# Techniques for Strengthening 21st Century Learners' Critical Thinking Skills

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*Abstract:* **Critical thinking, as opposed to technical or professional abilities, enhances intellectual capacities and promotes the development of multi perspective thinking. It promotes the growth of the mind's analytical and creative regions. Enhancing critical thinking abilities in higher education constructs an excellent platform for aspirant engineers. To analyze complex problems, investigate various techniques, and design solutions, critical thinking skills are required. The most vivid imaginations are born to artists and musicians. Teaching artists how to use software and graphics tools is relatively simple; however, transforming engineers into artists is far more difficult. Students who use visualization in their studies are encouraged to look at the world from various angles. Sports and academics complement each other well. There are also links between the arts, logic, and athletics. It is beneficial to understand the relationship between critical thinking and academics. This study covers some strategies related to puzzle solving, problem-based learning, design thinking, picture analysis, and experiential learning in order to develop critical thinking and practical problem-solving skills.**
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## I. INTRODUCTION

The process of actively and successfully conceiving, applying, analyzing, synthesizing, and/or evaluating knowledge as a basis for belief and action is known as critical thinking, Michel (1987). In order to arrive at unbiased judgments, critical thinkers refuse to accept situations as they are and are aware of their cognitive biases. Critical thinking is self-directed, self-disciplined thinking that aspires to the greatest standard of fair-minded reasoning Michel (1987). Critical thinkers continually strive to live rationally, sensibly, and compassionately. Critical thinking, for example, allows us to actively learn rather than passively absorb the information presented. In this age of globalization, students must become scholars rather than specialists in a specific field of engineering (source: https://www.educationtimes.com/article/careers-science/80003909/portal-exclusive-how-liberal-arts-and-critical-thinking-are-important-for-engineers). They must broaden their skills and carve out a niche for themselves in the Engineering Industry.

Engineers who work for international corporations need more than just technical skills to solve the challenging problems. Even the creation of a small product necessitates a diverse set of skills, such as agile technology where the stake holders/ customers are involved so that the product developed is as per their requirement. Design thinking practices creative and novel problem-solving methods that are oriented on the needs of people. Problem-solving abilities are very much critical which are essential for product development.

These essential skills are rarely imparted in engineering programs. Modern engineers will fail if they lack such capabilities. Our students should be able to acquire these talents required to prosper in their work place. An innovative stratagem with comprehensive engineering approach is required. Holistic edification must be amalgamated into current courses. A perfect blend of science, technology, engineering, and mathematics (STEM) and general education is required. A comprehensive education model is required by all organizations seeking to shape "modern" engineers.

The ability to blend technical proficiency and social skill is crucial because novelty is at the vanguard of all businesses. Educational institutions must promote essential skills including invention, collaboration, communication and critical thinking. By incorporating liberal arts courses into engineering curricula, students can develop critical thinking skills for exploring a wide range of academic subjects and developing interdisciplinary perspectives on the human experience from various angles.

This will go beyond the restrictions of technical education and produce people who contribute to society and constantly learn new things.

An experienced critical thinker, Richard (2008) may explain vital issues and concerns in clear, specific language, gather and assess crucial evidence, comprehend abstract concepts well, and draw clever conclusions that are then put to the test against relevant standards and criteria. Liberal arts require various types of thinking that are difficult to quantify but are implicit in critical thinking.

Although logic and linear thinking are simple to assess, they are only one component of critical thinking. A good thinker possesses qualities such as creativity, innovation, and inspiration, as well as the ability to view things holistically (Holistic thinking). They are difficult to quantify, but they are an essential component of liberal arts education. Logic and linear thinking will aid in the improvement of existing

abilities, whereas innovative thinking will aid in the discovery of new things.

The education of liberal arts enables one to broaden their horizons and explore previously unconsidered professional paths. The most essential abilities for making choices and finding solutions are those of critical thinking, and they can be developed over time.

Even though literatures are available on critical thinking and its impact but, there is no systematic approach to inculcate it in higher education. In this section we the discusses various effective methods/techniques of promoting critical thinking skills.

