Design Thinking Instructions and Cognitive Processes

Conference Paper · April 2021

DOI: 10.1007/978-981-16-0119-4_27

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Chapter 27
Design Thinking Instructions and Cognitive Processes

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Abstract In the era of the 4th industrial revolution, new jobs demand that the workforce should have several essential skills such as problem-solving, creativity, critical thinking and innovation skill. School education is the right time to impart these skills in young children who are members of the future workforce. Literature shows that several cognitive processes are at the core of these skills. These cognitive processes are also mentioned to be at the heart of the design thinking process, justifying the need for teaching design thinking process at the school education level. In the pedagogic context, the revised Bloom's taxonomy defines 19 specific cognitive processes and classifies these into six major categories. With the help of this taxonomy framework, an attempt has been made to find the association between the instruction for activities within the 'IISC design thinking' process (a specific process that aims to optimise design thinking) and the cognitive processes. Results indicate that following the above instructions while performing IISC design thinking activities enable most of the cognitive processes recommended by Bloom, covering all his six categories. This has the potential to support the development of higher-level cognitive skills that are required for the twenty-first-century workforce.

27.1 Introduction

According to Merriam-Webster dictionary, skill is 'a learned power of doing something competently: a developed aptitude or ability.' Unlike specific skills (e.g., factoring polynomials and solving square-root problems), skills like problem-solving

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A. Chakrabarti et al. (eds.), *Design for Tomorrow–Volume 2*, Smart Innovation, Systems and Technologies 222, https://doi.org/10.1007/978-981-16-0119-4_27

and critical thinking are general skills because they are useful in acquiring a range of cognitive, motor, and social skills [1]. Authors have reviewed various research papers, international reports, as well as articles and identified the 21st-century skills, which are essential for the workforce to have and be developed by students during the education [2–6]. All the above sources are primarily emphasising creativity (ability to produce a novel outcome), critical thinking (ability to analyze and evaluate information), problem-solving (ability to choose means to reach toward a goal), adaptability (ability to adjust to new conditions) and collaboration (ability to work together) skills as essential skills. In addition, there is a coherence between the skills required from a workforce and the skills needed to be developed by students. [7] noted that in order to develop creative, critical, and innovative thinking, the required core skills are not limited to remembering skills but also focusing, information gathering, organizing, analyzing, integrating and evaluating skills [7]. Thus, school education is the right time to inculcate those skills in young children who are the future workforce.

27.1.1 The Current Indian Education System

Current teaching and assessment techniques in the Indian education system emphasize rote learning over meaningful learning. During teaching and assessment, more importance is given to retention skills. Moreover, repetitions of questions throughout exams indirectly hinder the transfer of knowledge to students. This leads to a lack of inculcation of higher-level cognitive processes in children. According to the National Education Policy 2016 (draft), Ministry of Human Resource Development, Government of India, quality of the education imparted is a critical challenge in the education sector [8]. In most cases, the assessment of learning achievement focuses on memory-based learning and testing the students' ability to reproduce content knowledge [8] where more emphasis is given to the retention of explicit written instructions and leaves no scope for development of essential skills (i.e., creativity, critical thinking and problem-solving skills). Moreover, in the classrooms, learning is receptive (where teacher demonstrates, describes or writes the teaching content and information passes one way), and the assignments given ask students to work individually. This inhibits the development of collaboration and communication skills in students. The above discussion leaves the scope of assessing the current education system and its effects on the development of different skills.

