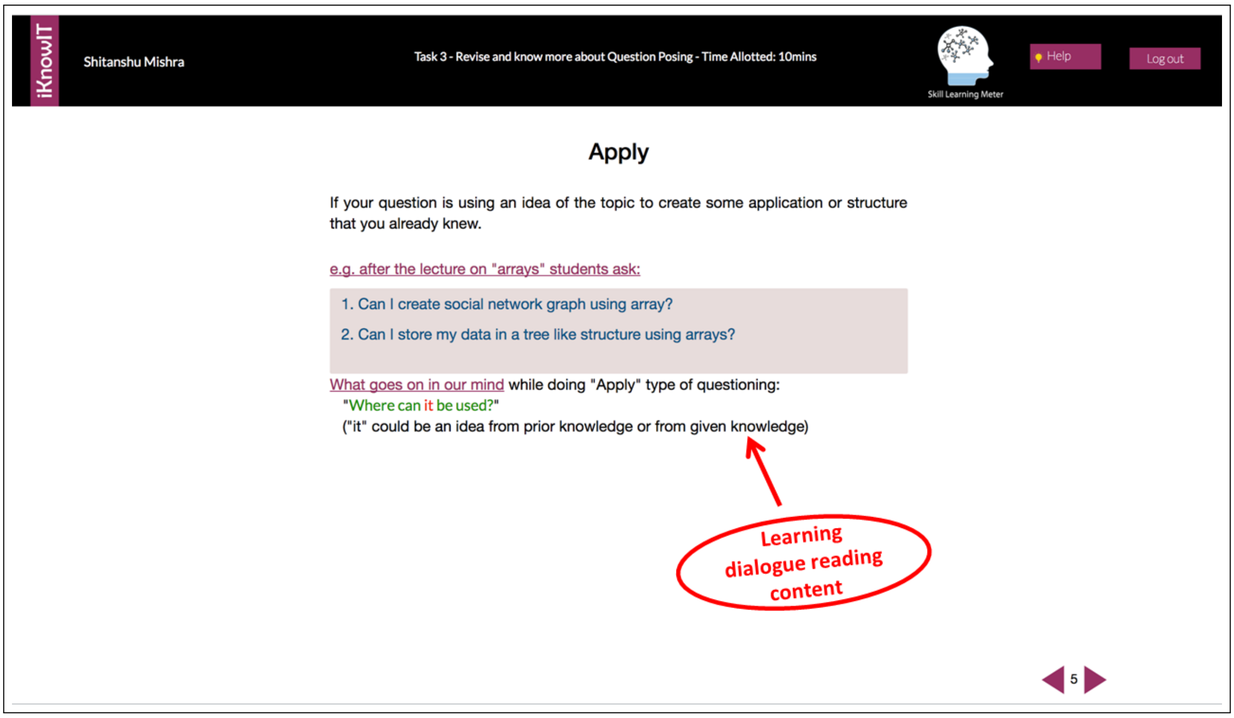


Figure 8.3: IKnowIT Phase C: Detailed EQP Instruction (Learning Dialogue 2)

Operationalization

Question categorization phase is operationalized using a categorization unit, which is built using a list of "learning artifact categorizers" and "category descriptors" (Figure 8.4). A learning artifact categorizer contains the learner's previously posed question with the list of check-boxes corresponding to the exploratory question-posing (EQP) strategies. A learner can categorize an artifact (question) using the check-boxes into more than one categories. The category descriptors contain short descriptions of each of the EQP strategies, which the learner can refer to while selecting the check-boxes for categorization.

There were specific features in the Question Categorization environment, which came out to be crucial for the IKnowIT-pedagogy. These are as follows:

1. ***Inclusion of the "OTHER" as the fourth EQP category tag***
   In addition to the three EQP strategies: 'Apply,' 'Operate,' and 'Associate,' along with the 'Clarification' category, we also included a category option of 'OTHER,' (see Figure 8.4). Data from DBR Cycle 1 has shown that there also exist (although less frequent) EQP strategies, apart from these three. Therefore its crucial to reinforce that the three categories are not exhaustive and there could be other strategies of EQP, and learners should be ready to explore more types of EQP strategies, and not just rely on only these

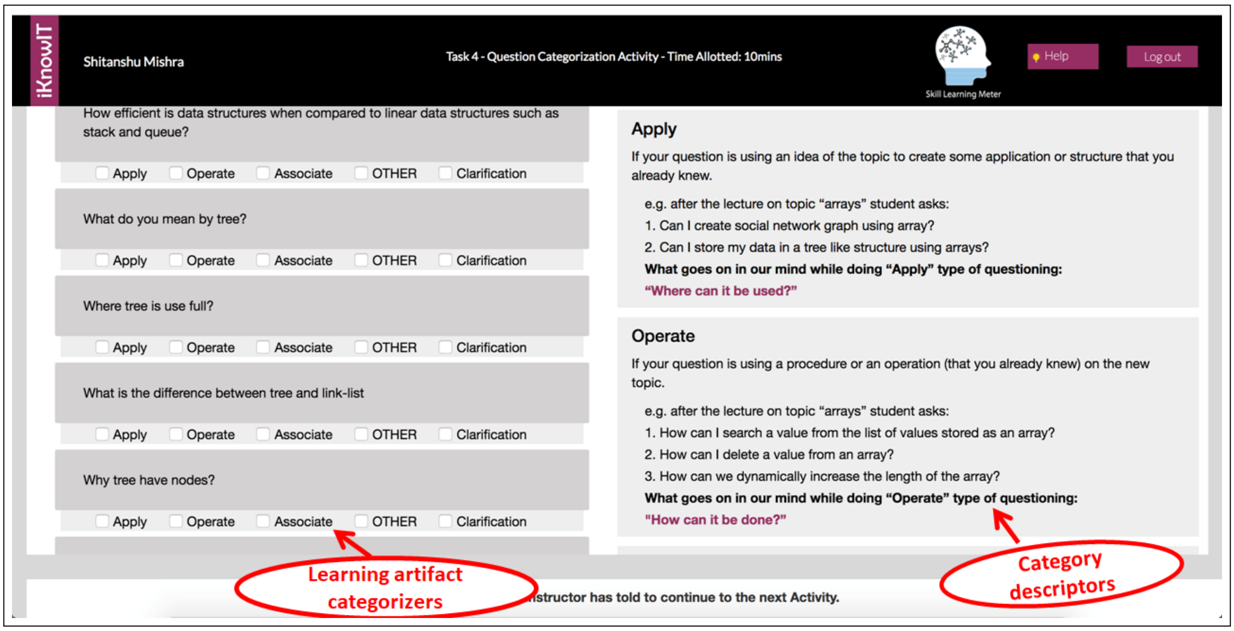


Figure 8.4: IKnowIT Phase D: Question Categorization

three. This reinforcement becomes useful if the learner is watching any lecture video from domains other than Data Structures, as the three EQP strategies identified are more prominent (i.e. frequently employed) in the Data Structures domain and we have not tested their prominence in other domains.

2. ***Description of the above EQP strategies on the same page with categorization activity interface, using category descriptor***

   Instead of making learners attempt recalling the descriptions of the EQP strategies from the previous phase ("Detailed EQP Instruction" phase), or making them navigate back and forth between the previous and the current phase on the browser to refer to the descriptions (see Figure 8.4), we listed the descriptions on the 'category descriptors.'

8.1.5 Phase E: Question Critiquing

Role: The initial objective of this phase was the same as that of the previous phase, but this time the learner is engaged with the EQP strategies at an even higher cognitive level. In this phase, the learner is made to use their understanding of the EQP strategies and critique the questions generated and the categorization done by some other learner. The learner is shown a list of the questions generated by some other learner, along with the categories, and asked to comment with the reasons why does s/he think that the tagging (categorization) is debatable or not. This cognitive engagement is at the evaluate level (Krathwohl, 2002). Learners also reported that this phase helped them get more clarity on the distinctions among the three strategies. However, similar to the previous phase, the data in iDEEN study has shown an additional and important role of this phase too. We found that this phase helps the learner to reflect on the cognitive processes involved in QP. Moreover, when a learner gets questions generated by others, it induces more conflict and elicits more thought process.

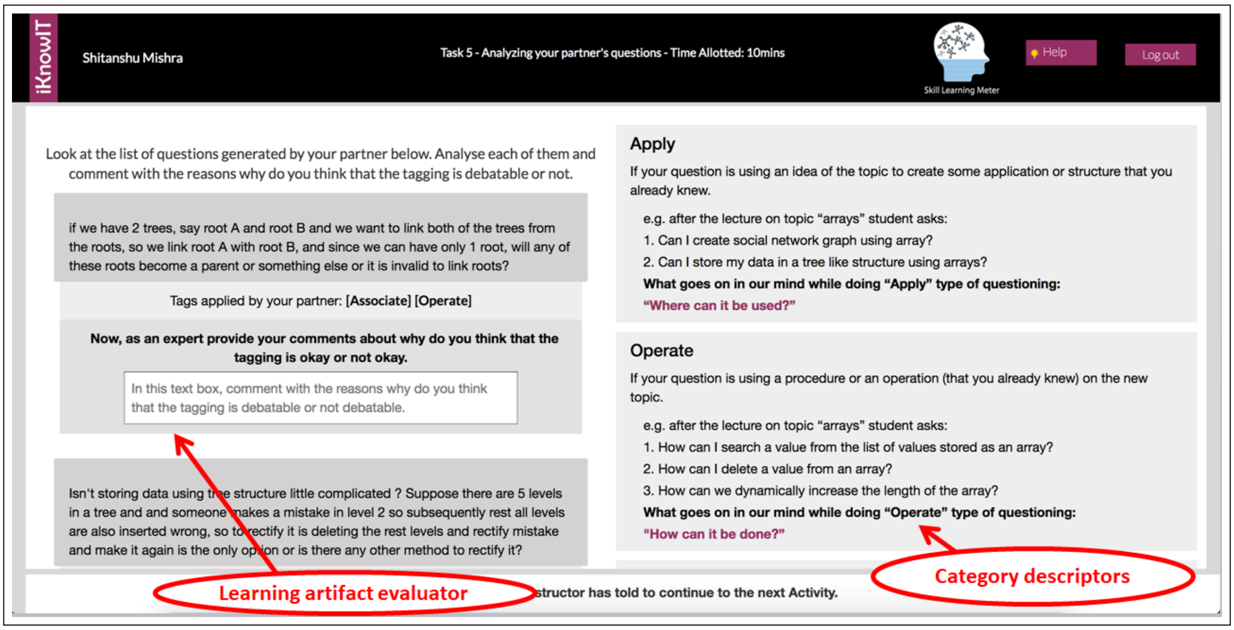


Figure 8.5: IKnowIT Phase E: Question Critiquing

Operationalization

Question Critiquing phase is operationalized using an evaluation unit, which is built using a list of learning artifact evaluators and category descriptors (Figure 8.5). A learning artifact evaluator contains a previously posed question by some other learner (online partner), the list of categories (EQP strategies) that the other learner had tagged the question with and a comment authoring textbox. The learner is required to comment on the reasons about why is the tagging done by the online partner is debatable or not debatable. The category descriptors, similar to the categorization phase contains short descriptions of each of the EQP strategies, which the learner can refer to while evaluating the tags and the questions.

8.1.6 Phase F: Reflection

Role: The need for reflection activity arose during the iDEEN iteration when we found that the face-to-face interviews themselves had effects on learners' learning. Literature recommends that reflecting and articulating intentionally, can promote knowledge building at the individual level (Scardamalia and Bereiter, 1991). Moreover, reflection and articulation processes support process management and sense-making (Quintana et al., 2005). The data in iDEEN study has shown that the reflection activity in the IKnowIT-pedagogy helped learners in "consolidating and concluding their learning." Learners reported that the activity made them think about their thought processes.

Operationalization

This phase is operationalized using a series of metacognitive reflection questions. Different reflection questions are structured as multiple choice questions (single correct response, multiple choice questions, more than one correct response, true-false questions, Likert scale questions) and open response questions. Some of the reflection questions have feedback, and some do not have. A representative screen is shown in Figure 8.6

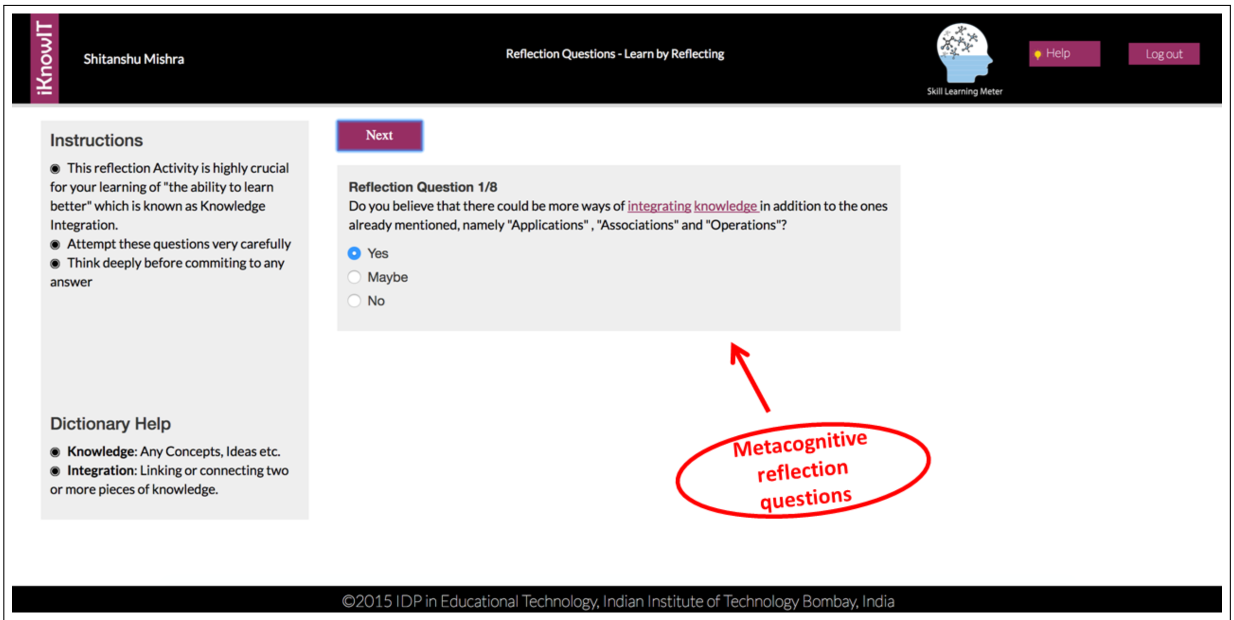


Figure 8.6: IKnowIT Phase F: Reflection Activity

There are total eight reflection questions in the reflection phase, out of which, two questions on the generalizability and applicability of the EQP strategies; one question is on the importance of KI and QP to learning and their relation with KI; three questions are to make the learners reflect on the KI processes that they have executed while questioning; one question is to make them reflect on their cognitive processes during QP; and the last question is to make the learners reflect on planning about how would they use their learning in the IKnowIT session in future. Three of these reflection questions are listed below, as an example. The full list of reflection questions can be seen in Appendix V.

- ***Reflection Question 1/8:*** *"Do you believe that there could be more ways of integrating knowledge in addition to the ones already mentioned, namely 'Applications,' 'Associations' and 'Operations?'*
  Options available in this question are 'Yes,' 'No,' and 'Maybe.'

- ***Reflection Question 4/8:*** *"While doing exploratory questioning, how important is focusing on the concepts or ideas from the video lecture (new knowledge)?"*
  Options available in this question are five-point Likert scale from "Least important" to "Completely important."

- ***Reflection Question 8/8:*** *"Based on your experience today, what would you do from now on when you are reading, watching or listening to lecture on a new topic?"*
  This question was an open response question.

Few of the reflection questions also give feedback against the learner's response. These feedbacks were the paraphrased statements given after the learners select and submit an answer. For example, in the first (1/8) question, when the learner submits 'Yes' as the answer, the system gives feedback, *"Exactly! There could be many different ways to relate and integrate two knowledge pieces. 'Application,' 'Association' and 'Operation' are just a few of the possible ways."* This feedback is nothing but the paraphrased extended statement created from the question itself. This structure of the feedback was chosen since literature suggests that paraphrasing same answer and providing it as feedback has benefits in reflection (Katz et al., 2016).

Another feature in the learning environment was the vocabulary help. To make sure that the learners comprehend the words used in the reflection questions, we underlined the selected words in the question text. When any learner clicks or hovers on any underlined word using the mouse pointer, the system displays the corresponding meaning of the word.

8.1.7 IKnowIT-pedagogy Second Run: Repetition of Phases B - F

Role: A learner is made to undergo a repetition run of the QP (Figure 8.7), Categorize, Critiquing and Reflection phases in the context of a video lecture on a new topic. One repetition of the phases was done, as the data in iDEEN study recommended that the second run provided learners with an opportunity to apply what they understood from the first run. Learners reported that *"...the first [run] was like an example; the second [run] was like an exercise..."* It was the second run when the learners recognized that what they have learned in the first run actually works. The decision of repetition is also supported by literature, which suggests that the repetitions of activity are expected to yield better results (Coughlan et al., 2014). Murthy et al. (2016) recommends repetition of the learning activities in different task contexts (different topic in our case) is beneficial for the acquisition of thinking skills.

Operationalization

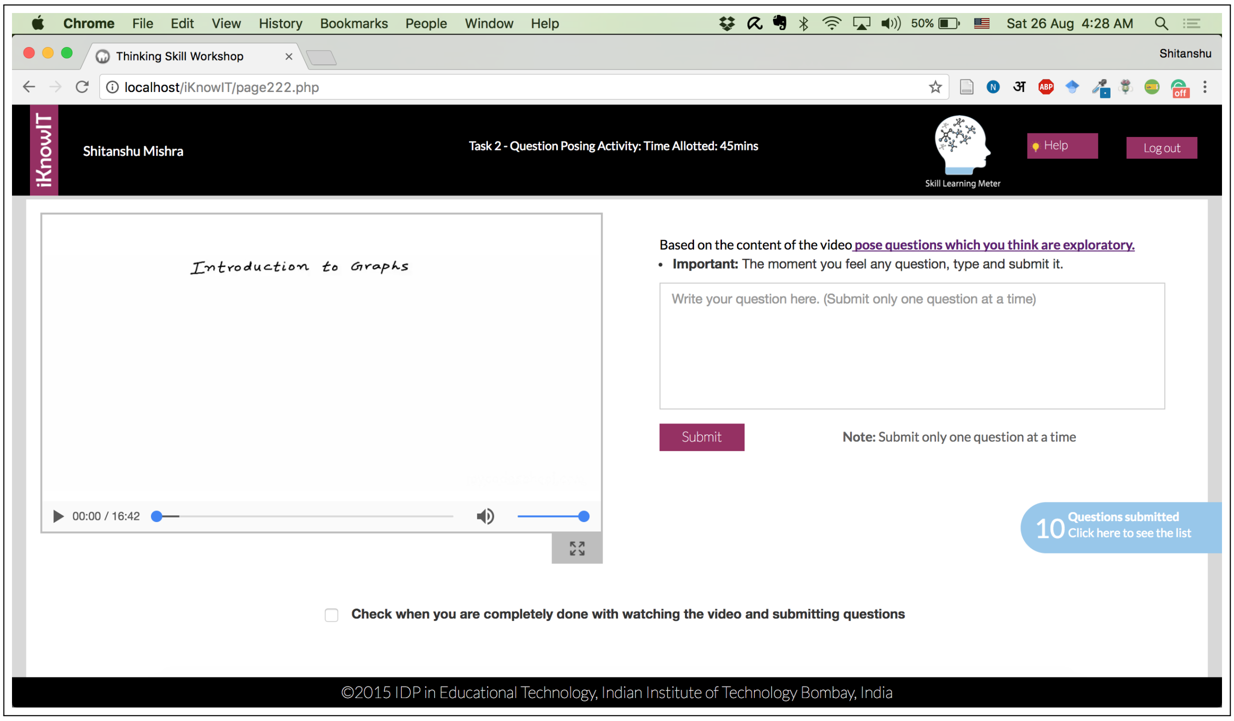


Figure 8.7: IKnowIT - Start of the Second Run

All implementations were same as for the first run, except that the video in the QP phase was replaced by another video (Figure 8.7) on a different topic within Data Structures.

8.2 Technology and Implementation

The front-end of IKnowIT has been built using HTML5 stack (HTML, Java Script, CSS) and the back-end has been built using PHP. The database is managed on MySQL. Apache is used as the web server. The system architecture is detailed in Figure 8.8. Regarding the modules of the web-based learning environment, as we have seen in the previous sections, the pedagogical phases are operationalized using pedagogical features. Each pedagogical features are built using the learning environment components. Every learning environment components correspond to a unit software module of the web application. The mapping of the pedagogy phases, pedagogical features, and learning environment components is shown in Table 8.1.