27.1.2 Design Thinking Process, Activities, and Instructions

Design thinking (DT) is the cognitive process from which design concepts emerge [9]. It is an iterative process which involves identifying goals (needs), generating proposals to satisfy the goals, and improving both the goals and proposals [10]. In the previous work, the authors have described a design thinking model known as

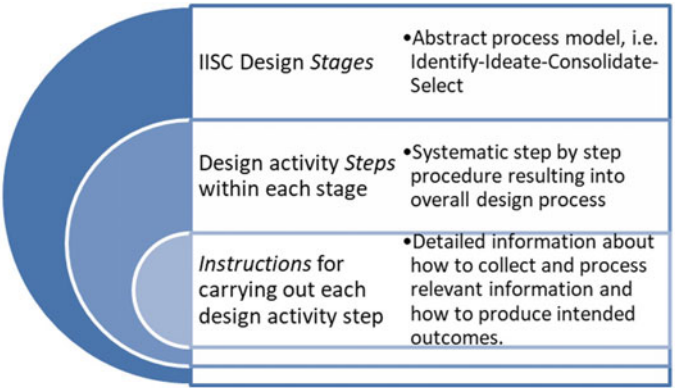

Fig. 27.1 IISC design thinking model: stages, activity steps and instructions

IISC by analysing and combining various activities from existing models [11]. The IISC design thinking model (developed at the Indian Institute of Science, Bangalore) consists of four broad generic stages: Identify, Ideate, Consolidate and Select. Each stage is further divided into several activity steps. IISC design activities direct students and that leads to the generation of solution. Each activity of IISC design thinking has specific instructions which help students or learners to generate different outcomes like a list of requirements, ideas, concepts and prototypes in an effective manner (see Fig. 27.1). In previous work, the outcome produced by the students was assessed by the experts, and mentors' and students' feedback were taken. The results revealed the effectiveness of IISC design thinking as a useful tool for problem-finding and problem-solving [12].

27.2 Elementary Cognitive Operations in Design

Various attempts were made to link steps/activities of DT phases with other theoretical constructs. For example, by conducting a review of the literature [13], shown how specific design thinking processes and tools help decision-makers to reduce their individual-level cognitive biases, and to increase the potential for improving innovation outcomes. [11] established the link between the DTP steps and their potential impact on learning objectives and subsequently derived their favorability to the learning approaches. Similarly, [14] established the link between the activities of the design thinking process with the various constructivist learning principles.

On the one hand, design approaches help us produce a specific outcome in the form of a product (artefact), process or service, which can be novel and have a social value. On the other hand, performing design activities helps designers or learners to acquire certain kinds of skills and instil a school of thought which may contribute to the development of the twenty first-century skillset. From the literature, authors

Table 27.1 Elementary operations in the design process

Elementary operations in the design process				
See	Observe	Read	Listen	Interpret
Measure	Remember	Keep in mind	Recall	Speak
Explain	Write	Report	Sketch	Draw
Dimension	Set up parts list	Calculate	Note, annotate	Order, classify
Compare	Combine	Analyze	Synthesise	Abstract
Concretize	Establish analogy	Invert	Induct	Deduce

have tried to identify the skills/operations/mental processes that can be acquired by performing design activities. Hubka and Eder [15] explained the structure of possible activities in the design process, in which they argued that various elementary operations are used in the design process (As shown in Table 27.1) [15].

Taylor et al. [16] developed a design education program to enable individuals to acquire behaviours related to the following five 'mental processes,' i.e., (1) problem solving, (2) creative thinking, (3) visual thinking, (4) group interaction, and (5) communication skills [16]. Based on a review of top technologists, Halfin identified a total of 17 mental processes used by design practitioners. These mental processes consist of the following: defining the problem or opportunity operationally, observing, analysing, visualising, computing, communicating, measuring, predicting, questioning and hypothesising, interpreting data, constructing model and prototypes, experimenting, testing, designing, modeling, creating and managing [17]. Further, Hill developed and tested a technique for assessing these mental processes as used by students who participated in instructional learning activities in technology education [18]. Similar kinds of work were found in the literature where the effectiveness of technology education in increasing students' cognitive abilities with respect to problem-solving was evaluated by using Halfin's code of mental process [19].