Table 8.1: Mapping the Pedagogy Phases and the required Learning Environment Components (Unit Software Modules)

Pedagogy Phases	**Pedagogical Features**	**Learning Environment Components**
Minimal EQP Instruction	Learning Dialogue	Learning Content Reflection Prompt
Question-posing	QP Environment	QP Situation Question Authoring Tool Question Log
Detailed EQP Instruction	Learning Dialogue	Learning Content Reflection Prompt
Question Categorization	Categorization Unit	Learning Artifact Categorizer Category Descriptors
Question Critiquing	Evaluation Unit	Learning Artifact Evaluator Category Descriptors
Meta-cognitive Reflections	Meta-cognitive Reflections Prompts	Reflection Questions
All	Pedagogical Agent	Pedagogical Agent Dialogue
All	Task Dashboard	Dashboard
N/A	N/A	Learner Login

Continued on next page

Table 8.1 – *Continued from previous page*

Pedagogy Phases	**Pedagogical Features**	**Learning Environment Components**
N/A	N/A	Learner Sign-up

In addition to the pedagogical features discussed in the previous section, there are two learning environment features used in IKnowIT. First of which is the "Task Dashboard," which displays the current progress of the learner, name of the current pedagogy phase and that of the learner, 'help' and the 'logout' buttons. The second pedagogical feature is the "Pedagogical agent," which is there to tell the learner about essential information about what to do in any phase. The pedagogical agent, technologically, is a static dialog box containing an avatar of an instructor and appropriate messages. The pedagogical agent pops up whenever a learner enters into a new phase. During the activity, the agent can be accessed by clicking on the help button in the task dashboard.

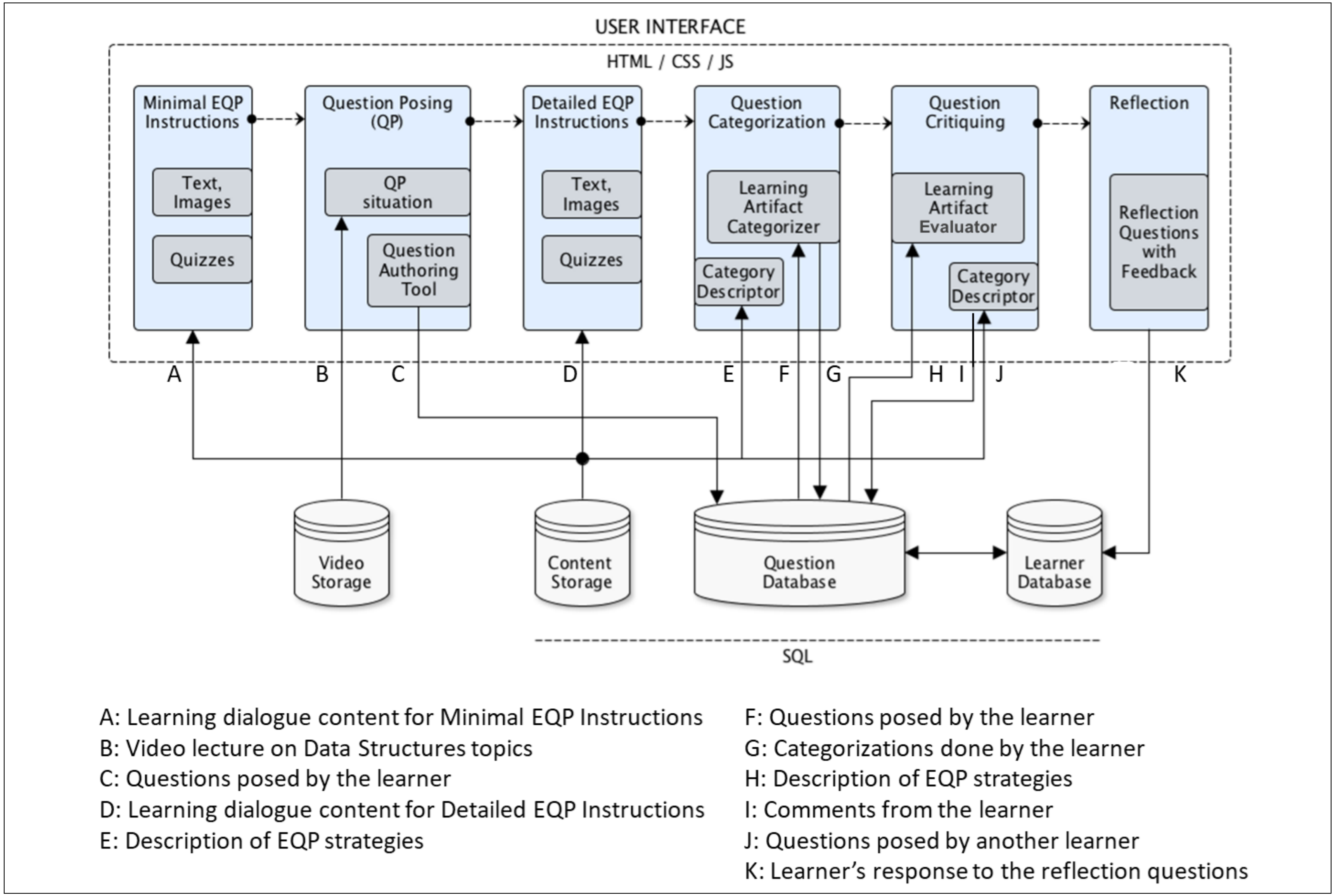


Figure 8.8: IKnowIT System Architecture

8.3 Summary

In this chapter, we have reported the roles of each pedagogical phases and how each of the phases has been operationalized as a web-based learning environment. We have shown the screenshots of different UIs of the IKnowIT-environment. The actual system can be accessed on the url: http://www.et.iitb.ac.in/iknowit/. In the next chapter, we present the local learning theories, which would explain in detail how these pedagogical phases and learner's interaction with them lead to the fostering of cognitive processes of KI in learners.

Chapter 9

Cycle 2: Local Learning Theories

In the previous two chapters, we reported the two outcomes of the iDEEN study, i.e., the IKnowIT-pedagogy and the IKnowIT-environment. This chapter presents the third set of outcomes of the iDEEN study. These outcomes are the local learning theories (LLT), also referred to as 'local instructional theories' in literature (Plomp and Nieveen, 2010; Liljekvist et al., 2017; Gravemeijer and Cobb, 2006). LLTs explain how the learner's interaction with the features of the IKnowIT learning environment leads to learning, i.e., improvement of cognitive processes associated with knowledge integration (KI) in the learner. These theories about "how does learning happen in IKnowIT are primarily extracted in the iDEEN study (Study 5), and to further elaborate theories and explanations this chapter uses the findings from both of the DBR cycles.

9.1 Organization of the Local Learning Theories (LLTs)

The iDEEN study resulted in the identification of two prominent concepts, i.e., question-posing (QP) and the exploratory question-posing (EQP) strategies, around which most of the aspects of local learning theories were anchored. Mechanisms related to these two concepts along with the answer to the question that how are the cognitive processes of KI are improved by the IKnowIT-pedagogy form the organization of out LLT. Therefore, the LLTs have been organized in three parts as described below.

1. **QP in IKnowIT:** First we present details about learners' questioning mechanisms as evident from the findings of the iDEEN study (primarily) and Cycle 1 of DBR. We discuss the following aspects related to QP:
   (a) How and when do questions arise in a learner's mind?
   (b) Additional factors that determine the quality and quantity of the QP.
   (c) What are the roles of QP in IKnowIT-pedagogy?
2. **EQP Strategies:** In this part, we present the following aspects of the EQP strategies used in the IKnowIT-pedagogy.
   (a) How are the EQP strategies learned in IKnowIT?
   (b) What are the roles of the EQP strategies in IKnowIT-pedagogy?
3. **Cognitive processes of KI:** In this part, we present the aggregated mechanism from the previous above two parts and show how does a learner improve her/his cognitive processes associated with KI using the IKnowIT-environment. This has been discussed using the following points.
   (a) Which of the KI processes are triggered?
   (b) How and when is any KI process triggered in IKnowIT?
   (c) What are the indicators that suggest that the KI processes are strengthened?
   (d) How would the KI processes be triggered in a learner's mind in future?

9.2 Question-Posing in IKnowIT

As per the findings from the Cycle 1 of DBR, we know that questions posed by the learners aim at either clarifying their doubts or to explore some new knowledge. In the case of EQP, the learner brings in concepts from her/his prior knowledge, connects them with the given new knowledge, and articulates her/his conflict or gap related to the connection. Let's see the QP in more detail.

9.2.1 How and when do the questions arise in learner's mind?

Effects of learning from the Minimal EQP Instruction and being conscious to the goal of the QP task

A learner is asked to pose questions in the QP phases of IKnowIT-pedagogy for the two runs of the pedagogy with two different video lectures. In the case of the first run, the learner knows very little about the QP, as till then s/he has only gone through the first phase of the pedagogy (Minimal EQP Instruction), where s/he learned about QP. In the Minimal-EQP-Instruction phase, only a basic introduction to the clarification questions, exploratory questions, and their importance are given. We find that both the Minimal-EQP-Instruction phase and the explicit task of posing questions in the QP phase has different effects on the learners questioning process. This has been illustrated in Figure 9.1. In this context, there are three distinct paths that are evident in the learner's questioning process. A learner may follow one or more of the three paths.

Few learners reported that the question arises in their mind because they were explicitly told by the system to pose questions. This means that questions arose because learners were conscious of the QP task (Figure 9.1, Path 1). For example:

> *Interviewer: If you were not told about exploratory [questions], etc. do you think that those questions still arise?*
> ***Learner:*** Even then [yes], the questions can come.
> **Interviewer:** Then, what is the difference?
> **Learner:** In this case, I was aware that I have to ask a question [thats why questions came.]

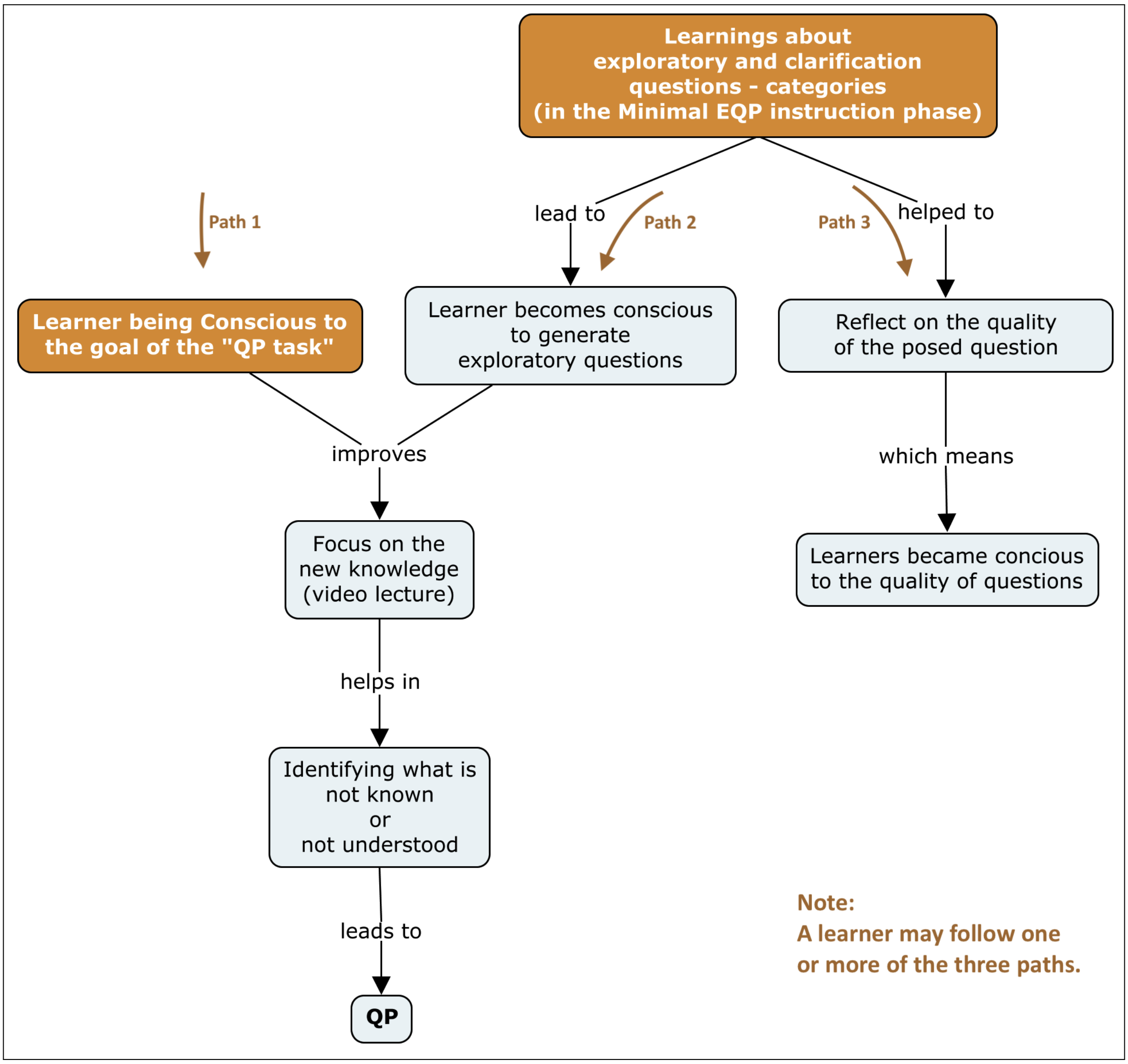


Figure 9.1: Effects of the Learnings from the "Minimal EQP Instruction Phase" and Effect of being Conscious to the Goal of "QP task" in the QP Phase

When probed further we found that being conscious of the QP task leads to an increased focus on the new knowledge (the video lecture). Increased focus on the new knowledge helps learners in identifying what they don't know and/or what they don't understand about the new knowledge. These identifications ultimately lead to QP For example:

> ***Learner:*** *When you [system] said to watch video and [pose] question, in that case, I have to concentrate to ask questions. I'll concentrate on each and everything [in the video], each and every second - is this [concept] okay? or if Don't I understand this? should I ask a question about this?*

We find that 'being conscious' of QP task played an important role for many learners. Few other learners reported that their focus on the new knowledge was more because of what they read about clarification and EQP in the 'Minimal EQP Instructions' phase. While watching the video they were trying to pose exploratory questions and therefore their focus was more and they ultimately generated more questions (Figure 9.1, Path 2). However, this was not true for all; few other learners reported that the knowledge of the categories ('exploratory' and 'clarification') actually helped them to reflect on the quality of the generated questions and did not helped them in focusing on the new knowledge - questions came with natural pace but the learners became conscious of the quality of questions (Figure 9.1, Path 3).

Life Cycles of Questions during the IKnowIT Training

Probing into the cases where learners posed (submitted) very few questions helped identify further interesting mechanisms. These mechanisms describe when a question becomes apparent to the learner, when it does not and when it is submitted to the learning environment (Figure 9.2). Many learners reported that questions arose in their mind but they did not submit them because they got the answer from the video within a few moments and therefore didn't submit them. For example:

> ***Learner:*** *No, questions did not come to my mind... I already understood the concept.*
>
> ***Interviewer:*** *What do you mean by "I already understood?"*
>
> ***Learner:*** *I understood the concept [thats why questions didn't come]*
>
> ***Interviewer:*** *What do you mean by "I already understood?"*
>
> ***Learner:*** *No! Questions did not come to my mind... I already understood the concept.*
>
> ***Interviewer:*** *...Ok then, did this happen to you that the questions came to your mind, and while watching video you got its answer?*
>
> ***Learner:*** *Yes! It happened!*
>
> ***Interviewer:*** *After which the question got resolved, when did it happen with you?*
>
> ***Learner:*** *In the Graph video, 2-3 times. And also in the Tree video. Maybe, the same incident happened, that question arose, but then it was answered by the content of the video. Then it resolved. [and not submitted to the IKnowIT-environment]*

This gave rise to the idea of two types of life cycle of a question: (1) In the case of the first type of cycle, questions arise in learner's mind , learner recognizes the question, and when s/he does not get its answer in the video, the learner articulates the questions and submits it to the system. (2) In the second case, the question arises in the learner's mind, the learner recognizes the question, and since s/he gets its answer in the video, s/he never articulates the questions.

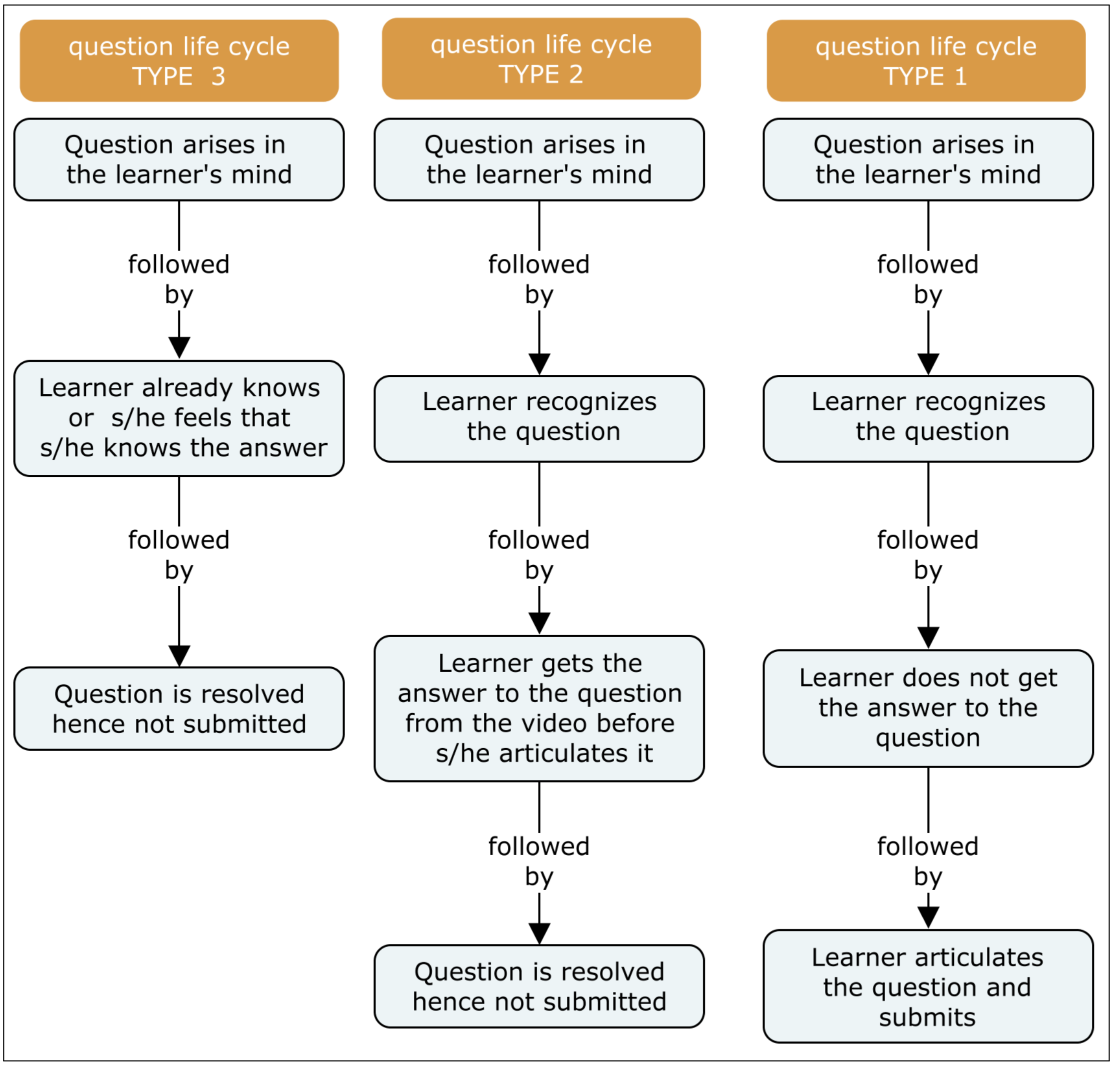


Figure 9.2: The Three Types of Life Cycles of Questions during the IKnowIT Training

Additionally, we found a third type, where a small subset of learners reported that occasionally questions popped up in their mind, but they immediately realized that they already know the answer, which immediately resolved the questions. Although we are not very certain about the frequency of occurrence of the third case, we propose that this third case, if added to the list of the first two cases enriches the story about the types of life cycles of questions, as follows. There are three types of life cycles of questions (Figure 9.2), as follows.

1. **Type 1:**

(a) Question arises in the learners' mind, (b) learner recognizes the question, (c) learner does not get the answer to the question, (d) s/he articulates the question and submits it. In this case, the question would be resolved if and only if it either gets answered or, with time learner forgets the question.

2. **Type 2:**
   (a) Question arises in the learners' mind, (b) learner recognizes the question, (c) learner gets the answer to the question from the video before s/he articulates it, hence (c) the question is resolved.

3. **Type 3:**
   (a) Question arises in the learners' mind, (b) learner already knows or s/he feels that s/he knows the answer, (c) hence the question is resolved.

These types are important for us because in IKnowIT we wanted that the learner to generate as many questions as possible as these questions are used as learning artifacts in the subsequent phases of IKnowIT-pedagogy. This made us add a one-line instruction in the question-posing phase in the learning environment that "The moment you feel any question in your mind, type and submit them." To facilitate this technologically, we added a new functionality in the learning environment, i.e., the moment a learner clicks on the question authoring box, the video automatically gets paused and resumes only when the learner clicks the "submit (question)" button or clicks outside the question authoring box. This was done to make learners capture as many questions as possible. This actually worked, and in later iDEEN iterations we found learners reporting that they submitted few questions for which they got answers after few seconds of further watching the video.

Change in the QP Experience in the Second Run: More Intrinsic Motivation and Authentic Questioning

During the QP phase in the second run of IKnowIT-pedagogy (with video lecture 2), learners report having significant improvements in their experience. It should be noted that before the second run, the learner has already gone through different phases of IKnowIT-pedagogy once. Therefore, effects of the IKnowIT phases should be expected on the learners' experience. Students reported that in the second time they were more conscious about the QP task, yet the QP happened more naturally in the second run, as shown in Figure 9.3.