Authors, however, found the following issues in the Halfin's code and definitions of mental processes, as explained below:

- Many of the above that are currently described as mental processes (e.g., communicating) are skills and not mental processes.
- Many mental processes (e.g., defining a problem, constructing models and prototypes, testing) are design activity steps rather than mental processes, and may contain physical and mental processes to be carried out.
- Only a few of the processes (i.e., predicting and hypothesising) are non-compound in nature. For instance, 'observing processes' not only stimulate the senses but also 'differentiate' between relevant parts of a piece of information, and 'retrieve' and 'compare' knowledge from long-term memory that is consistent with external information.

The above confusions created by the current use of overlapping terminology makes it difficult to distinguish between basic and compound cognitive/mental processes (which may or may not involve physical operations), and to investigate as to how these processes relate to and are supported by two systems of interest: the current system of education and the broad activities of design thinking.

In order to resolve this, we propose a common approach for assessment of the current education system as well as design thinking instructions, both using the lens of cognitive processes proposed in the revised Bloom's taxonomy. From a pedagogic point of view, the revised Bloom's taxonomy is a systematic classification for cognitive processes. The revised taxonomy consists of six major cognitive categories (viz. remember, understand, apply, analyze, evaluate, and create) under which it defines a total nineteen cognitive processes (viz. recognizing recalling, interpreting, exemplifying, classifying, summarizing, comparing, inferring, explaining, executing, implementing, differentiating, organizing, attributing, checking, critiquing, generating, planning, producing) [20]. The revised taxonomy is used heavily across the education domain, and it is useful not only for aligning education goals, instructions, and assessment but also for assessing student's abilities [21].

The focus of this work, therefore, is to seek the relationships between these cognitive processes and the two systems of interest: (1) the current teaching activities (in the Indian school education context); and (2) the design thinking activities. The first goal is to understand the extent to which the current school education promotes the cognitive processes. The second goal is to understand the extent to which design thinking has the potential to promote these cognitive processes. This study has been conducted with the following objectives: (1) to understand as to how the questions used in the test papers of Indian school-leaving examinations are associated with (testing of) the revised Bloom's cognitive processes; and (2) to understand as to how the instructions used for carrying out design thinking activities are associated with (promotion and practice of) these cognitive processes.

Based on these two research objectives, the following are taken as the research questions for this study.

Research Questions

1. Do the questions asked in school-leaving examinations have the potential to assess higher-level cognitive processes?
2. Do the instructions for carrying out design thinking activities have the potential to promote higher-level cognitive processes?

In order to answer these questions, the definitions of the cognitive processes, and test questions, and the instructions for IISC DT were analyzed in detail. Then, each question/instruction was mapped with the cognitive processes of the revised Bloom's taxonomy framework. As a rudimentary evaluation of the mapping procedure, an inter-coder reliability test was conducted. The results and future work have been discussed in the subsequent sections.

27.3 Analysis of Question Papers

CBSE is the national board of education followed by a majority of the public and private schools in India. There are approximately 21,000 schools in India and 220 schools in 28 foreign countries affiliated to the CBSE. The board exams conducted annually for class 10 and 12 is a uniform mode of testing throughout the country. As CBSE 10th board exams are conducted over a large number of schools, it is appropriate to investigate the current status of school education by taking CBSE board as a benchmark and analyzing the 10th class CBSE board science question papers assuming that assessment questions are aligned with the curriculum and teaching activities. A detailed analysis of these question papers and their curriculum has been done to evaluate how these exams test a student's brain. The questions in the CBSE class 10, science papers from 2015 to 2019, were classified based on which cognitive category it tests the brain. During the analysis, wherever required, the questions have been divided into sub-questions for a more precise classification. For simplification, association of marks/points with the questions has not been taken into consideration during the analysis.

27.3.1 Key Findings and Inferences from the Analysis

The results of analyzing year-wise data have been shown below in Table 27.2. Whereas number of questions in exams and associated cognitive categories and processes have been shown in Fig. 27.2.

Following a comprehensive analysis of the question papers over the past five years using the Bloom's taxonomy on the cognitive dimension, it was found that the CBSE questions covered mainly three categories: 'Remember,' 'Understand,' and 'Apply.' There were very few questions that tested 'Analyze,' and hardly any that tried 'Evaluate' or 'Create' categories. Based on the nature of questions asked in CBSE board exams, the material provided by CBSE was looked into and the questions asked

Table 27.2 Results of analyzing year-wise data: Percentage of questions to test different cognitive categories over five years

Category	Academic year					Average (Roundoff)
	2015	2016	2017	2018	2019	
Remember	32	35.7	32.6	37.5	31.3	34
Understand	46	40.5	48.8	47.9	47.9	46
Apply	14	19	11.6	8.3	10.4	13
Analyze	6	4.8	7	6.3	2.1	5
Evaluate	2	0	0	0	8.3	2
Create	0	0	0	0	0	0

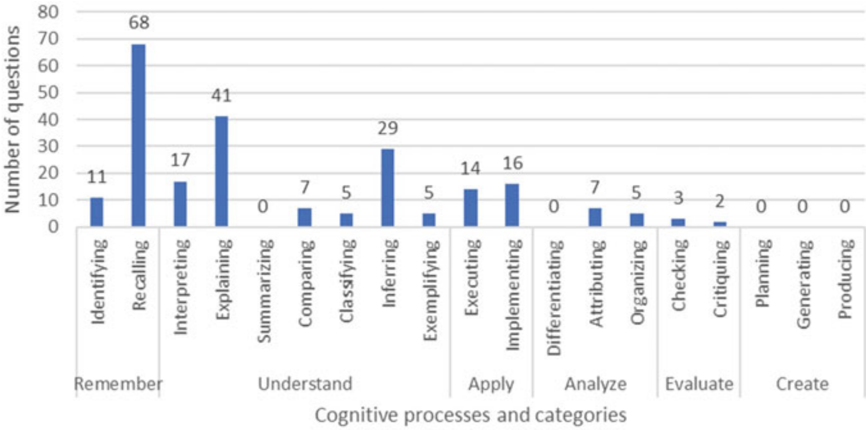

Fig. 27.2 Number of questions to test different cognitive categories and processes over the period of five years

as exercises in the textbook, and the NCERT exemplar book (containing practice questions offered by CBSE) were analyzed, so as to check the extent to which the questions in these textbooks matched the questions asked in the papers. Based on the nature of the questions asked in the materials provided by CBSE, three main categories were created:

'Exactly the same questions from study material', 'Similar to questions asked in the study material (change in values, specifics)' and 'Unfamiliar questions'. Each category of questions was analyzed separately and categorized to see the extent to which the questions match with the CBSE provided material.

From the findings, it is clear that, among the five-year questions, the percentage of precisely the same questions and similar questions from the textbook as well as exemplar book was about 73% of the total questions. This shows that majority of the questions asked were familiar to the student in some way before. According to [15] if the assessment task is identical to a task or example used during instruction, one is probably assessing remembering, despite one's efforts to the contrary. Unless more unfamiliar questions are asked, one cannot ensure that a higher level of cognitive processes rather than remembering is being assessed.

Authors have also observed that some questions have a proxy/auxiliary (optional) question, and it allows students to choose one question to attend out of two. Many of these questions test different categories, e.g., even if CBSE asks questions that test the application part of the brain, the students still have an option not to answer it and answer the proxy question that is purely memory-based. So, between the students who answered the application testing question and the students who answered the remembering type question, both will be evaluated similarly for the given question.

The findings indicate that the assessment questions hardly covered higher-level categories like analyze, evaluate and create. Moreover, the presence of familiar questions might have encouraged students to focus on retention skills instead of on transfer skills.

27.4 Association of the Design Thinking Activity Instructions and Cognitive Processes

This study identifies the instructions of IISC design activities and the underlying cognitive process. Authors have distinguished a total of 52 different instructions covering all steps of IISC design thinking process which are used by a learner while performing design activities. For the consistency and reliability, two authors have comprehended the definitions and examples of the cognitive process dimensions of revised Bloom's taxonomy, and based on their understanding, they have tagged each design instruction with the cognitive process and category independently. The similarity report has been made with the percentage agreement of 81% as a result.