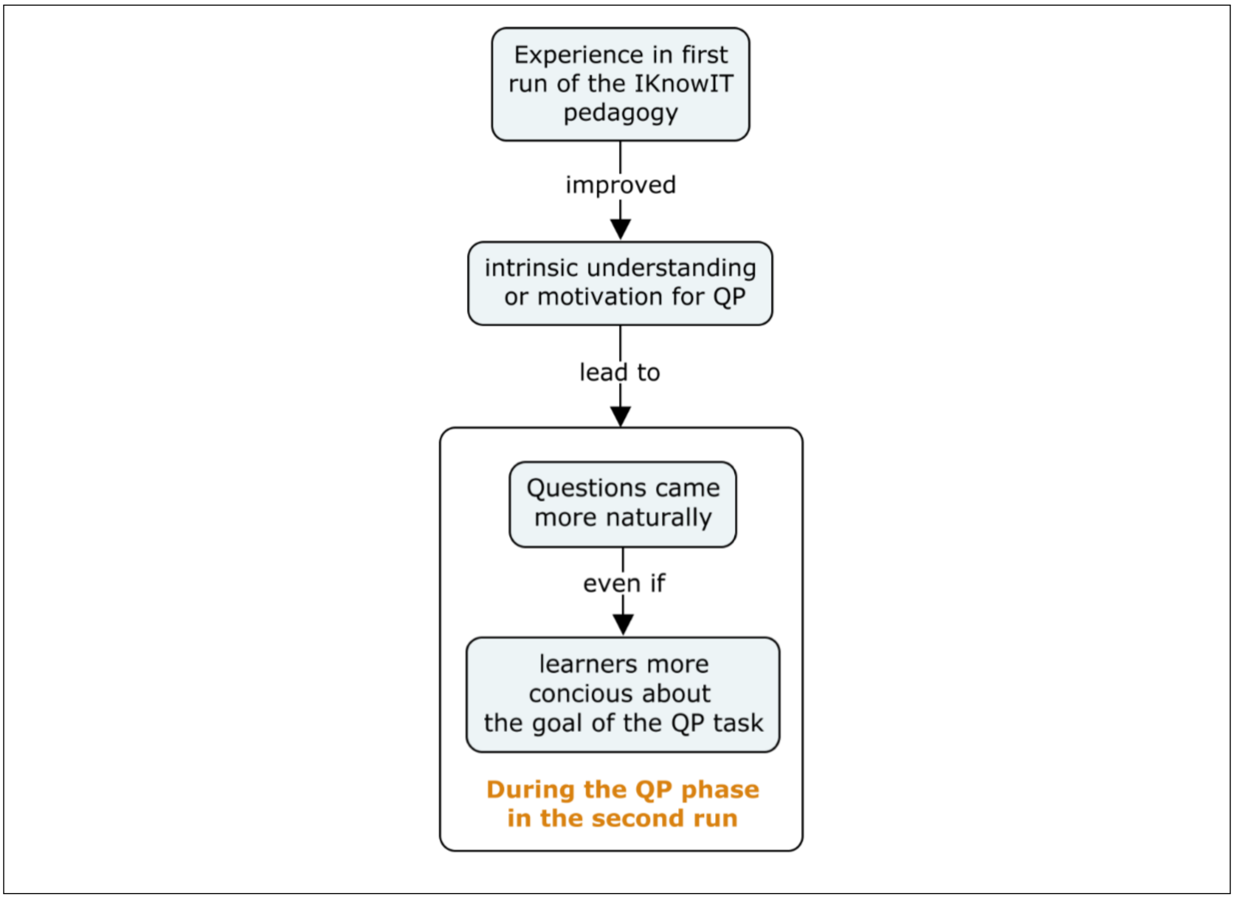


Figure 9.3: Change in the QP Experience in the Second Run

This was interesting because we were concerned that knowing so much about EQP may highly structure the QP process and may lead to inauthentic (Nystrand et al., 2003) generation of questions by a learner, (i.e., questions just for the sake of a questioning task). This inauthentic questioning is undesirable because we want our learners to develop a natural instinct to pose questions. Questioning should happen even after they come out of the IKnowIT-environment. Inauthentic questioning was found to be frequent in the first run, where learners reported to be focused on the new knowledge (video lecture 1) just because they were asked by the system to do a QP task (as we discussed before).

As mentioned previously, for QP, focusing on the new knowledge emerged to be important. In the first run learners reported to have more focus because of two reasons, viz.: (1) They wanted to complete a QP task given to them by IKnowIT; (2) They got basic knowledge about the question types ('exploratory' vs. 'clarification,' their importance, etc.) and were motivated to pose more and better exploratory questions. So in the first run focusing on the new knowledge was due to extrinsic motivation (Trevino and DeFreitas, 2014; Brown and Ryan, 2015) for some learners, due to intrinsic motivation (Trevino and DeFreitas, 2014; Brown and Ryan, 2015; Cerasoli et al., 2014) for others and a mix of extrinsic and intrinsic motivation for few others. In the second run, learners reported that the questions came more naturally (authentic), despite the fact that they were more conscious about the QP. For example:

> ***Interviewer:*** *[For the second iteration] Which questioning strategy did you use?*
> ***Learner 2:*** *All questions were automatically coming to my mind...that which is the question that I might not know the correct answer for. Questions were quickly striking to my mind..."*

This shows that the learners were more conscious about QP primarily because of some intrinsic understanding or motivation rather than because of an objective to complete a "QP task." This made us probe deeper into the reasons of their authentic QP. We found that the first run of the IKnowIT-pedagogy had many effects on learners conceptions about QP, which can lead to developing an intrinsic motivation about QP and may have made the learner do questioning more naturally. These effects are given below:

- Thoughts around the new knowledge increased. (Learners mentioned that they started looking for an application or use of the concepts from new knowledge.)
- Recognized that *"questioning leads to more knowledge"*
- Recognized that questioning leads to deeper understanding.
- Recognized that one should relate her/his prior knowledge with the given new knowledge.
- Motivated to ask more exploratory questions.

Moreover, there are significant roles of EQP strategies, quality of videos, etc. in QP. We shall discuss them in subsequent sections.

9.2.2 Additional Factors Determining Quality and Quantity of QP

There are many factors that determine the quality of QP. These are illustrated in Figure 9.4. First is the learners' level of prior knowledge. By prior knowledge, we mean that the learners' prior knowledge around the given new knowledge. There may be three cases: (1) Learners with low prior knowledge; (2) Learners with high prior knowledge; (3) Learners with no prior knowledge. As per the learners' experiences of QP in the IKnowIT-environment, if a

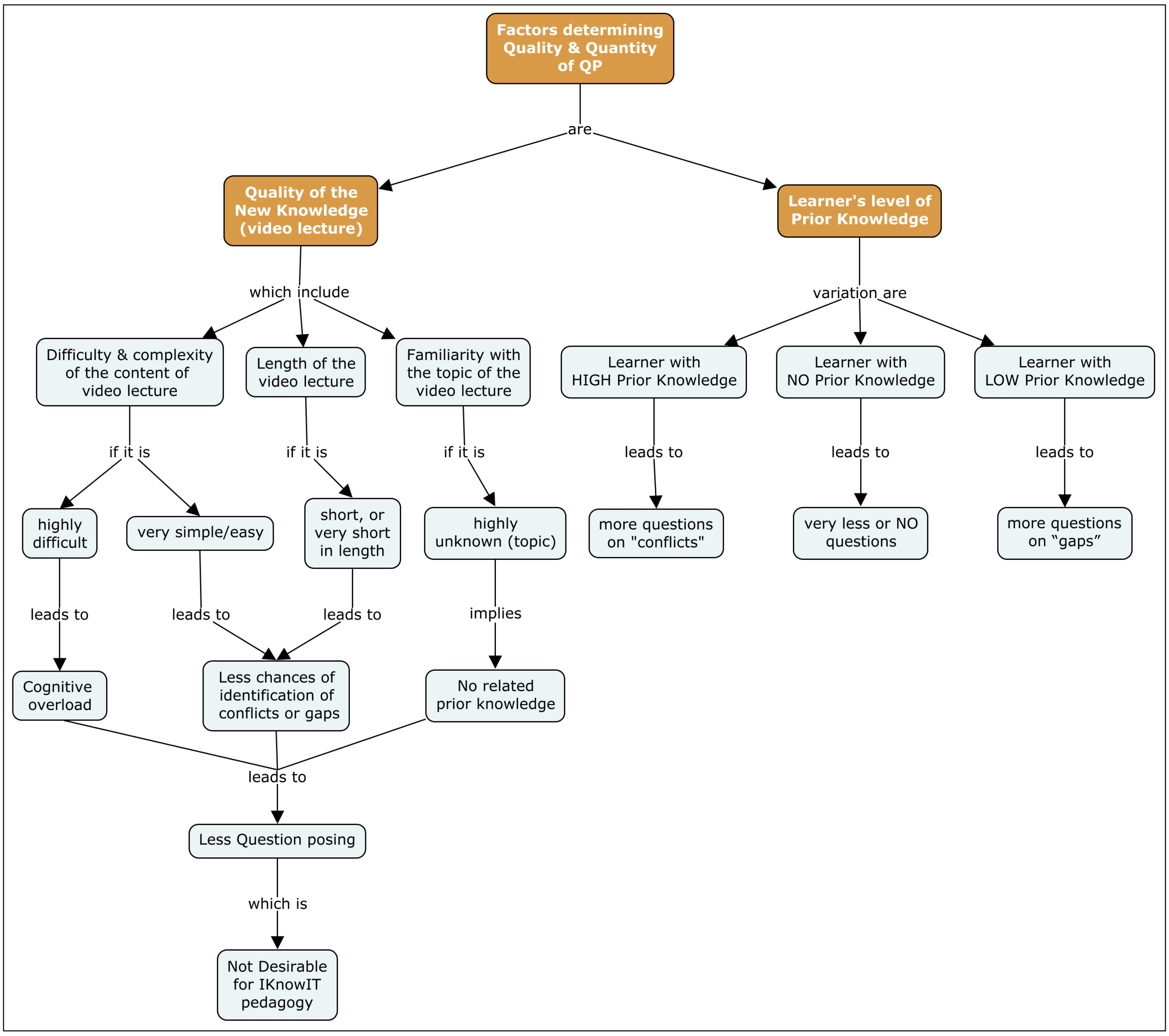


Figure 9.4: Factors Determining Quality and Quantity of QP

learner has low prior knowledge then s/he identifies and creates more questions on "gaps" ('about something which is not known'). If a learner has high prior knowledge, then s/he identifies and creates more questions on "conflicts" ('about something which I don't understand'). If a learner has no prior knowledge, then s/he would identify and create very less or no questions. These findings are the further extension of our findings in DBR 1, i.e., exploratory questions require the questioner to elicit her/his prior knowledge.

The second factor that determines the quality and quantity of QP is the quality of new knowledge, i.e., the quality of the content of the video lecture. Different learners reported five different qualities of new knowledge, viz.:(1) Length of the video lecture; (2) "Very simple or very easy" video lecture; (3) "Too good" video lecture; (4) Video lecture with unknown topics; (5) Highly difficult video. If a video lecture is short or very short, then it reduces the possibility that a learner may be able to recognize an idea from the video and elicit and relate prior knowledge around it. Whenever the learners were asked by the interviewer, "should we use a smaller video to save time of the session?," The learners replied with their dissent that it would reduce the number of questions. If a video lecture is "Very simple or very easy," it would reduce the chances of identification of conflicts and therefore the number of questions would reduce. "Too good" video lectures are those in which the creator of the video has presented a complex or difficult concept(s) such that it appears very simple and easy for the learners. It would reduce the chances of identification of gaps and conflicts and therefore reduce the number of questions. "Highly difficult videos," on the other hand, are those videos which a learner finds hard to comprehend. This leads to an excessive focus on the content and increases the cognitive load of the learner, as a result of which s/he finds it hard to generate questions. This result comes from those learners in the iDEEN study who found one video too difficult.

9.2.3 Roles of QP in IKnowIT-pedagogy

The role of QP can be discussed at two different times. First one is during the IKnowIT-environment learning intervention, and the second one after and outside the learning intervention. During the learning intervention, the QP has its role in most of the phases of IKnowIT, viz., "QP phase," "Categorize Phase," "Critiquing Phase" and in the "Second run of the IKnowIT-pedagogy," as outlined in Figure 9.5.

During the first run of the IKnowIT-pedagogy in the QP phase, the questions posed by the learner act as learning artifacts to be used in the later phases. In the Categorize and Critiquing phases of IKnowIT-pedagogy the learner dissects, analyzes and evaluates these learning artifacts to understand and reflect on the roles of prior knowledge and new knowledge, and different possibilities of their connections. These questions make the KI thinking processes embedded inside the QP visible and therefore accessible to the learners. Once these thinking processes become accessible, the learner can further use them to reflect on their role in the question formation.

In the repetition run of the pedagogy, the QP phase is not just about learning-artifact generation exercise but is a learning activity in itself. This QP activity makes the learners reflect how all the conceptions that s/he learned in the first run are actually applicable in a changed knowledge context (video 2). For example:

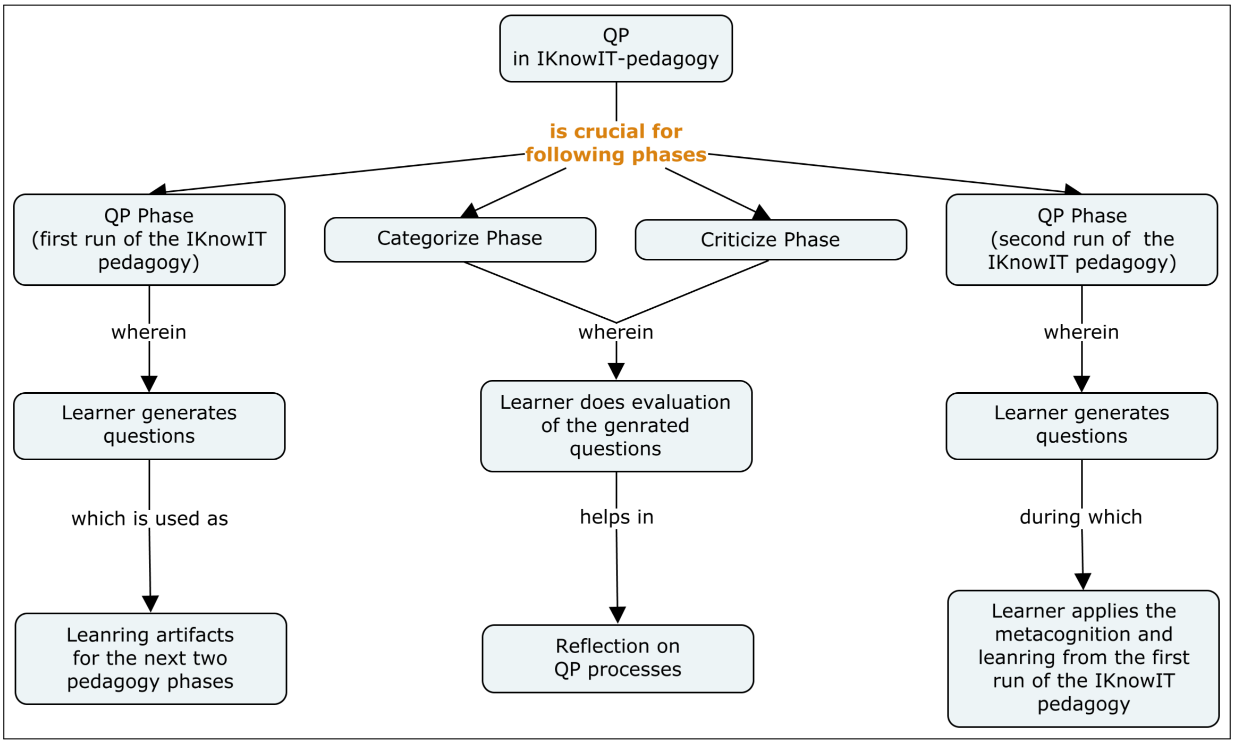


Figure 9.5: Roles of QP in the IKnowIT-pedagogy Phases

Interviewer: *What If I remove the second video watching exercise [QP activity in the first run] completely [from the pedagogy]?*

Learner 1 and Learner 2 [together]: *It'll affect a lot!*

Learner 1: *It's like I have not at all implemented what I learned!*

Learner 2: *First [QP activity] one was like an example, the second one was like an exercise.*

Learner 1: *Yes [agrees to the Student 2]*

The learner reflects on how the KI thinking processes are important in getting a deeper understanding of the video content. Learners reported that the EQP has made them use the EQP strategies ('apply,' 'Operate' and 'Associate'). It also made them execute the KI thinking processes of 'eliciting prior knowledge,' 'refocusing on new knowledge' and 'distinguishing among ideas.' (Distinguishing among ideas includes identification of gaps and conflicts). The learners also reported that the EQP activity also made them recognize the importance of the KI thinking processes.

After the learner completed her/his training on the IKnowIT-environment, s/he is equipped with the cognitive tool of EQP to execute the thinking processes of KI. More research would be needed to completely determine how effectively the learner is using this cognitive tool in far domains. However, based on how they used this cognitive tool along with the EQP strategies, we observe a desirable trend.

9.3 Exploratory Question-Posing Strategies

EQP strategies are the most crucial pedagogical element of the IKnowIT-pedagogy. We first present the mechanisms of how do learners learn these strategies, and then we present their roles in the IKnowIT-pedagogy.

9.3.1 Learning of the EQP Strategies

The first learning dialogue (LeD) in the 'Minimal EQP Instruction' phase gives the learners a primer on what is EQP. This lays down a foundation to introduce a new concept of EQP to them. To avoid making this concept daunting, LeD is broken into two parts, the second part being the 'Detailed EQP Instruction.' The learner reads more details about the EQP in the second LeD, where s/he gets introduced to the three broad EQP strategies in Data Structures: 'apply,' 'Operate' and 'associate.' The LeDs contain reading materials and reflection quizzes. These reflection-quizzes make sure that the learner reads each of the content of the LeD at least once. The LeDs provide an understanding of the strategies ('understand' level learning (Krathwohl, 2002)).

Next, in the 'Categorization' phase, the learner analyzes his generated artifacts using the EQP strategy definitions (provides an analyze level of learning of these strategies (Krathwohl, 2002)). In the 'Critiquing' phase, the learner uses these strategy definitions and criticizes the questions and categorization done by someone else. This provides an evaluate level of learning of these strategies (Krathwohl, 2002). Following excerpt from the interview, illustrates how the learner is engaged with (and therefore learns) the details of the EQP strategies, to complete the 'Critiquing' phase.

> ***Learner:*** *[Pointing at a question generated by another learner, listed in the 'Critiquing Phase'] It [this question] is about comparing the Linked list with the array. Therefore it should come in the 'Associate' category [EQP strategy]... He [the other learner] is trying to compare with something."*

Together these three activities engage the learner at the evaluate cognitive level of the blooms taxonomy (Krathwohl, 2002). It should be noted that, unlike any QP system, our aim is not to make learners to learn these strategies completely but to make them use these strategies during the IKnowIT intervention and learn about the cognitive processes of KI associated with EQP. In the next subsection, we'll see what roles the EQP strategies play in IKnowIT-pedagogy.

9.3.2 Roles of the EQP strategies in IKnowIT-pedagogy?

Anticipated vs. Counter-intuitive vs. Unanticipated Roles

Use of EQP strategies was found to be one of the crucial element of the IKnowIT-pedagogy. EQP strategies were found to have many roles. Many of them were anticipated, while others were either counter-intuitive or were unanticipated. These are outlined in Figure 9.6.