The document was made where the definition of each cognitive process is given along with the example of design activity instruction. The example of each process is shown in Table 27.3.

27.4.1 Results and Inferences

Association of instructions of IISC design thinking activities and cognitive processes shows that out of 19, a total of 17 cognitive processes are mentioned in the Table 27.3 which covers all the six cognitive categories (Fig. 27.3). A significant number of instructions cover the higher level of cognitive categories like analyze, evaluate, and apply (Table 27.4).

Moreover, while mapping the instructions with cognitive processes, authors have identified that:

Some instructions may associate with more than one cognitive process, and one process usually occurs in conjunction with other processes, e.g., making an analogy from any event/object is associated with comparing and inferring along with implementing.

Though exemplifying and inferring processes are not tabulated, they are inherently present in some of the instructions. For example, while observing any process/person/object in a given habitat, one may anticipate the possibility of occurrence of a problem. The process of predicting a problem is nothing but inferring. Thus, those instructions are implicitly associated with the inferring process.

As there are specific cognitive processes underlying the instructions which help in generating design outcomes, the design thinking steps do not only help to produce

Table 27.3 Association of instructions with the cognitive process

Activity step	Instruction	Cognitive process	Definition
Observe habitat	What activities and processes are happening in the habitat?	Identifying/Recognizing (Remember)	Locating knowledge in long-term memory that is consistent with the presented material [20]
	Do you observe any problems that are happening in the habitat?	Differentiating/Discriminating/selecting (Analyze)	Distinguishing relevant from irrelevant parts or important from unimportant parts of the presented material [20]
	If so, why are these problems occurring?	Explaining (Understand)	Constructing a cause-and-effect model of a system [20]
Group problems	Group the problems based on their similarities	Organising/structuring (Analyze)	Determining how elements fit or function within a structure [20]
Benchmark against objects	Check whether there is any existing solution to your problem	Recalling (Remember)	Retrieving relevant knowledge from long-term memory [20]
	Is the existing solution good enough to solve the problems in the situation you identified?	Critiquing/Judging (Evaluate)	Detecting inconsistencies between a product and external criteria, determining whether a product has external consistency; detecting the appropriateness of a procedure for a given problem [20]
Enlist the requirements	Based on the requirements make solution neutral problem statement	Summarising/Abstracting (Understand)	Abstracting a general theme or central point [20]
Enlist process steps and problems	Imagine and enlist the steps that are needed in the desired process to fulfil the requirements you have identified	Planning/Designing (Create)	Devising a procedure for accomplishing some task [20]

(continued)

Table 27.3 (continued)

Activity step	Instruction	Cognitive process	Definition
Generate	Generate as many alternate ideas as possible for carrying out each process step while avoiding the problems if any	Generating (Create)	Corning up with alternative hypotheses based on criteria [20]
Ideas from nature	Explore how does nature addresses similar problems occurring in habitats	Comparing (Understand)	Detecting correspondences between two ideas, objects, and the like [20]
	Can you learn from the principles behind nature's solutions to think of novel solutions to the problem you have identified?	Implementing/Using (Apply)	Applying a procedure to an unfamiliar task [20]
Remove infeasible ideas	Check all ideas for their feasibility and remove all ideas that are clearly not feasible	Checking/Coordinating/detecting (Evaluate)	Detecting inconsistencies or fallacies within a process or product; determining whether a process or product has, internal consistency [20]
	Group the similar ideas; the similarity in terms of the principles used behind the idea, and the process step/problem to be solved using the idea	Classifying/Categorizing (Understand)	Determining that something belongs to a category [20]
Combine Ideas	Combine individual ideas for each process step into a solution	Executing/Carrying out (Apply)	Applying a procedure to a familiar task [20]
Identify conflicts by acting as user	Imagine yourself to be the user and think how good the solution in the sketch/model (that you have made) would satisfy each requirement	Attributing (Analyze)	Determine a point of view, bias, values, or intent underlying presented material [20]
Identify conflicts by asking users	Resolve the conflicts and improve the solution and the model, so that each solution can satisfy each requirement without conflict among these	Producing (Create)	Inventing a product [20]
Make the final prototype	After dealing with the conflicts/discrepancies in the solutions, the changes should be reflected in the models/prototypes you had made earlier	Interpreting/representing (Understand)	Changing from one form of representation to another [20]