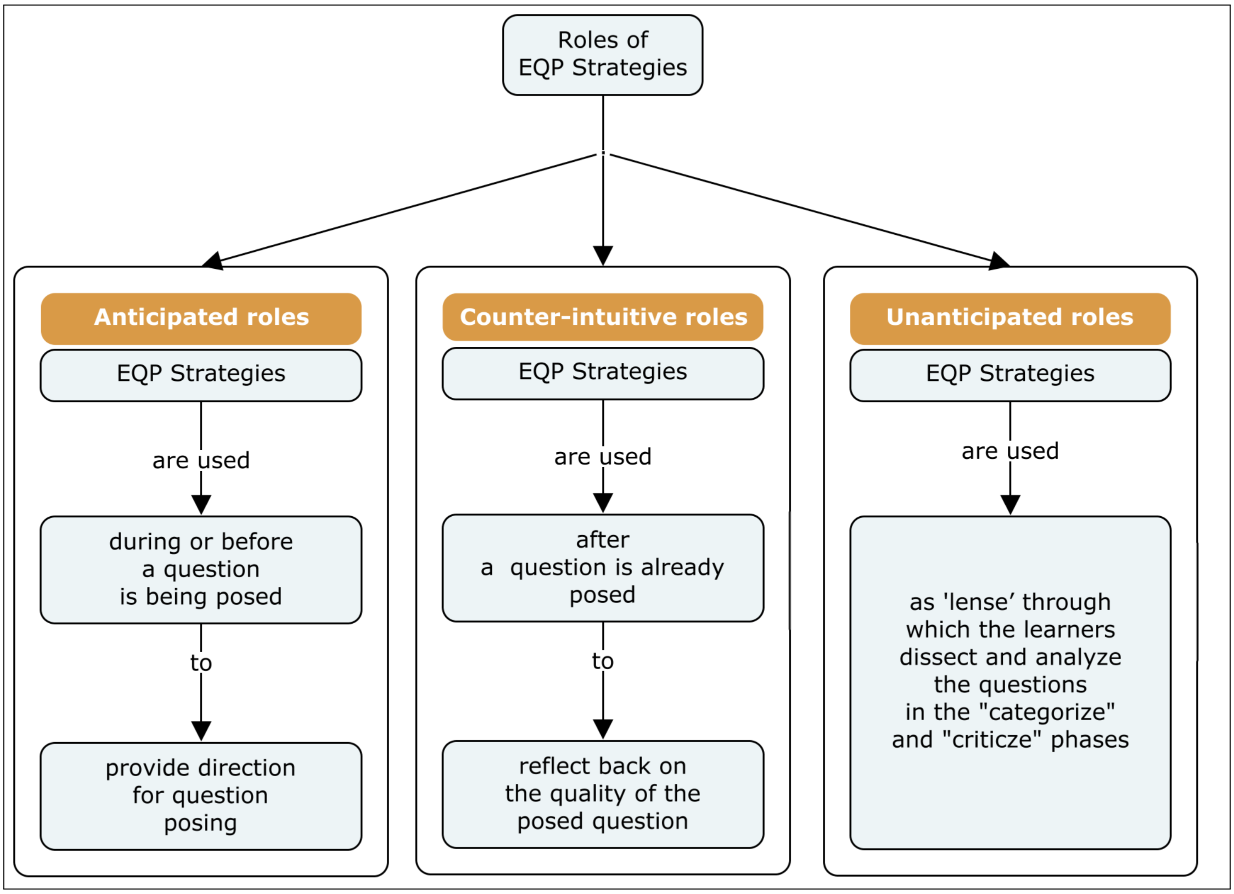


Figure 9.6: Roles of the EQP Strategies

The primary role that was hypothesized for the EQP strategies was to provide learners a tool/template to generate questions. This hypothesis was only partially validated. Most of the learners reported that the knowledge of strategies helped them in posing exploratory questions in the second video. However, few learners also reported that there was no role of the EQP strategies in the QP, simultaneously emphasizing that the EQP strategies are still really important. These seemed to be the two mutually-contradicting findings. When we probed further we found that the learners used the EQP strategies after they had generated the question to reflect back on the quality of their questions. These reflections may or may not lead to the revision of the generated questions. Example of this situation is as follows:

> ***Learner 1:*** *I think that it's better to have questions first, then categorize them. But don't pose questions according to the categories.*
> ***Learner 2:*** *Category [EQP strategies] comes into scene only after a question arises...*
> ***Interviewer:*** *Then, what is the benefit of knowing the categories?...*
> ***Learner 1:*** *It will give you a direction, that in which direction are you thinking? Are you thinking about "application" or "operation?"*

This was counter-intuitive as we anticipated that EQP strategies should not have any role once a question is generated. The EQP strategies emerged to be more than just a set of QP templates. It should be noted that the strategies making the learners reflect on their questions, is more desirable than just helping them to generate questions.

In the 'Categorize' and 'Critiquing' phases, which were primarily created to make the learner learn the EQP strategies, we found that the strategies are playing an unanticipated but even more desirable role. For example:

> [When questioned about the utility of the Categorize and Critiquing phases]
> ***Learner****: [When] I was asked to categorize my questions then I realized that most of the question that I asked actually did fit in those [three EQP] categories... I also realized how it actually works - the thought process of my question... how it goes hand in hand with the three categories [EQP strategies].*

While the questions played the role of 'learning artifacts' that learners dissect and analyze to abstract the KI thinking processes embedded in the QP, EQP strategies act as the 'lens' through which the learners dissect and analyze those learning artifacts. Questions make the KI thinking processes accessible and the EQP strategies make the KI thinking processes visible.

Overall Effects of EQP Strategies

The learners reported that the strategies helped them in improving the focus on the new knowledge. This, in turn, led to an increased identification of gaps and conflicts and ultimately led to more questions. Students also report that the strategies helped in eliciting prior knowledge. This was anticipated, as the different strategies, 'apply,' 'Operate' and 'associate' prompt a learner to look for respective nature of prior knowledge. For example, 'Apply' prompts the learner to look for applications of new knowledge, and 'Associate' prompts the learner to look for alternatives or contrasting ideas to the new knowledge. This provides a structure to the process of eliciting prior knowledge, which becomes useful in many situations. One of the interesting situations that emerged from our data was the case of fixation (Crilly and Cardoso, 2017) on a single question. A learner mentioned that the strategies are useful if *"I have got one question in my mind and I am so overwhelmed due to it that I can't see any other question."* The learner reported that the EQP strategies helped in overcoming this situation of fixation.

In section 9.2 we saw that there were factors that limit the rise of questions and execution of KI thinking processes. We found that the EQP strategies helped in overcoming them. For example, if learners have low or no prior knowledge then the strategies provide them directions to explore more. This increases the possibility of questions. It was found that these explorations precede the QP processes. Once a question is formed, the learner is ready to explore the answer to the question. To conclude we can say that exploration (of prior knowledge) precedes QP and (exploration of unfolded knowledge) follows QP.

As discussed before, strategies aid the elicitation of prior knowledge by giving different perspectives about the nature of prior knowledge. This also helps to increase the quality of questions and therefore also help in increasing the quality of the KI thinking process of "distinguishing among ideas." More perspectives on prior knowledge mean, better identification of conflicts and better exploration of gaps.

9.4 Improving Cognitive Processes of KI

In this section, we first present the overall effect of the IKnowIT-pedagogy related to the improvement of the cognitive processes of KI. Then we compile all our findings together to draw a picture of how the IKnowIT-pedagogy leads to the improvement of cognitive processes of KI in a learner.

9.4.1 Overall Effects of the IKnowIT-pedagogy

The three thinking processes which are triggered in the learner while interacting with IKnowIT-environment are: (i) Elicit prior ideas; (ii) Refocus on new ideas; (iii) Distinguish among ideas. Below are the three clusters of the learners' responses (in *italics*) to the question *"What did you learn from the whole IKnowIT session?"* corresponding the three cognitive processes of KI, respectively. These representative responses provide evidence that the three cognitive processes were fostered in the IKnowIT-environment.

1. **Eliciting Prior Ideas**

   Learners perceived that after completing the IKnowIT session, they became able to better select appropriate concept from prior knowledge which relates to the identified new knowledge. This is evident in number of learners' responses, for example:

   Quote1: *"Now, I'll think about prior knowledge properly....."*
   Quote2: *"I would not have thought much about prior knowledge otherwise..."*
   Quote3: *"Questioning leads to getting ideas and leads to explore more"*
   Quote4: *"Asking questions helps in knowing that where can any concept be used..."*

2. **Refocus on New Ideas**

   Learners also perceived that their ability to identify concepts from the new knowledge which may relate to prior knowledge as per the standard (EQP) types. Illustrations of this point can be seen in the following learner responses:

   Quote1: *"Started analyzing things (video) more deeply..."*
   Quote2: *"Categories give directions about what to look for about a given knowledge."*
   Quote3: *"Waiting/watching for questions to come, excited about which category would it be - made better concentration on the video... [otherwise] Traditionally videos are boring after 5-10 minutes."*

   Learners also perceived that their ability to relate various concepts improved. Illustrative quotes from learners' responses are shown below:

Quote1: *"Learnt how to inter-relate my previous knowledge with the knowledge in the video....."*

Quote2: *"Learnt about how to link better..."*

Quote3: *"Learnt how to relate topics."*

Quote4: *'Thought process of using my prior knowledge and the video concepts happened while watching video 2..."*

3. **Distinguish Among Ideas**

   Learners also perceived that the learnings from the IKnowIT session would help them in better identifying conflicts or gaps or extensions while relating prior knowledge and new knowledge. This is evident from the following illustrative quotes:

   Quote1: *"Questioning can help in keeping track of what we don't understand, and we can use this information to know more.."*

   Quote2: *"Now, ... would compare according to video - what missing, what inconsistent, what extension, what different....."*

Looking at the illustrative excerpts (quotes), we can say that the learners, in many ways have reported about the positive effects of the IKnowIT-pedagogy on the improvement in their cognitive processes of KI. It should be noted that the data similar to the above data is considered just as a "perception data" because these are the answer to a very shallow interview question, *"What did you learn from the whole IKnowIT session?"* Reporting this data is useful, as it gives a strong perception-level evidence of the positive effects of IKnowIT. However, the deeper interview questions actually helped us in looking deeper into the insights of the learners' learning mechanisms and extract local learning theories.

In the light of this strong perception data, we can at least claim that these cognitive processes were triggered in the learners while they were undergoing the IKnowIT session. In the next subsection, we present the last part of our local learning theory that explains that when are the cognitive processes of KI triggered in the learner's mind, and how does the pedagogy lead to improvement of these processes in learners.

9.4.2 The Cognitive Processes of KI: When and in what form are they triggered?

We have seen that on the one hand the role of QP, primarily is to set a cognitive requirement of eliciting prior knowledge, focusing on new ideas and identification of gaps and conflicts. The learner is, in a way pushed to do all these processes to come up with questions. On the other hand, the role of the EQP strategies primarily is to scaffold the execution of these processes. These and other roles are executed at different times in the IKnowIT-pedagogy to make the learners undergo different levels of metacognitive abstractions of the cognitive processes of KI. These different abstractions are as follows.

During the QP Phase (in the First Run)

Before the learner attempts QP activity for the first time in IKnowIT-environment, s/he gets only a minimal knowledge and motivation related to the clarification questions, exploratory questions, and their importance. With this much primming s/he attempts the QP activity in the context of video lecture 1. All the processes of EQP and KI are executed by the learners without any prior knowledge about them, unknowingly and infrequently. Thus, in this phase learners perform **"implicit execution"** of the cognitive processes of KI.

During the Categorization and Critiquing Phases

In the categorization phase, the learner dissects, analyzes and evaluates the generated questions. The definitions of the EQP strategies provide the learner with a structure to perform all these tasks. This enables her/him to access, understand and reflect on the roles of cognitive processes of KI that s/he had implicitly performed in QP. This awareness of implicitly executed cognitive processes is known as "knowledge of cognition," which is one of the components of metacognition (Cooper and Sandi-Urena, 2009; Schraw, 1998; Flavell, 1979). Thus in this phase, the learners acquire metacognition of the level **"knowledge of cognition"**.

During the Reflection Phase

As we discussed in Chapter 7 the need for reflection activity arose during the iDEEN iteration when we found that the face-to-face interviews themselves had effects on learners learning. So we decided to convert these opportunities for reflections as a feature of the learning environment. The objective of the reflection questions was to get learners to think about learning objectives mentioned in Chapter 4, and we find that the learners report having achieved those objectives in one way or the other.

The reflection activity, using a series of feedback based reflection questions ensures that: (1) the learner recognizes the KI thinking processes that s/he executed consciously or unconsciously; (2) the learner recognizes that these processes were executed while s/he posed exploratory questions; and (3) the learner recognizes these processes and QP are important for their learning. Learners reported that the broad role of reflection activity was that it helped them in concluding and consolidating their learning. It made them to explicitly think about their thinking, and therefore it assisted in organizing their thought process. So the reflection phase makes the learner synthesize these learnings from the previous phases, contextualize these learnings as an 'important aspect' of her/his ability to learn.

Thus, the Reflection phase makes the learner to reflect explicitly and become aware of how, when, and why to use cognitive strategies (related to EQP and KI). This level of awareness of cognitive strategies (processes) is the "knowledge of cognition" component of the metacognition (Cooper and Sandi-Urena, 2009; Schraw, 1998; Flavell, 1979). In addition to the "knowledge of cognition," Reflection phase also includes reflection question that makes the learner reflect on the planning of how should s/he use her/his learnings from the various phases of IKnowIT in future while watching a new video lecture. This level of awareness is the 'planning' aspect of the 'regulation of cognition' (Cooper and Sandi-Urena, 2009; Schraw, 1998; Flavell, 1979). Thus in this phase, the learners acquire metacognition of the level **"knowledge of Cognition and planning aspect of regulation of cognition"**.

During the QP Phase (in the Second Run)

The second time when the learner attempts the QP activity, the situation is completely different. S/he has now traversed through the three levels of learning of the cognitive processes of KI, viz., 'implicit execution,' 'Knowledge of cognition' and 'planning' aspect of the 'regulation of cognition.' The (video lecture on topic 2). This does not only makes the learner do the different aspects of "knowledge of cognition," but also makes them to "plan," "monitor," and "evaluate" the cognitive strategies that would be important in this QP-phase. Thus, in this phase, the learners acquire metacognition of the level of **"regulation of cognition"** (Cooper and Sandi-Urena, 2009; Schraw, 1998; Flavell, 1979). All other phases after the second QP activity further strengthened these metacognitive abstractions.

Summary

We see that the learner undergoes various levels of cognitive and metacognitive processes (see Figure 9.7) while traversing through the various phases of the IKnowIT pedagogy, as follows:

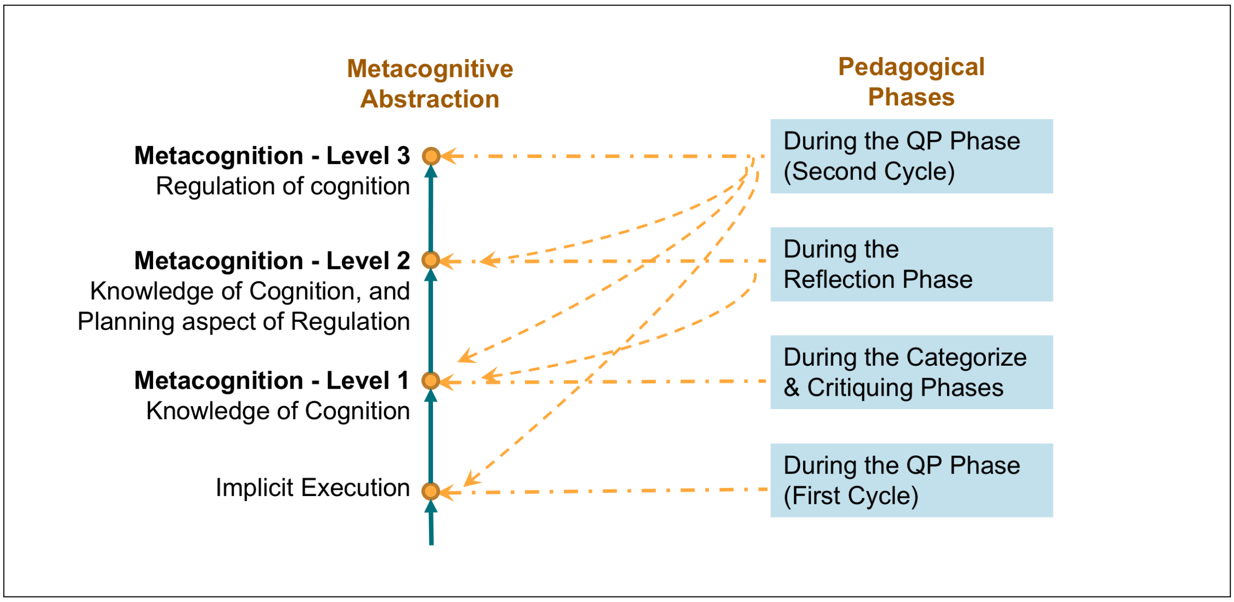


Figure 9.7: Local Learning Theory Summary: How does a learner perform progressive metacognitive abstractions of the cognitive processes of KI in IKnowIT-environment?

1. Implicit Execution
2. Knowledge of Cognition
3. Knowledge of Cognition, and Planning aspect of Regulation
4. Regulation of cognition

These processes do not only ensure that the learner identifies and becomes aware of different aspects of the cognitive processes of KI, but also makes the learner acquire the regulatory awareness of these cognitive processes. This makes it possible that the learner would be able to execute the cognitive processes of KI better, even in the contexts outside the IKnowIT-environment. In Figure 9.7, we see that different phases triggering different levels of metacognition. It should be noted that the QP phase in the second run does not just trigger the metacognition of level 3, but it also triggers the metacognition of other levels 2 and 1. Moreover, it may also trigger the pure cognitive level processes, i.e. "implicit execution." Also, the Reflection phase triggers the metacognition of the level 2 and 1, both.

9.5 Reflections on Forming the Pedagogical Design Principles

In this section, we summarize the pedagogical design principles that emerge from our data. These pedagogical principles may help in designing pedagogies for teaching-learning objectives where one wishes to foster thinking skills or cognitive processes. These pedagogical design principles are captured in following points.

- The key pedagogical idea is to make the learners learn how to use QP as a cognitive tool to foster KI processes. This means that we do not train the learners directly on executing the cognitive processes of KI. Instead, we train them on how to pose better exploratory questions, which in turn implicitly leads to the execution of the cognitive processes of KI. We do this by making learners pose questions and then do metacognitive reflection on them.
- One can design the "non-explicit" and "explicit" metacognition activities using the questions generated by the learners themselves. As in the case of IKnowIT, learners' generate questions, which are used in the Categorize and Critiquing phases to foster "non-explicit" metacognition.
- Different parts of the pedagogy foster different levels of metacognition. Further, one can foster metacognition in two ways. First, non-explicitly, as in the case of the Categorize, Critiquing, and second QP activities, where the learners do metacognition without explicitly being asked to do so. Second, explicitly, as with the reflection questions, where they explicitly think about the QP and KI processes.
- Minimum number of IKnowIT iterations needed are two. It is only the second iteration when a complete "regulation of cognition" is realized.
- The objective of the pedagogy is not to answer the domain-specific question, but it is to train the learners on how to us EQP such that they can perform the cognitive processes of KI better. An instructor or a learner can choose to answer the questions at the end of the IKnowIT session, but not during the IKnowIT session, as it may hamper the continuous

metacognitive processes that the pedagogy is triggering within the learner's mind. The pedagogical design does not require the questions to be even answered, as far as it's purpose is concerned.

9.6 Summary

This chapter presented the qualitative results (local learning theories) of the iterative Evaluation phases of DBR Cycle 2. It has also presented the final reflections on forming design principles. In order to further triangulate the results of the iDEEN study, about the effects of the IKnowIT-pedagogy, we administered additional field studies (Study 6, Study 7), reported in the next chapter.

Chapter 10

Cycle 2: Triangulation of Results

In this chapter, we present further evaluation of the IKnowIT-pedagogy as part of the Evaluation phase of DBR Cycle 2. The Evaluation presented in this chapter was done with an aim to triangulate the qualitative results (local learning theory) obtained in the iDEEN study. Triangulation is done by measuring the effects of the pedagogy on learners' question-posing (QP) quality and explanatory assessment items; and by examining the learners' perceptions of usefulness of the pedagogy. We start by presenting our quantitative findings from the previous study (Study 5). Then we present Study 6, which examines the improvement in the KI quality in learners, as measured by the quality of their responses to explanatory questions. In the end, we present our usefulness and usability studies (Study 7), which re-examines the usefulness of the IKnowIT-pedagogy and examines the usability of the IKnowIT-environment.

10.1 Triangulation Studies in the Evaluation Phase

We triangulated the qualitative results obtained in the iDEEN study by answering following research question (RQ):

- **RQ2b. What are the effects of the learner's interaction with the IKnowIT learning environment on their improvement of knowledge integration (KI) quality?**

The local learning theory has shown how the activities in IKnowIT which are around "learner QP" lead to the fostering of cognitive processes of KI. To triangulate that the IKnowIT-pedagogy is successful in doing so, we administered primarily two-levels of triangulation studies. In the first level, we analyze the **quality of the questions**, generated by the learners in Study 5 to examine the improvement in the learners' KI. In the second level, we analyze the **quality of learners' responses** to explanatory assessment items in Study 6 to evaluate the improvement in the learners' KI. Both these levels are important for a complete triangulation. The first level shows that learners perform improved KI while they pose questions and the second level shows that the learners do better KI while watching a lecture on a new topic. The better KI performance while watching the new video lecture is indicated by better responses to the explanatory assessment items related to that topic. If IKnowIT is found to have positive effects at these two levels, we can say that we have triangulated our results that 'the learners learned how to better use the cognitive tool of exploratory question-posing (EQP) to do better KI.'

10.2 Study 5 - Effect of the IKnowIT-pedagogy on Learners' KI Performance, as Inferred by the Quality of their Questions

This section presents a rubric based quantitative results which inform about the effects of the IKnowIT-pedagogy on learner's improvement of KI. The study implementations have been discussed in Chapter 7 as Study 5. The artifacts used in this investigation were the learner-generated questions in the QP phases, which they submitted to the IKnowIT-environment at the start of the two runs of the pedagogy. In this analysis, we refer to the QP phase of the first run as 'pre-QP activity,' as it happened at the very initial stage of the pedagogy. Whereas, we refer to the QP phase of the second run as 'post-QP activity,' as it happened after the learners have completed one run of the IKnowIT phase. The analysis aim at comparing the qualities of questions generated in the pre-QP activity, with those generated in the post-QP activity.

10.2.1 Analysis of Learner Generated Questions

The standard (Lee et al., 2011) rubric for assessing the KI construct in the learners' explanatory text responses, was adapted (as shown in Table 10.1) for evaluating the texts of the learner-posed questions. The original rubric is meant to analyze the **explanatory text responses** and is not specifically designed to analyze the **'question texts.'** We adapted the same rubric to analyze the question texts generated by the learners.

Analyzing the question text is slightly different than analyzing the text of the explanatory responses. To understand this we need to understand the structure of a question text. A question text can be divided into two parts: (i) one part which contains the "chain of concepts and ideas" on which the question is based, and (ii) the other part which specifies the nature of the question or the "question stem." For example, consider the question, *"Which, between graphs and trees has a better time complexity associated with traversal?"*, and it's equivalent concept-map representation in Figure 10.1.

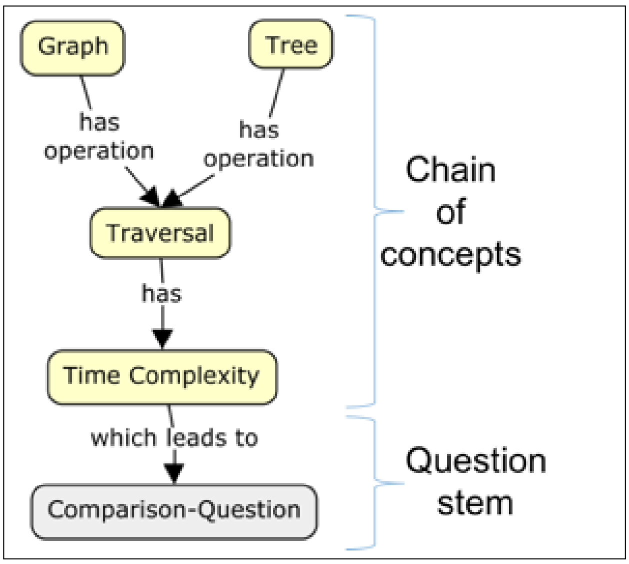


Figure 10.1: KI-Tree representation of a question, *"Which, between graphs and trees, has a better time complexity associated with traversal?"*

This is a "comparison-question," where the learner is inquiring about a comparison between graph Data Structures and tree Data Structures with respect to a property known as "time complexity." Here the "chain of concepts and ideas" is the part of the question text that include "graph," "tree," "time complexity" and "traversal operation," and the "question stem" is identified as "Comparison-question." This is more clearly demonstrated in the previously shown KI-tree corresponding to this question (in Figure 10.1). In a normal text response, we have only chain of concepts, and not the question stem. The adaptation of the rubric to analyze the question text is shown in Table 10.1.

Analyzing any text artifacts (learner's explanatory response or questions) for assessing KI is not a straightforward task. As suggested by the rubric (Table 10.1), the first task in the analysis of the text artifacts is the identification of separate ideas. Then comes the task of identification of links between the ideas. After that, analysts are required to identify if the artifacts have partial-links, full-links or complex links. In parallel, analysts also need to keep assessing if the ideas and links are relevant and valid.

Table 10.1: KI Assessment Rubric (increasing ordinal score from top to bottom)

KI scoring rubric for analyzing learner responses to explanation items (Lee et al., 2011)	**Adapted KI scoring rubric for analyzing learner generated questions in Data Structures**
KI Level 0 - Irrelevant Elicit ideas that are irrelevant to the domain context	**KI Level 0** Elicit ideas that are irrelevant to the Data Structures context, or Elicit non-normative ideas
KI Level 1- No Links Elicit ideas but make non-normative links between the ideas, or Elicit non-normative ideas	**KI Level 1** Elicit ideas but make non-normative links between the ideas, or Elicit one idea with a valid question stem
KI Level 2 - Partial-Link Elicit normative and relevant ideas but do not fully elaborate the links among them	**KI Level 2** Elicit normative and relevant ideas but do not fully elaborate the links among them along with a question link, or Elicit two relevant ideas and connect them with a question stem

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Table 10.1 – *Continued from previous page*

KI scoring rubric for analyzing learner responses to explanation items (Lee et al., 2011)	**Adapted KI scoring rubric for analyzing learner generated questions in Data Structures**
KI Level 3 - Full-Link Elicit two normative and relevant ideas and elaborate one scientifically valid link between the two ideas	**KI Level 3** Elicit two relevant and normative ideas and elaborate a scientifically valid link between them along with one, or more valid question stems
KI Level 4 - Complex-Link Elicit three or more normative and relevant ideas, and elaborate two or more scientifically valid links among the ideas	**KI Level 4** Elicit three or more normative and relevant ideas and elaborate two or more scientifically valid links among the ideas along with one or more valid question stems

To ensure the reliability and validity of the analysis tasks we took two levels of precautions. Firstly, two different analysts performed all the analysis tasks individually, and after analyzing each chunk of artifacts (20-25 questions), they sit together and discuss and revise their analysis till they both come to a common agreement. The analysis experiences were logged and refined, and the analysts used them for the analysis of next chunk of artifacts.

Secondly, to further reduce the subjectivity in the analysis, both analysts used to first create an intermediate representation of the text-artifacts in the form of a tree and then they use the tree to discuss their analysis. This representation is similar to concept-map (Wu et al., 2012) representation shown in Figure 10.1. A node of the tree represents a concept and link represent the relationship between a pair of connected concepts. In this chapter, we call the tree representation as KI-Tree. Below are the steps followed by the analysts to analyze the question-texts.

1. Analyze the question text and create corresponding KI-Tree.
2. Analyze the KI-Tree to identify ideas present in the question-text. (Generally, two valid and relevant concept nodes of a KI-Tree having valid link are considered as one idea.)
3. Analyze the KI-Tree to identify if any two ideas have a valid connection. Such a pair of ideas makes **'full-link.'** However, if ideas do not have connections or valid-connections

then the KI-Tree is said to have only **‘partial-link.’** If there is more than one full link present, then the KI-Tree is said to have **‘complex-link.’**

4. During the discussion with the other analyst, for each question-text first discuss to reach a common agreement over the KI-Tree representation.
5. Then discuss to reach a common agreement over the relevance and validity of the identified ideas, partial-links, full-links and complex-links.
6. In the end, apply the rubric (second column of Table 10.1) to assign scores to each question.

10.2.2 Result

Effect of the IKnowIT Intervention on Learners’ KI

The quality of learner’s questions was used as an operationalization of her/his knowledge integration performance. Rubric and procedure described before were used to assess the quality of the questions generated by the learners.

A Wilcoxon signed-rank test showed that the KI-score of the questions posed during the post-QP activity was statistically significantly higher than the KI-score of the questions posed during the pre-QP activity. The Z-score and significance of the difference are shown in Table 10.2.

Table 10.2: Wilcoxon Signed Rank Test Statistics

N	Z	Asymp. Sig. (2-tailed)
18	-2.463*	.014

*Based on negative ranks.

These statistics come after analyzing the KI qualities of 149 questions coming from 23 learners in Study 5. Out of 149 questions, 80 questions were posed in pre-QP activity (in the start of the pedagogy) and 69 questions were generated in the post-QP activity which was administered after one run of the IKnowIT phases are completed. Out of 23 learners, there were 18 learners who generated questions in both the QP sessions. Therefore we compared the question KI quality scores only for those learners. For each learner, the net question KI quality scores, separately for the pre-QP and post-QP activities were computed by taking the median of the KI scores of each question generated by her/him in that session.

It should be noted that the above statistics correspond to the improvement in KI quality, as demonstrated by the analysis of questions. Moreover, these results correspond to the performance improvements of different learners across various iDEEN iterations. Therefore this result can be used to make claims of effects of only those pedagogical features which were consistently present in all of the IKnowIT-pedagogy sub-versions across the iDEEN iterations. Those features include: 'Minimal EQP Instruction,' 'Detailed EQP Instruction' 'QP-activity,' 'categorization activity' and 'critiquing activity.'

Quality of Learner Generated Question

Distribution of EQP Strategies: We find that the three EQP strategies in Data Structures, 'Apply,' 'Associate,'' and 'Operate' were evident in most of the questions generated by the learners. Out of total 149 questions generated by the learners, 82% of the questions used at least one of the three broad EQP strategies. 6% of the questions were those which used at least two out of the three EQP strategies. This result further revalidates the generalizability of the EQP strategies in the Data Structures domain (previously done by Study 2).

Moreover, in the pre-QP activity total 80 questions were posed out of which 74% of the questions used at least one of the three EQP strategies and in the post-QP activity total 69 questions were posed out of which 91% of the questions used at least one of the three EQP strategies. The increment in the use of the EQP strategies is an indicator that learners may have learned and used the EQP strategies in the post-QP session.

Distribution of Question Stems: As discussed before, a question-text is made of two parts: concept chain and question stem. Table 10.3 shows the distribution of different question stems, present in the collection of all 149 questions generated by the learners. Many questions contained more than one question stems. Few other question stems including "What-if-Question" (2%), "How-much-quantity-question" (2%) had less than 3% frequency. It is interesting to note that EQP strategies are applicable, irrespective of the type of question-stems. Therefore, the opportunity of KI during QP appears to be independent of the question types.

Table 10.3: Distribution of Question Stems

Question Stems	**Frequency (N=149)**
Yes/No - questions	32%
What - questions	19%

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Table 10.3 – *Continued from previous page*

Question Stems	**Frequency (N=149)**
Conceptual How - questions	14%
Comparison - questions	11%
Why-an-idea - questions	9%
Procedural How - questions	9%

10.2.3 Summary

The results have shown that the QP-based activities in the IKnowIT-environment have significant impact on the learners' quality of KI in the learners' questions. In other words, we can say that learners' quality of QP have improved in such a way that they performed significantly more KI during Question-Posing. Moreover, the results about the distribution of EQP strategies firstly revalidates the generalizability of the EQP strategies in the Data Structures domain. Secondly, the increment in the use of the EQP strategies from the pre-QP activity to the post-QP activity is an indicator that the pedagogy has positive effects on learners' use of EQP strategies.

In the next study (Study 6), we present another quantitative investigation, wherein we analyze the KI improvement as reflected by the KI quality of the learners' explanatory responses to a KI-assessment quiz.

10.3 Study 6 - Effect of IKnowIT-pedagogy on Learners' KI as Reflected by the Quality of their Responses to KI Assessment Items

The results from the previous study show that IKnowIT-pedagogy leads to the improvement of KI, as measured by the quality of the questions that they posed in the QP activities. Now, in order to examine if the improvement in KI is also evident when a learner watches a new video lecture outside the IKnowIT environment and answers explanatory questions on that lecture, we administered Study 6. Moreover, in Study 6 we also collect instructor's interview data that would further throw light on the effects of IKnowIT on the learners for a longer time.

10.3.1 Sample

Thirty computer science undergraduates were recruited for this effectiveness study. All of the learners had not studied the Data Structures course in their first year of engineering, and they were about to start studying it in their second year. The recruitment was done from a batch of ninety learners. The session was not mandatory for them. However, the motivation for them was to get a workshop completion certificate from the host university, which is considered to be a big motivation among the learners.

10.3.2 Design

We administered a two-group post-test-only quasi-experimental design. The experimental group had 19 learners, and the control group had 11 learners. The sampling was purposive based on first come first serve basis. Figure 10.2 shows the research design of this study.

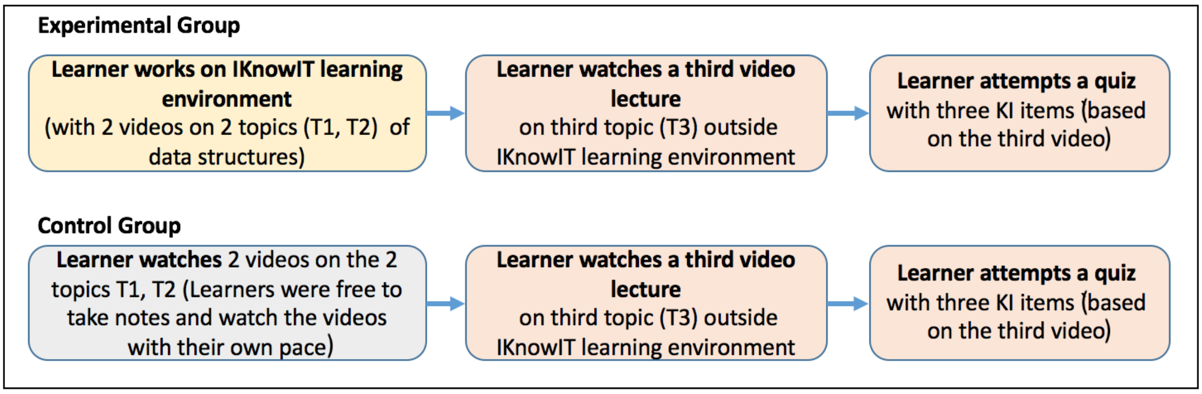

Figure 10.2: Study 6 - Design

10.3.3 Implementation

One session of IKnowIT was administered in the form of workshops for the two groups (control and experimental). Following activities were done in the sessions for the experimental group.

1. The researcher, as an instructor gives a 4-5 minute introduction about the workshop session. The introduction aimed at introducing learners to the four aspects: (1) What are Thinking Skills? (2) Why Thinking Skills? (3) What are we going to learn in this

workshop? (4) Important instructions for attending the workshop. The transcript of the introduction statements from one implementation is given in Appendix IV.

2. Learners are asked to sign-up in the IKnowIT-environment.

3. Learners perform all the activities in the IKnowIT-environment. The Data Structure videos used in the IKnowIT-environment were: (i) ***"introduction to Linked list data structure"***, for the first QP phase, and (ii) ***"introduction to tree data structure"***, for the QP phase in the second run of the IKnowIT-pedagogy.

4. Once the learners complete attempting the activities, we provide them a link to the post-test video lecture (on the topic ***"introduction to graph data structure"***), outside the IKnowIT-environment.

5. After watching post-test video learner responds to the three KI assessment items where they have to write explanations for all the three items.

10.3.4 Data Source

The first data source is the learners' response to the three KI assessment items prepared to test KI. Figure 10.3 shows the test items. Another important data collected was the instructor's interview, which was administered 20 days after the quantitative study. This was done to get an account of the long-term behavioral and/or cognitive changes in the learners.

KI assessment items were created for the Data Structures **(DS)** domain and specifically for the topic of Graph Data Structures. The quality parameters of the assessment items were synthesized from literature (Lee et al., 2011; Liu et al., 2008), and included following characteristics:

1. The item should be such that there is a definite subset of choice(s) which are correct. Essentially, it should be possible to assess the multiple choices as right or wrong.

2. The items should be able to elicit scientific (Data Structure (DS), in our case) ideas and tap varied contexts.

3. The multiple-choice part serves as an anchor for the learner to articulate reasons for choosing a particular answer in the explanation part. (The item should be such that it provides a scope for the explanation of the chosen answer.)

4. The choice of contexts can include abstract as well as everyday uses of the science (DS in our case).
5. All KI items should provide opportunities for learners to link their ideas about scientific phenomena (DS in our case) that vary in difficulty.

In addition to these characteristics, we evaluated the assessment items with a set of learners (not part of Study 6). This helped us in identifying two basic problems with the open-ended explanatory assessment items: (i) firstly, learners appeared to expand their answers when they know that they have extra time; and (ii) secondly, learners also expand their answers when they were told about marks distribution. Length of the explanatory answers are very much subjective to marks and time motivation, that may lead to the threat that the learner presents an inauthentic account of their KI. For this, we restricted the explanatory response length to a maximum of 150 words.

An expert having more than twenty years of experience in teaching Data Structures was consulted and was shown one draft of the assessment items along with the list of above discussed desired characteristics of the assessment items. The items were revised and refined and took shape as shown in Figure 10.3, below.

Q1. Which of the following data structures is/are suitable for implementing an app similar to Google Map Navigation System? (choose the correct answer from below. More than one may be correct)

1. Directed Graph
2. Undirected Graph
3. Weighted graph
4. Unweighted
5. Tree

- Explain and justify your answer in maximum **150 words**.
  (Write your answers in the blank sheet provided).

Q2. Give an example scenario, OTHER THAN THOSE SHOWN IN THE VIDEO where the Graph data structure can be used. Justify HOW and WHY the graph is suitable for those scenarios?

a. First mention the scenario (in one line).
b. Explain and justify your answer in maximum **150 words**.
   (Write your answers in the blank sheet provided).

Figure 10.3: KI Assessment Items - Topic: Graph Data Structures

Out of the two assessment items 10.3, the first question is on choosing a specific type of data structure from among the four options (i.e., 'directed graph,' 'undirected graph,' 'weighted graph,' and 'unweighted graph'), which were described in the video lecture used in the post-test. This means that to answer the first question more deeply, the learners needed better recall and understanding of the topic that they have just studied in the video. Therefore, **the first question would assess how well the learner has integrated concepts close to those within the video.** The second question demanded the learner to come up with an example from real life. Therefore, **the second question would assess how well the learner has integrated concepts both from within the video and from their real-life experiences.**

10.3.5 Analysis and Results

Learner Responses to the KI Assessment Items

The analysis of learner's explanatory responses was done using the guidelines coming from the KI assessment rubric (Liu et al., 2008), shown in the first column of Table 10.1. The challenge in using the rubric directly, was that rubric had only three levels of non-zero scores possible (i.e., in the cases of partial-link, full-link, and complex-link). The discrimination power of the assessment with these number of levels is limited when we are dealing with the learner's responses of 150 words. Most of the learners' responses had more than four well connected normative ideas, that means a learner who used four normative ideas would be given the same score as the learner who used six normative ideas. To address this, we chose to use a simple count of the valid and well-connected ideas present in a response, as it's KI score. Two analysts, who are education researchers and have masters level background in computer science and are well versed with graph Data Structures topic were involved in this analysis. We followed following protocol while analyzing each response.

1. Both analysts skimmed through all the responses once to get an overview of the range of concepts that learners have used in their responses.
2. For each response, analyst read and identified the unit ideas.
3. The analyst then labeled each idea valid or invalid based on whether an idea was normative or non-normative with respect to the Data Structures domain.
4. When 30% of the data was analyzed for the first time, the two analysts sat together, discussed their analysis with each other, and came to a consensus. They modified their previous analysis, if needed and departed.

5. Once the whole corpus of data was analyzed once, analysts again sat together and discussed each analysis until they came to a common decision.

Table 10.4: Results - Study 6 : Mann-Whitney U test

	Mean (sd) (experimental group)	**Mean (sd) (control group)**	**U-Value**	**Z-Score**	**p (2-tailed)**
Question 1	7.11 (2.21)	4.09 (2.17)	36	2.926	0.00338
Question 2	6.05 (2.68)	4.36 (2.11)	66.5	1.614	0.1074
Total	13.16 (4.12)	8.45 (3.36)	39	2.797	.00512
N=30 (11 control and 19 experimental); U at p <.05 is 58					

Scores of the experimental and the control groups were compared using the Mann-Whitney U test. The results are shown in Table 10.4. We see that for the first assessment item the experimental group has performed statistically significantly outperformed the control group. In the case of the second assessment item, the experimental group showed better performance than the control group, but the difference was not statistically significant. When we compare the two groups based on their aggregated score we find that the experimental group has performed statistically significantly better than the control group.

Instructor's interview to examine change in learner behavior

Twenty days, after the IKnowIT session was administered, the course instructor was interviewed. The interview was semi-structured and focused on the desirable behavioral changes in the learners. The interview was transcribed and inductive thematic analysis (Fereday and Muir-Cochrane, 2006) was done to extract range of effects of the IKnowIT session on learners, as perceived by their course instructor. Following themes emerged at the end of thematic analysis:

- The number of questions posed by the learners increased
- Learners started exploring concepts more
- Learners started exploring concepts more - using QP
- On-task behavior increased
- Classroom attention improved
- Learners experimenting on their own increased

10.3.6 Summary

Both quantitative and qualitative results in the Study 6 has shown positive effects of IKnowIT session on the learner's indicators of cognitive processes of KI. The quantitative results have shown a significantly better performance by the experimental group learners, in the first assessment item. Considering the nature of the first assessment item (described in Section 10.3.4), we can say that IKnowIT has affected the learner's ability to do better KI when it comes to understanding and linking the concepts closer to the concepts in the video lecture. However, in the case of the second assessment item, which is more about testing the KI among the concepts more from real life and the video, the difference between the two groups is not statistically significant, though positively inclining towards the experimental group. In case of the aggregated score, the experimental group has significantly performed better than the control group.

These results certainly show that there is a significant positive effect of the IKnowIT session on the learners with respect to some level of KI. Despite N was low (19+11=30 learners), our results have successfully corroborated the positive effects of IKnowIT on learners improvement of the cognitive processes of KI. However, it would be a desirable future work to repeat the same test on larger sample size.

In addition to the quantitative indicators of improvement in KI cognitive processes, the results from the instructor's interview have further ascertained that the IKnowIT has positive effects on the learners' cognitive processes of KI. Presence of the qualitative indicators in the classroom, i.e., increase in the learner's exploration behavior, questioning, attention, and on-task behavior corroborated this. Moreover, the fact that the interview was done after 20 days of the intervention show an encouraging trend about the persistent acquisition of the skills and/or attitude that positively impact KI.

Overall, the quantitative results reported previously from Study 5 (about the quality of learners' response) and the results coming from Study 6 (about the quality of learners' questions), together will triangulate the findings from the local learning theory that IKnowIT-pedagogy successfully fosters cognitive processes of KI in learners, by enabling the learners with a cognitive tool of EQP.

10.4 Study 7 - Usefulness and Usability of IKnowIT

We further triangulate the results using Study 7, wherein we first train the learners on the IKnowIT-environment, and then we survey them to find out their perceptions about the how much are the IKnowIT pedagogical activities are useful and how much is the overall IKnowIT-environment is usable.

10.4.1 Sample

Thirty five Computer Science undergraduates were recruited for the usefulness and usability study. Not all learners studied Data Structures course in their first year of engineering, they were about to start studying it in their second year. Out of the 35 learners, 16 learners were from one engineering college in Mumbai, and 19 learners were from another engineering college.