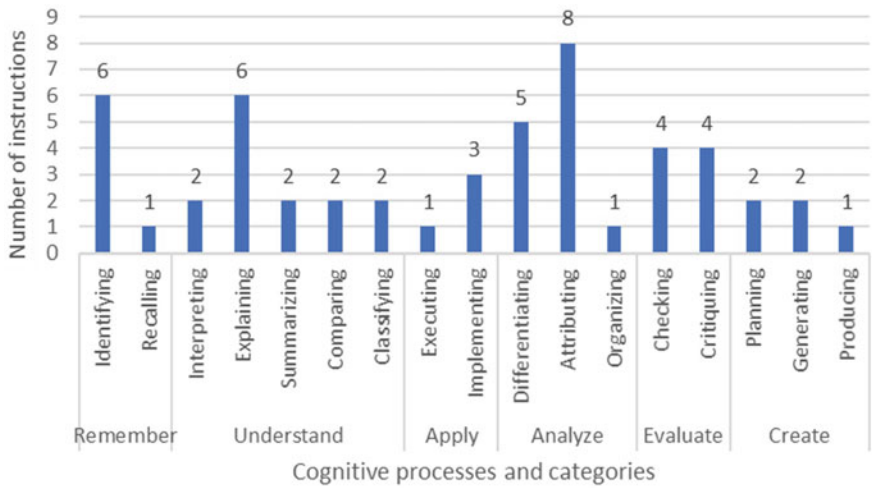

Fig. 27.3 Design thinking instructions and associated cognitive processes and categories

Table 27.4 Percentage of instructions of design thinking activities that cover different cognitive categories

Category	Remember	Understand	Apply	Analyze	Evaluate	Create
Percentage of instructions	13	27	8	27	15	10

outcomes that lead to a solution of the given problem but also can be used as a tool for fostering different cognitive processes. Also, from the above discussion, we can say that IISC design thinking process allows students to get engaged in different activities that contain instructions of a higher level of cognitive processes. Performing which learners may improve their higher-order cognitive processes and these processes can lead to the development of skills which are requisite for the twenty-first-century workforce.

27.5 Conclusion and Future Work

An attempt has been made to examine educational opportunities in India. This has been done by analyzing the last five years of the CBSE board science question papers and classifying them into cognitive categories defined by the revised Bloom's taxonomy. The results suggest that the test questions put a heavy emphasis on the retention abilities and do not demand higher levels of cognitive categories which may lead to the lack of development of skills like critical thinking, creativity and complex problem-solving.

The same taxonomy was used to identify the association between instructions which are used in performing IISC design thinking activities and the cognitive processes. The results show that attaining instructions while performing design activities enables most of the cognitive processes and cover all six cognitive categories, which can lead to the development of skills. Given that students need to develop higher-level cognitive processes to be competent, design thinking seems well suited to prepare a twenty-first-century workforce. Therefore, teaching design thinking should be an essential component of K-12 education system in India.

However, the work is still preliminary in that while overall results are encouraging, there is a scope of covering more instructions which are present in IISC design thinking process. In addition, the presence of the cognitive processes can be identified by carefully observing and studying the learners' activities while they are solving design problems. Also, observation of these cognitive processes may also help in the evaluation of the learners' performance and corrective feedback.

The above results, even though found in the context of school education, are likely to be similar to those in regular engineering and other graduate-level education in India, where rote learning and descriptive content dominate. These will have a consequent impact on the workforce.

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