10.4.2 Design

The study design includes usefulness and usability survey conducted after the learners complete a full session on the IKnowIT-environment, i.e., complete two rounds of IKnowIT pedagogical phases, as recommended in the IKnowIT-pedagogy.

10.4.3 Implementation

Total two separate sessions of IKnowIT were administered for the two groups of learners on two different dates. The session were conducted in their computer labs. Following activities were done in the sessions.

1. The researcher, as an instructor gave a 4-5 minutes introduction about the session similar to the one described in Study 6 (Section 10.3.3) and detailed in Appendix IV.
2. Learners were asked to sign-up in the IKnowIT-environment.
3. Learners perform all the activities in the IKnowIT-environment.
4. Once the learners complete attempting the activities, we provided them link to our survey-questionnaires.

10.4.4 Data Source

The data collection instrument in this study were the two survey questionnaires. The first one was for examining the usefulness and the second one was for usability. We present each of them one by one.

Usefulness Survey

The first survey questionnaire contained three sets of Likert scale questions. The questions were guided by the local learning theory findings from the iDEEN study. The questions are shown in Table 10.5. Out of the three sets of questions, first aims at examining the learners' perception of usefulness of each phase of the IKnowIT-pedagogy. The second set was about learners' perception of the effect of IKnowIT session on their learning of EQP strategies and knowledge about the benefits of QP. The third set of questions aim at examining learners' perception of the effects of the IKnowIT session on their improvement of cognitive abilities related to KI. These include processes and indicators such as: attention, deep understanding, recalling prior knowledge, linking of ideas, identifying gaps, etc.

Table 10.5: Usefulness Survey Questionnaire

Statement	Likert Options
Q1. "How much did each of the following aspects of the class help your learning?"	
(a) Task of QP with video watching	'No help,' 'Little help, 'Moderate help,' 'Much help,' 'Great help,' 'Not applicable'
(b) Reading the slides about EQP	
(c) The task in which you were told to categorize (tag) your questions	
(d) The task in which you were told to analyze your online partner's questions and their categories, and comment on them	
(e) The reflection task in the first round (where you were asked to answer eight questions)	
(f) Repetition of the tasks (round 2) [Watch & Pose questions, Categorize own questions, Critiquing partners' Questions, Reflection]	

Continued on next page

Table 10.5 – *Continued from previous page*

Statement	**Likert options**
(g) Doing the QP and video watching again (with the second video lecture, in the second round)	
(h) The reflection task in the second round (where you were asked to answer the slightly modified eight questions)	
Q2. "As a result of your work in this workshop, what gains did you make in your understanding of each of the following?"	
(a) Knowledge about strategies (categories) of exploratory QP	'No gain,' 'Little gain, 'Moderate gain,'
(b) Knowledge about using QP to do better knowledge integration	
Q3. "As a result of your work in this workshop, what gains did you make in the following skills?"	
(a) Ability to pay attention to any given lecture/video.	'No gain,' 'Little gain,' 'Moderate gain,' 'Much gain,' 'Great gain,' 'Not applicable'
(b) Ability to deeply understand any topic (lecture/video).	
(c) Ability to pose good exploratory QP knowledge.	
(d) Ability to recall prior knowledge related to the given lecture/video.	
(e) Ability to link different knowledge components.	
(f) Ability to find out gaps and inconsistencies in your knowledge.	
(g) Ability to identify whether knowledge expansion is possible.	

Usability Survey

The second survey questionnaire contained ten questions as recommended by the standard "system usability scoring (SUS)" test (Brooke et al., 1996; Bangor et al., 2009). All the questions were five-point-Likert items *(with scales 'Strongly disagree,' 'disagree, 'Neutral,' 'Agree,' 'Strongly agree')*. System Usability Scale was developed by (Brooke et al., 1996) as a 'quick and dirty' survey scale to quickly and easily assess the usability of a given product or service. We choose SUS for the following reasons:

- The study is both easy to use by both study learners and administrators.
- It is technology agnostic and flexible enough to assess a wide range of interface technologies.

- Provides a single score that can be interpreted easily by anyone even without detailed domain knowledge of human factor and usability
- It is reliable (reliability is 0.85, according to Table 1 in Bangor et al. 2008) and non-proprietary, making it a cost-effective tool as well.

The 10 item SUS survey was given to the learners at the end of the IKnowIT session, shown in Table 10.6.

Table 10.6: Usability Survey Questionnaire

Statement	**Likert Options**
1. I think that I would like to use IKnowIT frequently.	'strongly disagree', "disagree', "neutral", "agree', 'strongly agree'
2. I found IKnowIT unnecessarily complex	
3. I thought IKnowIT was easy to use	
4. I think that I would need the support of a technical person to be able to use IKnowIT.	
5. I found the various functions in IKnowIT were well integrated.	
6. I thought there was too much inconsistency in IKnowIT.	
7. I would imagine that most people would learn to use IKnowIT.	
8. Very quickly I found IKnowIT very cumbersome to use.	
9. I felt very confident using IKnowIT.	
10. I needed to learn a lot of things before I could get going with IKnowIT.	

10.4.5 Results

Perceived Usefulness of IKnowIT Session

The usefulness survey administered has thrown light on the three aspects of the effects of the IKnowIT-environment, as follows.

1. ***Usefulness of each phase of the pedagogy***: The results are shown in Figure 10.4. We see that most of the learners perceived all of the phases of the IKnowIT-pedagogy to be of 'much' or 'great' help. Out of which, the QP phase in the second run appears to be perceived as most useful.
2. ***Usefulness with respect to the gains in the learners' acquisition of certain knowledge:***

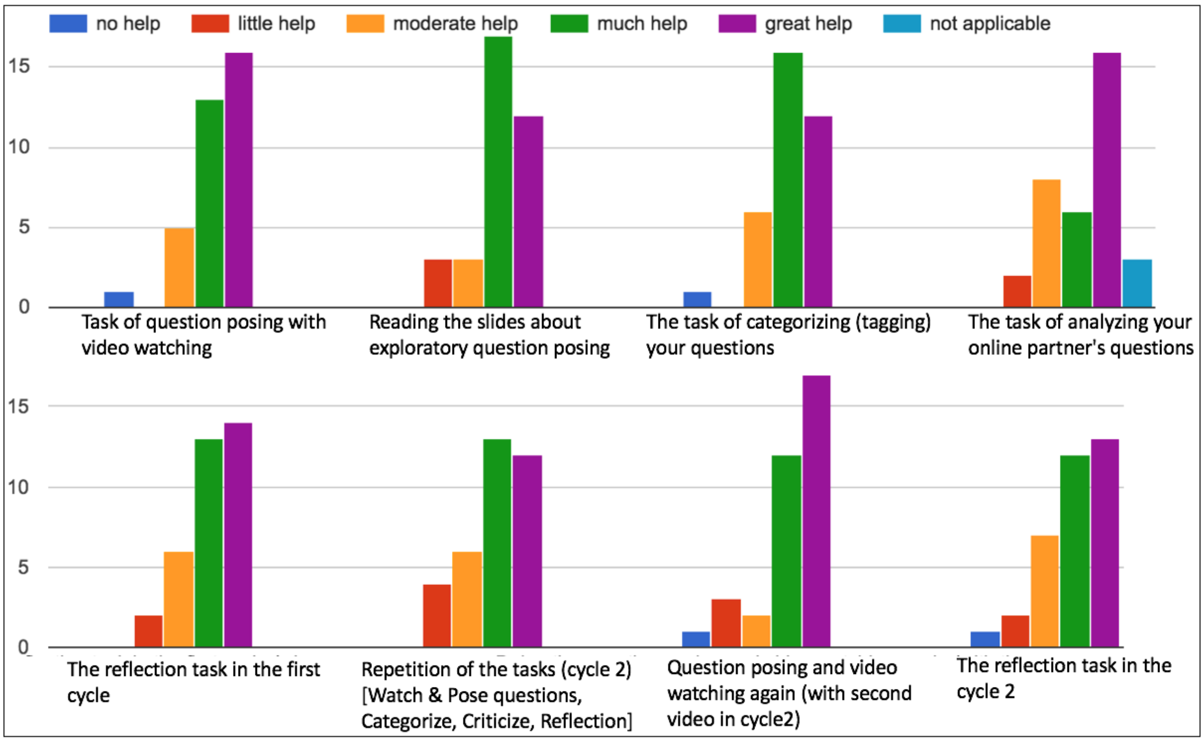

Figure 10.4: Learner Perception of the Usefulness of the Pedagogical Features of IKnowIT on their Learning. N=35

The results are shown in Figure 10.5. We see that most of the learners perceived that the IKnowIT session has made them to learn EQP strategies and develop their understanding of using QP for better KI.

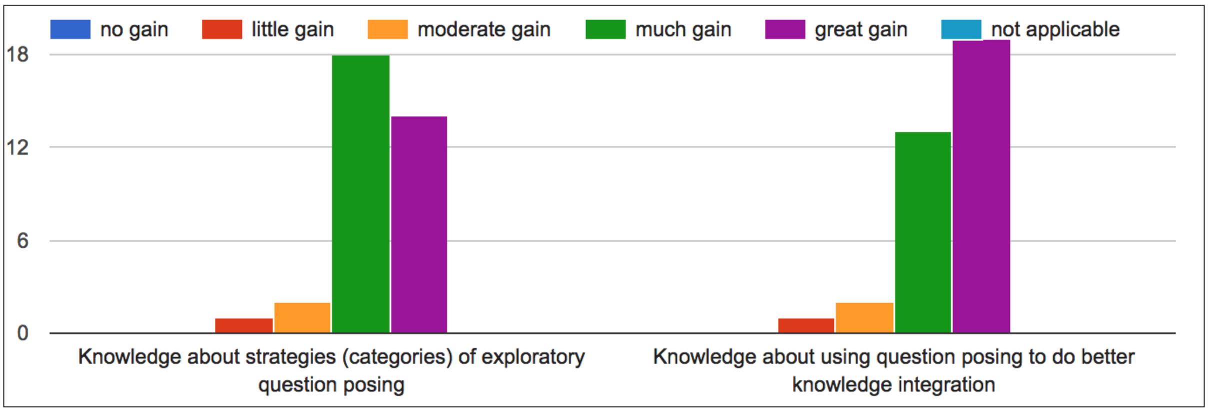

Figure 10.5: Learner Perception of the Gains in their Understandings about EQP and QP. N=35

3. ***Usefulness with respect to the gains in the learners' acquisition of certain skills:*** The results are shown in Figure 10.6. We see that most of the learners perceived IKnowIT session to have improved their skills to: (i) pay attention to a video lecture; (ii) deeply

understand any topic; (iii) pose good exploratory questions; (iv) recall prior knowledge; (v) link different knowledge pieces; (vi) identifying gaps, inconsistencies; and (vii) identifying possibility of knowledge expansion.

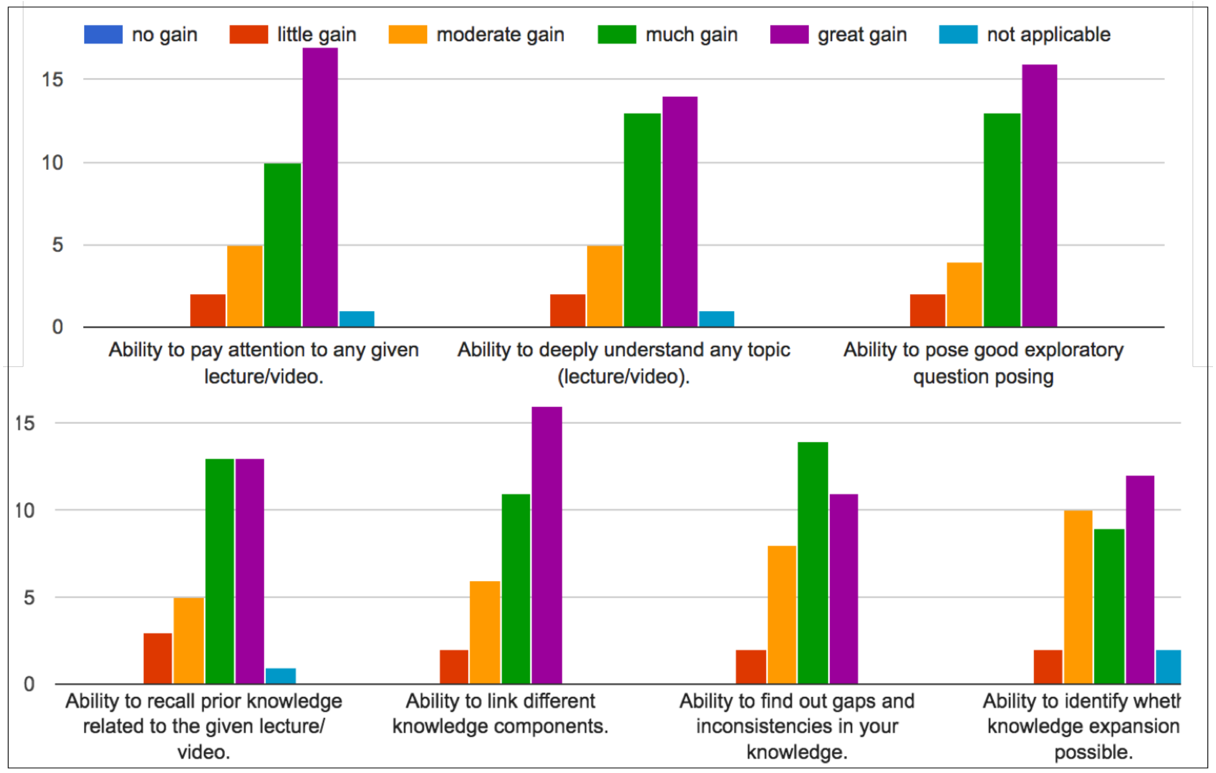

Figure 10.6: Learners Perception of the Gains in their Cognitive Skills. N=35

Perceived Usability of IKnowIT-environment

Out of total the 35 learners, only 27 responded to the SUS survey. The average SUS score was found to be 73.5 (SD = 12.4) for the 27 users. Fig 10.7, given by Bangor et al. (2008) explains how to interpret the SUS score. This shows that the perceived usability of IKnowIT comes out to be between ‘Acceptable’ and more than ‘Good.’

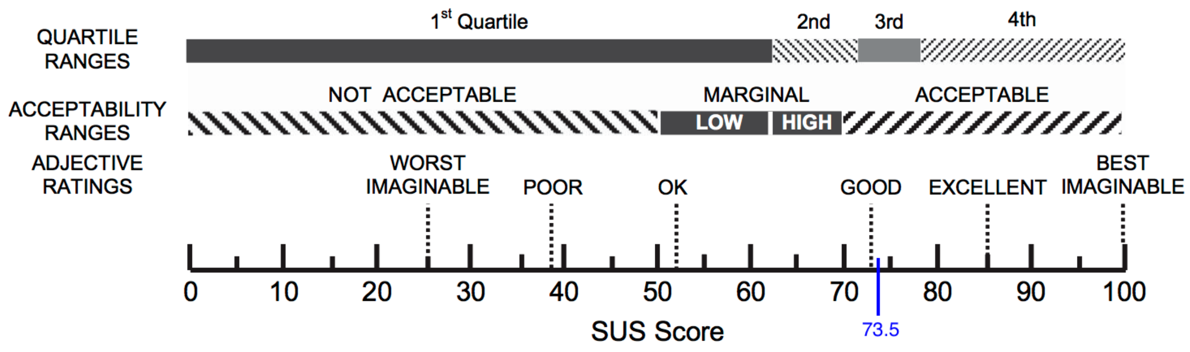

Figure 10.7: Interpreting SUS Score (Bangor et al., 2008). N=27

10.5 Summary

This chapter has presented additional research studies of the Evaluation phase of the second DBR cycle. The studies have successfully triangulated the results about the effect of the IKnowIT-pedagogy in various dimensions. The results of the usability survey establish that the created learning environment is acceptably usable. In the next chapter, we present the final discussions coming out of this thesis.

Chapter 11

Discussion

In this chapter, we first discuss the results of this thesis and show how the results answer each of our research questions. Then we present the generalizations from our thesis followed by the limitations of this research.

11.1 Overview of the Research

In this thesis, we reported two design-based research (DBR) cycles of problem analysis, design, evaluation, and reflection. These cycles led to the design of a pedagogy and development of a corresponding technology enhanced learning environment IKnowIT, which improves learners' cognitive processes of knowledge integration (KI). The key pedagogical idea revolves around learners' question-posing (QP). One of the contributions of the Cycle 1 of DBR is that it has provided a proof of the concept that learner QP can influence the cognitive processes of KI. More specifically, we found that exploratory question-posing (EQP) requires the cognitive processes of KI. Cycle 1 of DBR also contributed to the initial pedagogical design which was a semi-computer based adaptation of guided cooperative questioning (King, 1994b), implemented using the new domain-specific exploratory questioning prompts. The research in DBR Cycle 2 led to the refinement and evaluation of the pedagogy and development of the final learning environment. Cycle 2 of DBR also led to the extraction of local learning theories, which explain the mechanisms of how the learners' interaction with the learning environment leads to the improvement of the cognitive process of KI.

11.2 Answering the Research Questions

RQ1: How is QP applicable for improving knowledge integration?

The first RQ addressed the issue of empirically establishing that learners' QP is applicable for the pedagogy targeting the improvement of KI. This RQ has been answered by the several design and evaluation activities administered in the DBR Cycle 1. The first RQ is answered by answering the four sub-RQs: (i) **RQ1a:** How do the learners integrate knowledge during EQP? (ii) **RQ1b:** Are the EQP strategies 'Apply,' 'Associate' and 'Operate' valid within the domain of Data Structures? (iii) **RQ1c:** Can guided cooperative questioning - based intervention improve learners' KI? (iv) **RQ1d:** What do learners perceive about the guided cooperative questioning based intervention? All these four RQs have been answered by the four research studies (Study 1, Study 2, Study 3, and Study 4) in DBR Cycle 1, respectively.

The results of the inductive thematic analysis of **Study 1** provided three levels of findings. At the very basic level, we saw that learners pose questions either to clarify what has already been said by the instructor or to explore new knowledge. In other words, we can say that with respect to the purpose of questioning, learners' questions can be categorized broadly into two categories: (i) Clarification Questions, (ii) Exploratory Questions. The next level of qualitative finding from Study 1 was that when learners pose exploratory questions they connect the knowledge pieces from the given new knowledge and/or from their prior knowledge. The third level of the finding was that the learners connected different knowledge pieces from their prior and given new knowledge via three frequently-observed strategies, which are: 'Apply,' 'Associate' and 'Operate' (Section 5.1.1.7). These findings show that when learners pose exploratory questions, they elicit their prior knowledge, they add new ideas while they try to connect different knowledge pieces, and they also distinguish among ideas by identifying the gaps, inconsistencies and/or conflicts as they articulate them in the form of questions. This means that the first three processes of KI are executed by the learners when they pose exploratory questions. The results of Study 1 were further corroborated in **Study 2**, which validated that the identified EQP strategies ('Apply,' 'Associate' and 'Operate') are prominent (*frequently-employed*) within the Data Structures domain.

Study 3 and Study 4 used the three strategies as questioning prompts in the adapted versions of the guided cooperative questioning pedagogy (King and Rosenshine, 1993). The quantitative study (**Study 3**) showed that the learners who had undergone the QP-based learning activities performed better in a KI post-test than the learners who did not. The qualitative study (**Study 4**) showed that the learners who had undergone the QP-based learning activities perceived that they had a deeper exploration of the topic.

Therefore, the first two studies (Study 1 and Study 2) showed that EQP makes learners perform various cognitive processes of KI, and the next two studies (Study 3 and Study 4) established that EQP-based pedagogy can be used to affect learners' KI, thus answering RQ1. These results have explicitly established the direct applicability of QP for KI at the cognitive and pedagogical levels, and have empirically shown that EQP can foster the cognitive processes of KI.

In addition to the results related to the applicability of QP for KI, these studies have contributed to the body of knowledge related to the domain of data structures education by explicitly diagnosing the EQP mechanism in this domain.

RQ2: How can training learners on an EQP - based learning environment (IKnowIT) enable them to foster the cognitive processes associated with KI?

To answer the second RQ, we performed the iDEEN study (**Study 5**), where we iteratively evolved the EQP-based pedagogy and qualitatively evaluated the effects of the pedagogical features on learners. The qualitative analysis in the iDEEN study led to the identification of the actual roles that every feature of the IKnowIT-pedagogy plays towards achieving the learning objective of “improving learners cognitive processes of KI.” The findings from this qualitative study, in light of the findings of the studies from the DBR Cycle 1 (**Study 1 through Study 4**), lead to the development of local learning theories (Chapter 9). These local learning theories explain how the learners’ interaction with the pedagogical features of IKnowIT fosters the cognitive processes of KI in the learner. These local learning theories show that the learner undergoes various levels of metacognitive reflections in IKnowIT. Except for the first QP phase, all other phases in the IKnowIT-pedagogy (including the act of repetition) make learners achieve some kind of metacognition.

The first QP phase made the learner perform the cognitive activity of posing question. The Categorization and Critiquing phases made the learners to diagnose and analyze the questions that they and their online partners have generated. This lead to the metacognitive activity in which the learners, (non-explicitly) reflect about how did they use their prior knowledge and new knowledge, and linked them while coming up with any question. The reflection phase of the pedagogy made the learners to do an explicit and even higher level of metacognition, where they explicitly synthesized various aspects of their experience, which are: (i) the cognitive processes that they executed while questioning; (ii) the importance and the benefit of the questioning to their learning; (iii) the strategies (using EQP) that they would adopt to learn any new topic in future. Another metacognition, of a further higher level, is performed by the learners when they undergo the QP phase the second time. While the first run of the IKnowIT phases had provided learners the understanding of the cognitive processes, their importance to learning and strategy for future learning, the second run (especially the second QP phase) provided learners with practice in applying what they understood from the first run, so that they recognized that it actually works.

The local learning theories are the answer to our second RQ. However, the quantitative results from **Study 5**, and **Study 6** further corroborate the results, specifically, the result related to the improvement of KI quality of the questions generated by the learners in the second QP phase as compared to the first QP phase. These results show that the learners did significantly better KI while generating questions the second time. The results of Study 6 show that the learners in the intervention group perform better KI as reflected by their understanding of a third topic (not used in the first and second QP phases). However, out of the two post-test KI-assessment item, we saw a statistically significant difference between the groups only on one question, and on the aggregated score. On the other KI-assessment question, while there was a positive difference between the groups, it was not statistically significant.

Interestingly, the instructor's interview done 20 days after the intervention has triangulated the prolonged positive effects of the intervention on the learners. The analysis shows that, as per the instructors' observation, the learners who had undergone the IKnowIT session tend to ask more questions in the class, they have started exploring concepts more, their on-task behavior increased, classroom attention improved, and the learners increasingly started experimenting on their own. These behavioral observations show desirable changes in the learners, which are the indicators of an increase in learners' KI processes.

It should be noted that IKnowIT-pedagogy does not only improves cognitive processes of KI, but it also improves learners' EQP skills. This has been explicitly proved by the quantitative part of the Study 5 (Section 10.2), where we see that the quality of learners' questions have significantly improved due to IKnowIT-pedagogy, where the goodness measure of questions are determined by their KI quality.

While answering RQ2, we contribute not only with a learning environment, but also with a pedagogy, pedagogical design principles and set of local learning theories. Therefore, by this research, we do not just cater to our specific research problem, but we also contribute to the body of knowledge related to the domain of Question-Posing and knowledge integration research, in general.

RQ3: What are the usefulness and usability of IKnowIT-environment as perceived by the learners?

The surveys administered in **Study 7** have thrown light on the various aspects of the usefulness of the learning environment. The system usability survey (SUS) has quantitatively established that the learning environment is acceptably usable. The usefulness survey results can be broadly classified in three parts: (i) usefulness of each phase of the pedagogy (ii) usefulness with respect to the gains in the learners' acquisition of certain knowledge and (iii) usefulness with respect to the gains in the learners' acquisition of certain skills.

Regarding the usefulness of the pedagogy phases, the majority of the learners perceived all of the phases to be either much or greatly helpful. Specifically, we saw that the second QP phase was perceived to be "greatly helpful" by more number of the learners than the first QP phase. This corroborates our findings from Study 5 (discussed in the previous section), which has explained the importance of the second QP phase.

Regarding the usefulness with respect to the gains in the learners' acquisition of certain knowledge and skills, we again found that there were very fewer number of learners reported to have 'no' or 'little' gains. Most of the learners perceived that the learning environment has led to 'much' or 'great' gains in terms of the knowledge about the EQP strategies and the knowledge about using questioning to get deeper conceptual understanding (KI). Similarly, the learning environment was significantly perceived to be helpful in improving the abilities of **(a)** paying attention to a given topic/lecture; **(b)** deeply understanding any topic/lecture; **(c)** posing good exploratory questions; **(d)** recalling prior knowledge related to the given topic/lecture; **(e)** linking different knowledge pieces; **(f)** finding out gaps inconsistencies in one's knowledge; and **(g)** identifying whether the knowledge expansion is possible or not.

It should be noted that, the ability to recall prior knowledge corresponds to the first cognitive process of KI, similarly the ability to pay attention to the given knowledge and the ability to link different knowledge pieces correspond to the second cognitive process of KI, and together correspond to the third cognitive process of KI, i.e. distinguishing among ideas. This corroborates our findings of the previous studies by implying that the learners strongly perceived that different cognitive processes of KI are positively affected by the IKnowIT session.

11.3 Establishing Generalizability

The goal of this thesis was to design a pedagogy to foster cognitive processes of KI in learners and to evaluate if and how the pedagogy leads to the fostering. Thus the central part of the thesis is the IKnowIT-pedagogy. Another important aspect of the thesis is the set of the three EQP strategies. These EQP strategies play a crucial role especially in the Categorization and Critiquing phases of the pedagogy and supporting learner's important metacognitive processes during these phases. We thus examine the thesis work for generalizability around these aspects.

11.3.1 Establishing Generalizability of the Pedagogy

The effects of the pedagogy seem to be generalizable across various topics within the Data Structures domain. Except for the lecture video and the Data Structures specific EQP strategies, there is no other resource in the intervention which is domain specific and used by the pedagogy. It should be noted that the lecture video and the EQP strategies are just the learning artifact/resource that the pedagogy consumes, and themselves are not a part of the pedagogical design. Therefore, the pedagogy in isolation is domain independent. Domain (the topics) used in the lecture video and EQP strategies are just the vehicle that pedagogy uses to train the learner on the cognitive processes of KI. While designing (evolving) the pedagogy, domain did not play any apparent role. Even, while extracting the local learning theories, we could not find a single instance where it appeared that the pedagogical design is domain dependent. In this thesis, we have established that the within-domain-transfer (near transfer) (Perkins et al., 1992) is successful, i.e., the learners trained using two different topics of Data Structures and demonstrate the positive effects in a third topic in data structure. However, if someone wants to embed IKnowIT in another course or domain and does not want to use the Data Structures topics as the training vehicle, s/he may need to use the EQP strategies and the lecture videos specific to that domain. Generalizability with respect to the EQP strategies is discussed in the Section 11.3.2.

The pedagogy was largely designed using the iDEEN methodology in Study 5. The design decisions were driven by the data collected about the "learner's experiences with the pedagogy and the learning environment." These learners were sophomore Computer Science (CS) undergraduate engineering learners, and have specific characteristics. These learners had recently entered into the second year of their engineering undergraduate program. They belong to a mid-tier (Hewner and Mishra, 2016) Indian engineering institution. The pedagogical design is generalizable to all the learners having similar characteristics. However, we don't claim generalization of the pedagogy for a learner belonging to a top-tier (Hewner and Mishra, 2016) Indian engineering institution. The top-tier learners are among the highest ranked (they are among the top 1000 out of 500000 learners) in an extremely competitive exam testing analytical skills (Mishra and Iyer, 2013), and the pedagogy may play out differently for those learners. Regarding prior knowledge of the learner, the local learning theories have shown that the pedagogy plays differently for the learners with different prior knowledge. Still, the pedagogy affects all the learners. The generalizability of the pedagogy for a wider range of learners and learner characteristics would need further investigation and may be undertaken as future directions of this thesis research work.

11.3.2 Establishing Generalizability of the EQP Strategies

To understand how much the EQP strategies are generalizable, we need to reflect on the role of the EQP strategies in the pedagogy. The role of the EQP strategies is discussed in detail in Chapter 9. Broadly, the role of the EQP strategies have two facets: (i) primarily, they help the learners to analyze their generated questions and perform the metacognitive reflection of how they used their prior knowledge and the new knowledge while coming up with any question; (ii) secondarily, they help the learners as a tool/template to explore knowledge and generate questions. As far as the first task of analyzing the questions is concerned, the learners need to do following:

1. Reflect and identify the prior knowledge used in a question.
2. Reflect and identify the (new) knowledge/concept used in the question from the video lecture.
3. Analyze the nature of the link between the prior knowledge and the new knowledge, and compare it with the nature of links described for each of the three EQP strategies ('Apply,' 'Operate' and 'Associate'). If none of the three strategies matches the nature of the link between the prior knowledge an the given knowledge, then choose the option 'others.'

We see that, while analyzing the questions, even if none of the three EQP strategies matches with the nature of link(s) present in the question, then also the learner performs all of the analytical processes. Therefore the primary goal of performing the metacognitive reflections (about one's cognitive processes of QP) is achieved using the current set of the EQP strategies, irrespective of the domain.

However, only for the secondary role of using the strategies as a tool/template to explore knowledge and generate questions, if one wishes to use IKnowIT in another domain, one needs to choose domain specific EQP prompts. In this case, we claim our generalizability across different topics within the Data Structures domain only, as Study 1 and Study 2 has validated that the three EQP strategies are significantly observed across the learners' exploratory questions in various topics within the data structure domains.

However, one can speculate that 'Apply' and 'Associate' strategies would be prominent (*frequently-employed*) in several other domains too. The 'Apply' strategies correspond to the links such as *"one knowledge piece is 'an application' of another knowledge piece."* Therefore it should be prominent in all computer application domains or even engineering domains, where concepts have applications. The 'Associate' strategies are even more generic, as they correspond to the links such as *"one knowledge piece is 'contrasting,' 'different,' 'similar,' or 'analogous' to another knowledge piece."* The third EQP strategy ('Operate') is more specific to the Data Structures domain, and it could be applicable to only those similar domains which involve some kind of implementations or operations. One needs to perform a detailed characterization of the new domain to identify the prominent patterns of the links in that domain, before evaluating if our EQP strategies are applicable to it or not. One possible methodology to perform the domain characterization is to replicate method used in Study 1 with the new domain. This methodology can also be used to extract the prominent EQP strategies specific to any other domain, as, we did for the Data Structures domain in this thesis.

11.4 Limitations of Thesis

The research carried out in this thesis has the following limitations:

1. **Limitations related to Learner Characteristics**

   As discussed before, all of the studies have been done with the sophomore engineering undergraduates coming from mid-tier (Hewner and Mishra, 2016) engineering institute, who have just entered into their second year. These learners were computer-literate and had already taken a formal course on introduction to programming, which is a precursor to the Data Structures course, which had been used in field studies administered in this thesis. The findings of this thesis are limited to these academic (learner) characteristics.

   In addition to the academic characteristics (prior knowledge, education level, education type, computer literacy), various personal, social, emotional and cognitive characteristics may affect the learning experience. Some of these characteristics may include age, gender, language, social-economic status, cultural background, learning style, attention span, learning traits, etc. It is desirable to develop learning materials that would be appropriate for learners from a wide range of academic backgrounds. Hence our primary focus was on the academic characteristics of the learners, and we ensured, wherever appropriate, academic equivalence of learners in the research studies we conducted. Thus, the results of this thesis are not generalizable to other characteristics of learners such as their affect and motivation. This limitation can be taken up as an opportunity for future research to ensure that IKnowIT is useful and effective for an, even wider range of learners.

2. **Limitations Related to Domain**

   The domain context plays a crucial role in the acquisition and demonstration of any thinking skill. As discussed before, topics from Data Structures were used in all of the field studies as a vehicle to train the learners, and also as a context where the effects of the training were assessed. Exactly what would happen if the topics from other undergraduate domains (engineering as well as non-engineering) are used, can only be known by administering separate research studies in future. Applicability of the findings from this thesis will depend on the features of the topics and the specific domain of engineering being considered. Hence, we must be careful while generalizing these research findings even to other domains within engineering.

3. **Limitations Related to Research Method**

   The overarching research design of this thesis is design-based research (DBR). The goal of the thesis was to design a pedagogy and identify the mechanisms (local learning theories) that explain how the pedagogy effects the learners. Therefore, the inquiries in this thesis are primarily qualitative in nature. The quantitative studies were used either to establish validity of (as done in Study 1, Study 6 and Study 7) or to get a proof of concept (as done in Study 3 and Study 4). The two broad qualitative inquiries, in Study 1 and Study 5 form the main body of this thesis. Thus, this thesis is primarily limited to qualitative methods and results. With the final pedagogy we may, as part of future work, do randomized control studies to extend this research further.

   As far as the local learning theories are concerned, they were identified through the iDEEN process, which is based on the philosophy of the grounded theory. One of the characteristics of the grounded theory analysis is that the direction of theory development depends heavily on theoretical lens which has been used for analysis. Moreover, the direction of analysis is also subjective to the team of analysts, and therefore it can vary from another set of analysts, even if theoretical lenses are kept constant. Therefore, one may identify a new set of theories, if different theoretical lenses and analysts are used. We limit our qualitative claims to theoretical lens as described in Section 7.2.5, further expansion of these findings can be an interesting future work.

4. **Limitations Related to KI Processes**

This thesis has focused on the three processes of KI Linn (2013), viz., (i) eliciting prior ideas; (ii) focusing on new ideas; and (iii) distinguishing among ideas. These three processes can be executed using cognitive resources. The fourth process of sorting out ideas requires the learner to address (get the answer to) the gaps, inconsistencies, or conflicts that s/he has identified by the time s/he has executed the “distinguishing among ideas” process. Therefore, the fourth process requires the learning environment to facilitate the learner with external resources, such as internet-wikis, knowledge base, or a teacher. We train the learners on how to do exploratory questioning better such that the first three processes can be executed at the cognitive level. By the end of the EQP, our learner is ready with the articulation of the gaps, inconsistencies, or conflicts in the form of a question statement. It can be anticipated that this articulation would aid the ‘sorting-out’ process. The quantitative results in DBR Cycle 2 seem to support this assumption. However, we do not train the learners on how to use the articulated questions to further carry out the ‘sorting-out’ process. To investigate how an explicit training of this kind would change the effects on the learners KI performance can make for interesting future work.

5. **Limitations related to Usability of the Learning Environment**
   Although Study 7 establishes that the learning environment is acceptably usable, this does not mean that there is no scope for improvement in the user experience as far as the user-interface is concerned. Currently, the user interface is only fit for the desktop-based browser; we have not yet adapted it for the hand-held devices. The user experience may vary with the variation in the type of device. These variations could be screen size, input devices (keyboard versus touch screen), portability, etc. The IKnowIT-pedagogy largely deals with the activities at the metacognitive level, therefore it should be investigated that how would these variations affect the learning experiences. This could be an interesting agenda for future work.

11.5 Who can use IKnowIT?

IKnowIT is an online self-learning environment. It has ideally been evaluated for the undergraduates who have not already studied the Data Structures course. Although the IKnowIT-environment is self-learning yet the teachers may choose to train their learners with IKnowIT in a lab-based workshop mode.

For Learners

Any undergraduate learner who is willing to improve her/his cognitive processes associated with KI can choose to login and learn from IKnowIT. The current version of IKnowIT-pedagogy assumes that the learner has willingness and interest to improve her/his thinking skill and do harps much on fostering interest in the interested learners. This implies that the learners who are willing to use the IKnowIT-environment should seriously and carefully attend to each and every instruction given by the IKnowIT-environment.

For Teachers

Though the IKnowIT-environment is primarily built for improving learners' cognitive processes of KI, there could be a range of ways in which the teachers can adapt IKnowIT into their curriculum. For example, the teachers can choose to implement the IKnowIT based session as a part of their lab work. Another adaptation could be to use the IKnowIT-environment a platform to disburse their flipped classroom learning videos. This would ensure that the learners do not just watch the lecture videos actively, but it would also make them acquire the thinking approach of posing exploratory questions to do better KI. The teacher would be able to collect the set of questions posed by the learners which can further be used to plan the face-to-face discussions and activities.

As far as the use of IKnowIT by the teachers from the domains other than Data Structures is concerned, IKnowIT may require additional knowledge. The current system uses EQP strategies which are inductively extracted from data obtained from the field studies in the context of Data Structures course. For the teachers who want to use the system with the QP situation (video lecture) from other courses or domains, the current set of questioning strategies need to be validated for the new domain and/or the new set of strategies are to be inducted using the methodology that we have used in the case of Data Structures (as described in Chapter 5).

Chapter 12

Conclusion

This chapter summarizes the contributions of this thesis work, discusses the future research directions coming out of this thesis, the presents the final reflections of the researcher about the thesis.

12.1 Thesis Contribution

This thesis makes contributions in the field of educational technology, specifically in the research area of technology-enhanced learning of thinking skills (TELoTS) (Murthy et al., 2016), more specifically in improving the cognitive processes of knowledge integration (KI). The contributions, primarily are in terms of pedagogy (IKnowIT-pedagogy), educational technology tools (IKnowIT-environment) and knowledge in the form of local learning theory. In this section, we report the contributions of this thesis, as identified in the three categories, viz., (1) research contributions, (2) development contributions, and (3) outreach contributions, as follows.

1. **Research Contributions**

   (a) ***IKnowIT-pedagogy***

   The IKnowIT-pedagogy is designed to foster learners' cognitive processes of KI. The pedagogy trains the learners on how to pose better exploratory questions, which in turn improves their cognitive processes of KI. Therefore, the pedagogy does not only improves cognitive processes of KI, but it also improves learners' EQP skills.

   Who can use it: Consumers of the IKnowIT-pedagogy could be the technology-enhanced learning (TEL) environment developers and teachers, who wish to operationalize the pedagogy in a face-to-face classroom environment or by implementing a TEL environment.

   (b) ***Exploratory Question-Posing (EQP) Strategies***

   These are the domain-specific questioning strategies from the Data Structures domain. In addition to the IKnowIT-environment, they can be used as the question-posing (QP)-prompts also with any other pedagogy that involves learner-QP activity and which is implemented with the undergraduate Data Structures learners.

   Who can use it: Students, Teachers, Researchers, all who want to create any QP based activities in Data Structures.

   (c) ***Local Learning Theories (LLTs)***

   The LLTs describe mechanisms of how the learners' interaction with the learning environment features can lead to the improvement of her/his cognitive processes of KI. Theories throw light on the role of QP activities and the EQP strategies in the context of IKnowIT-pedagogy. These theoretical insights can be used by the researchers and the teachers, who wish to work with QP, EQP prompts, or even video lectures, to make more informed research and pedagogical decisions. More interestingly, the LLTs demonstrates how the cognitive and different levels of metacognitive processes come together and lead to the learners' improvement of a thinking skill (KI processes).

   Who can use it: Researchers, who want to work in the domain of QP, cognitive processes of KI, and TEL environment for learning-teaching of thinking skills.

Practitioners who are willing to employ QP based pedagogical techniques or KI as instructional objectives in their classrooms will also find these local learning theories helpful.

2. **Development Contribution**

   (a) ***IKnowIT learning environment***

   The IKnowIT-environment is a TEL environment that instantiates the IKnowIT-pedagogy, as a web-based self-learning environment. It can be accessed, preferably from any desktop-based internet browser. Currently, the environment contains the EQP strategies extracted from Data Structures domain. Therefore it is ready to be incorporated into any Data Structures course by any instructor. Any Computer Science (CS) undergraduate, who has not undertaken the Data Structures course formally, but have completed the introductory programming course can use the environment with the pre-embedded Data Structures videos. Else, s/he need to provide a link to any other two Data Structures videos containing the topic which s/he has not studied before.

   Who can use it: Undergraduate students who wish to improve their cognitive processes of KI, and the teachers who wish to train their students on EQP or KI.

   (b) ***Iterative Design Evaluation and Evolution (iDEEN) Method***

   iDEEN is a qualitative research method based on the principles of grounded theory and education design research. The method works similar to the grounded theory approach, but in addition to just producing data-driven theories, it also produces data-driven design decisions. The method can be favorably used to design any TEL environment and extract underlying local learning theories.

   Who can use it: Researchers, who want to design TEL environments.

3. **Outreach Contribution**

   We trained 785 undergraduate students in Data Structures topics at various stages of this exploratory research. Most of these trainings were the pilot studies which we administered in the initial years of this Ph.D. to explore various research directions. Studies in this thesis (Study 1 through 7) was administered with total 255 out of these 785 learners.

12.2 Future Work

In this section, we present a list of plausible future work that comes out of this thesis. Some of these future work proposals come out as the solution to address the limitations of this thesis, discussed in the previous chapter, while others come out with an objective to further push the research agenda of this thesis. We report each of the proposals one by one below.

12.2.1 Related to the Affective Factors of the Learners

Studying the effects of learners' initial affective aspects on the performance of the IKnowIT-pedagogy

In this thesis, we scoped the sampling criteria only to the academic characteristics, which include learners' year of study and field of study. The learners in all of the studies were invited on a voluntary basis, with an external motivation of getting a participation certificate from a reputed institute (Hewner and Mishra, 2016). Therefore we can assume that combination of this external motivation and some sort of their internal motivation may have led them to voluntarily participate in the studies. Investigating learners' intrinsic motivation and other affective factors as learners' characteristics were kept out of the scope of this thesis. However, we propose that examining the effects of these affective factors on the performance of the IKnowIT-pedagogy and learning environment would be an interesting research objective to pursue in the future. We propose following as future research questions (RQs):

1. **RQ:** Which affective aspects of a learner can impact her/his learning in the IKnowIT environment?

2. **RQ:** How do the affective aspects of a learner impact her/his learning in the IKnowIT environment?

These affective factors may include, but are not limited to, following factors: (i) Intrinsic motivation of the learner towards improving the KI skill; (ii) Intrinsic motivation of the learner towards improving the QP skill; (iii) Learners' self efficacy about how well /she can perform KI and/or QP; (iv) Learners' self efficacy about how well /she can work in a web-based environment; (v) Learners' outcome expectations; (vi) Learners' task interest/value; (vii) Learners' goal orientation.

Studying the effects of IKnowIT-pedagogy and learning environment on learners' affective factors

On one hand, as discussed in the previous subsection, the affective states of learners can have effects on the learners' improvement of cognitive processes of KI. On the other hand, the current version of the IKnowIT-pedagogy and learning environment may also have effects on the learners' affective parameters, such as her/his motivation towards posing questions, exploring knowledge, self-efficacy, etc. It would be interesting to answer following future RQs.

1. **RQ:** Which affective aspects of a learner are influenced by the IKnowIT session?

2. **RQ:** How does the IKnowIT session impacts various affective aspects of a learner?

In this thesis, we found that the IKnowIT environment successfully makes the learners recognize the importance of QP and other important cognitive processes. However, it would be interesting to explicitly investigate the effects of the IKnowIT session on the learners' affective aspects, beyond just recognition of these specific aspects (questioning and exploration).

Improving learners intrinsic motivation to improve authentic engagement with the TEL environments for learning of thinking skills

To make the pedagogy and the environment effective, we need to ascertain whether the learner does authentic engagement with the learning environment. We need to make sure that the learner has a buy-in into the learning objective of improving cognitive processes of knowledge interaction. Having this buy-in is challenging, as the improvement of "KI" (or, even other thinking skills) is not a part of the regular curriculum due to which we cannot offer any motivation such as exam-grades or certificates, etc. Moreover, we have envisioned and created the IKnowIT environment as an online self-learning environment. This makes the task more challenging, as there is very less scope for providing personalized motivational support. Unlike the previous two future work proposals, which either study the affective aspects as the input or output learner characteristics with respect to the IKnowIT-pedagogy, this future work proposal targets the improvement of one of the learners' affective aspects. The future research problem that we propose here can be expressed as following RQs.

1. **RQ:** How to ascertain that the learners do authentic engagement in the IKnowIT environment?

This RQ would require following specific RQ to be answered.

2. **RQ:** How to foster the learner's buy-in into the problem that the IKnowIT (or any other TEL environment that is meant to improve learner's thinking skills) system is solving (improvement of cognitive processes of KI)?

The second RQ requires the learner to recognize that the problem of being not effectively able to do KI is worth addressing, as it can directly impact her/his learning. Further, we can target the improvements in the affective objectives as per several levels of Bloom's affective taxonomy (Bloom et al., 1964), i.e., we can choose to design a solution for the following affective objectives: (1) Learner follows or attends to the learning activities in the learning environment; (2) Learner answers, responses, or engages with the learning activities in the learning environment; (3) Learner values the learning activities in the learning environment. These objectives are corresponding to the bottom three objective-levels of the bloom's affective taxonomy (Bloom et al., 1964), i.e., receive, respond and value respectively.

12.2.2 Further Effectiveness Studies

Effect of Number of Times a Learner Undergoes The IKnowIT sessions

One of the questions that needs to be answered in future is how many runs of the IKnowIT-pedagogy is sufficient for a desirable level of training on using EQP to foster the cognitive processes of KI. This thesis recommends that minimum two runs are necessary. A longitudinal study may be administered to answer this question.

Randomized Control Quantitative Studies with Large Sample Size within the Data Structures Domain

This thesis primarily deals with qualitative analysis and findings. A quantitative study similar to Study 6, but with large sample size, would throw more light on the generalizability of the effects of IKnowIT. It would be desirable to execute one such study within the Data Structures domain.

Randomized Control Quantitative Studies with Large Sample Size in another CS or a Far Domain

As discussed in the limitations (previous chapter), this thesis doesn't examine the effect of the current state of the IKnowIT-environment on post-test topics from other domains. However, the effects have been seen across different topics, within the Data Structures domain. Examining the effects using the post-tests in other topics is important in order to verify if the skills acquired by the learners in IKnowIT is pan-domain or not. This examination would also throw light on whether the set of EQP strategies (from Data Structures) can be used to train learners from different domains.

12.2.3 Furthering the Research related to the Technology-Enhanced Learning of Thinking Skills

Applying the pedagogical design principles to the learning of other thinking skills

This thesis treats the cognitive processes of KI as a thinking skill that can be trained and improved. This skill seems to be a low level thinking skill when we compare it to other complex thinking skills such as troubleshooting (Alse, 2016), estimation skills (Kothiyal et al., 2016), etc. Moreover, skills such as computational thinking, problem-solving, critical thinking, etc. are even broader and complex. It would be interesting to see how the pedagogical principles emerging from this thesis can be applied to design pedagogies for the teaching-learning of other thinking skills.

Re-analyzing the qualitative data from different theoretical lens

Analyzing the qualitative data collected in the iDEEN study using a different theoretical lens can yield a new range of insights. One plausible lens could be from the methods perspective. The iDEEN interviews were semi-structured, and the interview-questions, that helped in extracting the cognitive and metacognitive processes, evolved within individual interviews and with iDEEN iterations. Analyzing how the interviews progressed and what range of interview-questions evolved, may help in coming up with guidelines for data collections (especially interviews) to mine the metacognitive processes of the learners in TEL environment. This is important, especially for the research related to the teaching-learning of thinking skills.

These guidelines can be a part of the next version of recommendations for the iDEEN method.

12.2.4 IKnowIT Further Development

Identification of generic EQP strategies

To ease the task of instructors and researchers who wish to use IKnowIT, it would be desirable to identify the generic set of EQP strategies which can be used with a wider range of domains.

Improving the Portability of IKnowIT

Currently, the IKnowIT-environment can run well on desktop browsers. It would be desirable to improve the portability of IKnowIT-environment such that it can be easily used with the hand-held devices. Moreover, even though the IKnowIT environment got good scores in the usability survey, further enriching the user experience in the current user interface can be done.

12.2.5 Utility of individual Modules of the IKnowIT-environment in Isolation

The IKnowIT-environment is made up of different user interfaces (UIs) corresponding to different pedagogy phases. These UI modules, in isolation of the whole IKnowIT-environment, can have distinctive utility and usefulness. One of such UI module in IKnowIT is the "QP-environment," (see Table 8.1) corresponding to the QP-phase of the IKnowIT-pedagogy. Even if someone is not using the complete IKnowIT-environment, s/he can use its QP-environment in isolation. We may conjecture that a learner watching a video lecture on the QP-environment would have a better learning experience than a learner watching the same video lecture on traditional video player environments. It would be interesting to empirically examine the effects of the QP-environment as a separate tool on learners' comprehension of any video lecture.

Moreover, in the post-tests (in our studies) we made the learners watch the post-test video outside the IKnowIT environment. It would be interesting to study how the KI performance varies if the same post-test video is watched on this QP environment.

12.3 Final Reflections

This thesis work has been a continuous effort towards designing and developing a TEL environment for improving learner's skill to execute the cognitive processes of KI. We have recommended that a learner should perform at least a necessary number (two) of runs of the IKnowIT pedagogical phases, to have a minimal desired effects. We anticipate that a continuous interaction with IKnowIT would help the learners to elicit more apparent effects. What should be the sufficient number of IKnowIT iterations is still a question to be answered through future studies. In this thesis, the evaluation of the IKnowIT-pedagogy was done, primarily qualitatively.

If we reflect on the research processes, we find that we started with a broad research objective of designing a TEL environment. All the RQs, sub-RQs, literature questions and design questions, evolved as we kept executing the DBR phases and the DBR cycles. For example, before DBR Cycle 1 we did not have RQ2: "How can training learners on an EQP - based learning environment (IKnowIT) enable them to foster the cognitive processes associated with KI?" This is because, before DBR Cycle 1, we did not have any idea of EQP. This is a demonstration of the beauty of DBR, wherein the problems and subgoals are evolved and identified while we work on the problem in real and authentic settings. Therefore, this thesis is a good example for those who want to understand how to set your expectations while choosing DBR as a design for your exploratory research.

This thesis has successfully made a little dent in the research area of KI. But more interestingly thesis has widened the doors of QP research, by examining the cognitive mechanisms related to QP in a technology enhanced learning context. This thesis has viewed the improvement of cognitive processes of KI and even the development of the skill to pose better exploratory questions, as a transferable thinking skill. There is a huge potential for furthering these research explorations.

There is a good possibility that the chronological development of an exploratory research, does not match with its logical development. In this exploratory research too, we have explored a lot of such branches of research with roots being in KI and QP, which were eventually excluded from the main logical path. One of them being our work on exploring QP as a pedagogical idea to facilitate learner-directed learning. Another was exploring QP as an instructional strategy and as an assessment tool in a first-year undergraduate programming course. Some of these research has been outlined as Mishra and Iyer (2015a, 2013).

To conclude, I would say that apart from contributing with this thesis, this doctoral research journey has trained me to look at everything from a more critical, acknowledging, and micro-macro perspective.

Appendices

Appendix I

Interview Consent Information

Student Views of their Experiences in the IKnowIT Environment
Consent Information

You are being asked to participate in a research study. The purpose of this study is to understand students' experiences in a web-based learning environment known as IKnowIT. You were selected for this study because you have mentioned in the prior-knowledge survey that you have formally done a course on introduction to programming and have not yet completed a formal course on data structures.

You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

If you choose to participate, you will be interviewed for 45-60 minutes about your experiences in the IKnowIT learning environment that you have worked with today.

You will not be given any financial compensation for participating in this study. However, your response and feedback would help us in improving the IKnowIT learning environment and learning strategies further, such that it can become more effective for future learners.

Confidentiality

Your information will be kept confidential in this study: The data that is collected about you will be kept private to the extent allowed by law. Your interview transcripts and recordings in electronically secure files and only study staff will be allowed to look at them. Your name and any other fact that might point to you will not appear when the results of this study are presented or published. If any excerpts from your interview are published, any information that could identify you will be removed.

The interview will be audio recorded. The recordings will be transcribed and analyzed. Your interview recording may be sent to a professional transcription service, but any potentially identifying information will be removed before the recording is sent.

Your Rights

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to participate.
- You have the right to change your mind and leave the study without giving any reason, and without penalty.

Questions
If you have any questions about this study, please contact Shitanshu Mishra via +91-22-2576-4810 or shitanshu@iitb.ac.in.

Appendix II

Interview Guidelines

General Points to Remember

- Dig deeper into the thought processes (ask more HOWs and WHYs). You may treat the participant as an expert, but elicit specific examples from them, from their experiences in the IKnowIT session.
- Sometimes, use the screen or even their logged responses, to refer to them and talk to the participant.
- To elicit, you can ask the participant to compare their situation to someone else who has not got the training.
- You can go back and forth between any step as you feel comfortable, according to the natural flow of the conversation.
- Remember the key constructs: questions, questioning, knowledge integration, deep understanding.
- Don't interrupt in between, when a participant is responding. Let her/him complete.
- Let the response come naturally. Don't direct/prime the participant towards any direction of response. When you are completely sure that participant would not be able to elicit on her/his own, then give a slight hint (i.e., direction, not your own conception).

Language

- All participants can communicate in the English language, but they may be more comfortable in their local language (e.g. Hindi). If the interviewer also knows the local language, then s/he should feel free to allow them to use their local language.

Interview structure

- **Step 0:** Before the interview starts, a copy of the consent information is handed over to the participants, and they are also briefed about its content and are asked to read before anyone can go ahead with the interview.

- **Step 1:** Start with a "grand tour question" (asking the participant a question that they can definitely answer (therefore concrete), that only they can answer, that takes a while to answer). The questions may take following form.

  - **Q1.1: How was your experience today - was it good, bad, beneficial, etc.?**
  - **Q1.2: What did you learn today?**
  - Let the participant reflect completely, and at the end encourage her/him to further her/his thoughts - ask what were the benefits, why is it a benefit, what was good and why, what was bad and why?

- **Step 2:** Investigate about the effects of the overall session

  - Continue the discussion in Step 1 to elicit the effects of the overall IKnowIT session. Once the participant responds to the above questions, check if s/he has talked about the effects with respect to following: (i) Ability to pose questions. (ii) Ability to learn deeper/ knowledge integration

- **Step 3:** Investigate about the roles of each pedagogical features, viz., (i) Minimal EQP Instructions, (ii) Lecture-1 Video and QP, (iii) Detailed EQP Instruction, (iv) EQP Categories, (v) Categorize Activity, (vi) Critiquing Activity, (vii) Reflection Activity, (viii) Lecture-2 Video and QP. For each pedagogical features ask the following.

  - **Q3.1: How was [a particular feature/activity] useful or not useful according to your today's experience?**
  - After the participant has given the response to the above question, ask her/him to provide specific instances [that can validate their response] from their session's experience.
  - **Q3.2: How did you go about any activity? / How did you perform an activity?** (traverse me through)?

- **Step 4:** Final reflections
  - **Q4.1. You have told a number of points about the effect of today's session. Now tell me, what would you do from now on when you are reading, watching or listening to a lecture on a new topic?**

Appendix III

Exemplar Interview-Questions Excerpts

Illustrative example of questions asked in an interview

(An excerpt from an interview from iDEEN iteration #4)

Note: Even if the interview guidelines recommend a set of interview questions, but during the actual interview, the questions go more in-depth. Following is a subset of questions asked in the iDEEN iteration #4.

- Q. What was there in the activity that helped you?
- Q. Was the question-posing tough?
- Q. Was it also about knowledge integration, what was there in it about KI?
- Q. How were the questions arising in your mind - How did you think about the questions?
- Q. Did you ask questions in the second video?
- Q. So what was the difference in your experience in the second video, as compared to that in the case of the first video?
  - [w.r.t. understanding the second video, then w.r.t. to question-posing.]
  - Q. How were the activities that you did after the first video (QP session) helped you in this change of experience?
  - Q. How did the activity influence you in the second video, or didn't affect?
  - [Now continue for each activity]
  - Q. OK, then how will it effect in future? What was the benefit of the whole session?
  - [WHY?]
- Q. What could have been the difference when you were watching the same first video, again?

- Q. So, you are saying that it changes the way you learn, elaborate.
- Q. So, it changed the way you ask questions, does it has any effect on the way you study any new thing?
- Q. What do you mean by “Exploratory thing?"
  - Why do you think, it’s important?
- Q. What is more important: questioning or understanding the topic?
  - Q. [if both are important] Do you think both are related?
- Q. Can you give an example from your today’s experience to justify this?
- Q. You are saying that “if a question is asked, then someone should answer those questions?"
- Q. Do you have something to add? You can take time and think.
- Q. Was it consciously executed now, and before today was it sub-consciously already there?
- [more specific questions]
  - Q. What was the role of your prior knowledge? How did it play?
  - Q. Would you be able to better do Gap/conflict identification?
  - Q. Do you relate prior knowledge and new knowledge while exploring the topic?
- Q. What would you do now if you are reading, watching or listening lecture on a new topic [referring to the last question of the reflection activity]?

Appendix IV

Introduction given before an IKnowIT Session

Following instruction was given just before the start of the IKnowIT sessions, implemented in face-to-face settings. It remained more or less the same for all IKnowIT implementations. Study 6 of this thesis also used this introduction.

> *"...Thinking Skills are mental processes we use to do things like: solve problems, make decisions, ask questions, construct plans, evaluate ideas, organize information, etc.*
> *[Also an example] You vs. your friend, Same Educational Background BUT - one is a good programmer, and other is not...*
> *In our evolving world, the ability to think is fast becoming more desirable than any fixed set of concepts or knowledge. We need problem solvers, decision-makers, and innovators. Thinking skills have high importance in placement. A person with more thinking skill is more desirable for a recruiter...*
> *Gap between industry and academia... Academics don't teach you directly, but a person is expected to have a set of skills which are the most desired by a company.*
> *...Wonder why we possess different skills, why someone is good at problem-solving etc....*
> *[Introduction to the workshop title]*
> *[Why is question-posing relevant and how it is expected to help you deeper learning (knowledge integration)]*
> *....You are about to work on improving your thinking approach....*
> *....It's very very sensitive. It's not like learning any normal concept or topic from your traditional subjects.*

....So... attend every activity attentively....

....Read every instruction, statements, etc. very very carefully....

....Believe me! If you want to improve this special thinking skill, you have to be very very honest with yourself in this workshop. Otherwise, it will not be effective....”

Appendix V

List of Reflection Questions in the IKnowIT Reflection Phase

- **Reflection Question 1/8:** *“Do you believe that there could be more ways of integrating knowledge in addition to the ones already mentioned, namely "Applications," "Associations" and "Operations?”*
  Options available in this question are: ‘Yes,’ ‘Maybe’ and ‘No.’

- **Reflection Question 2/8:** *‘‘Do you think that you may do knowledge integration in more than one ways even when you ask a single exploratory question?”*
  Options available in this question are: ‘Yes,’ ‘Maybe’ and ‘No.’

- **Reflection Question 3/8:** *“Which statements do you agree with?”* Statements given for this question are:

  1. “Posing different exploratory questions helps in exploring knowledge.”
  2. “Different knowledge can be well explored using different ways of integrating knowledge.”
  3. “It is important to explore topics by using possible ways of integrating knowledge.”
  4. “Question posing is important, but knowledge integration is not for better understanding any topic.”
  5. “Posing exploratory questions would lead to better understanding of any topic.”
  6. “For a better understanding of any topic knowledge integration is important, but question posing is not.”

  Options given for each of these statements are: ‘Select,’ ‘Agree’ and ‘Disagree.’

- **Reflection question 4/8::** *“While doing the exploratory questioning, how important is focusing on the concepts or ideas from the video lecture (new knowledge)?”*

Options available in this question are five-point Likert scale from ‘least important’ to ‘completely important’

- **Reflection question 5/8:** *“How much do you agree with this statement: "I need to recall my prior knowledge or ideas while doing exploratory questioning?”*
  Options available in this question are five-point Likert scale from ‘completely disagree’ to ‘completely agree’

- **Reflection question 6/8:** *“Do you relate your prior knowledge and new knowledge (video lecture) while exploring the topic?”*
  Options available in this question are five-point Likert scale from ‘Never’ to ‘always’

- **Reflection question 7/8:** *“According to you when does any question arise in your mind.”*
  This question is an open response question, which is followed by the query: *“Now choose from the below statements which are true about "when does any question arise?”* For this follow-up query, options given are:

  – “When I identify inconsistencies while relating my prior knowledge and new knowledge.”

  – “When I identify gaps in understanding while relating prior knowledge and new knowledge.”

  – “When I look for ways in which new knowledge can be expanded using ideas from prior knowledge.”

  – “All of the above three are important?”

- **Reflection question 8/8:** *“Based on your experience today, what would you do from now on when you are reading, watching or listening lecture on a new topic?”*
  This question is an open response question.

Appendix VI

An Example of a Situational Map Created During the iDEEN Analysis

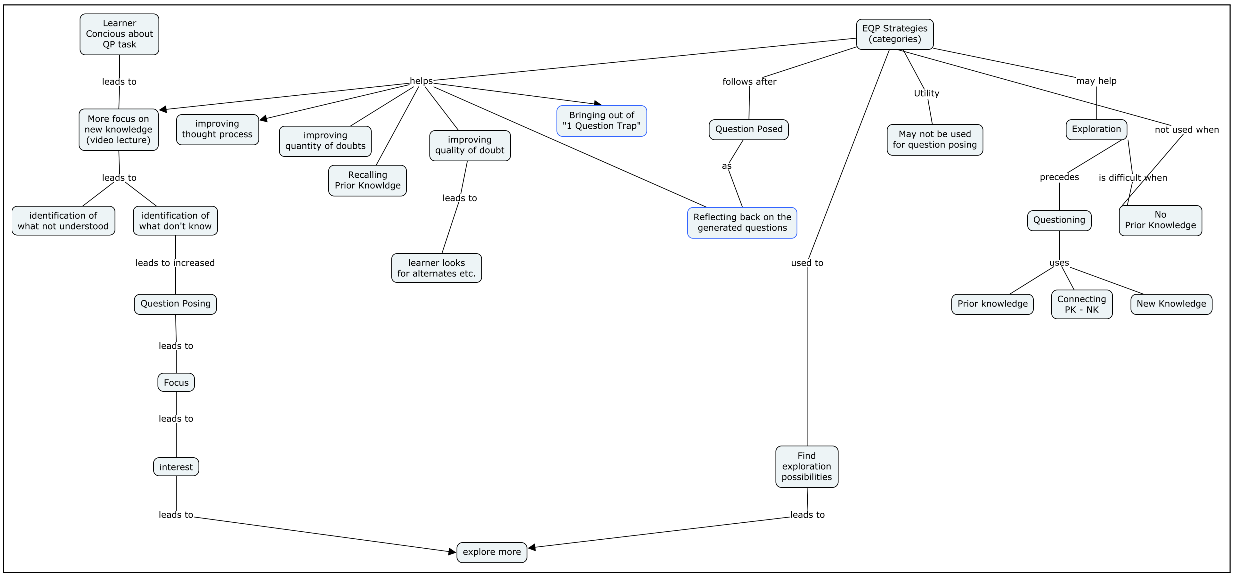

Figure VI.1: An Excerpt from a Situational Map Created During the iDEEN Analysis

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- **Shitanshu Mishra**, Sridhar Iyer. Question-Posing Strategies used by Students for Exploring Data Structures. ACM International conference on Innovation and Technology in Computer Science Education (ITiCSE), Vilnius, Lithuania, June 2015.
- **Shitanshu Mishra**, Mukulika Maity. A Software Solution to Conduct Inquiry Based Student Directed Learning. IEEE International conference on Technology for Education (T4E), Amritapuri, India, December 2014.
- **Shitanshu Mishra** and Sridhar Iyer. Problem Posing Exercises (PPE): An Instructional Strategy for Learning of Complex Material in Introductory Programming Courses. IEEE Conference on Technology for Education (T4E 2013), Kharagpur, India, December 2013.

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- **Shitanshu Mishra**. Improving Students' Knowledge Integration in Data Structures. ACM conference on International Computing Education Research, Melbourne, Australia, September 2016.
- **Shitanshu Mishra**. Developing Students' Problem-Posing Skills. ACM conference on International Computing Education Research, Glassgow, Scottland, August 2014.

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