## II. TECHNIQUES TO PROMOTE CRITICAL THINKING

Subject-related games, active learning strategies can be easily incorporated into the classroom to promote student engagement, and increased participation. Puzzle solving, cross word, millionaire and jeopardy are all examples of games. Human-centered approaches and problem-solving techniques help to assess Learner's potential and improve their thinking abilities. Once in a while, students can be given tasks for open-ended and passion projects of their choice. Learners are allowed to draw, write poetry, or engage in any activity that inspires them but is related to a subject from the curriculum of their choice. This will allow students to hone their decision-making and creative abilities. Switch roles and assign work to students as well.

These techniques were experimented on undergraduate engineering students. Design thinking, Experiential learning are part of the curriculum, other techniques like PS, GW, IA and PBL were part of the class room teaching. At the end feedback was taken regarding these activities.

### A. *Puzzle solving*:

The ability to solve problems creatively and critically is highly valued in the society. Puzzles assist in developing all of these important skills. Brute force method is involved in solving puzzles, one must try different approaches. The significance of developing theories, testing hypotheses, and shifting our perspectives when things do not go as planned are well learnt and understood. All of these skills are easily transferable to our professional lives, making us more innovative and adaptable.

To shape students in higher education, edification and learning procedures are intended to include a variety of inherent, creative, and imaginative techniques, Garcia (2012). There are many different kinds of puzzles, including verbal, logical, picture, numerical, and game puzzles. In addition to being entertaining, puzzles can also be thought-provoking, informative, and intriguing Slocum (2001). A crucial idea in computer science is the thinking that goes into solving puzzles Michalewicz (2007). Students can better understand concepts by solving STEM challenges Falkner (2012). Puzzles like cross word can help in retaining the concepts learnt forever and in turn to solve real world problems.

There are a total of 25 athletes, need to find the fastest 3 athletes. Only five athletes can run at once. The athlete's exact speed during a race cannot ever be determined (source: https://www.geeksforgeeks.org/). To obtain the top 3 fastest athletes, compute the optimal number of races. To solve this puzzle and compute the optimal number of races, all possibilities should be considered and very carefully solved.

Solution: Form a team of 5 athletes and conduct five races, say five groups are V, W, X, Y, Z and next letter is its rank in the group (of five athletes) as shown below e.g., Y2 means athlete from group Y with a rank 2

V1 W1 X1 Y1 Z1
V2 W2 X2 Y2 Z2
V3 W3 X3 Y3 Z3
V4 W4 X4 Y4 Z4
V5 W5 X5 Y5 Z5

Conduct the race for (V1, W1, X1, Y1, Z1) (6th race) Say result is V1> W1 >X1> Y1 >Z1, this implies V1 must be first, W1 and X1 may be 2nd and 3rd respectively. Athlete in II position will be either W1 or V2 (need to find fastest 3 athletes, thus choose athletes W1, W2, V2, V3, X1 for racing [7th RACE]. Optimal number of races is 7. Hence solving such puzzles provokes critical thinking to arrive at the optimal number of races. Puzzle solving can be incorporated in the daily class room teaching as well.

### B. *Experiential Learning (EL)*

There is a growing demand for skilled workers as technological development becomes more competitive. EL not only promotes self-learning but also enables application of the concept in solving problems. To make the educational system more Learner Centric, all of these approaches center on students Kolb (1984). The six propositions José (2015) of the theory of experiential learning are as follows:

1. The learning process is accompanied by feedback.

2. Relearning is always a part of learning, and it is challenged/verified with new ideas.

3. Learning process continuity is achieved through the resolution of issues and misconceptions.

4. Learning is implemented in a specific manner (thinking or feeling or perceiving etc.)

5. Learning occurs when new knowledge is added to existing knowledge and vice versa.

6. Learners generate new knowledge.

Concrete Experience (CE) and Abstract Conceptualization (AC) are the two types of learning experiences in experiential learning theory (AC). Reflective Observation (RO) and Active Experimentation (AE) are the two types of transforming experiences (AE). Concrete experience prompts reflective observation and covert reflections on abstract concepts, from which new ideas for new experiences emerge Sternberg (2000). Experiential learning is used in online classes to improve skills and competencies, acting as a conduit between knowledge and communication technologies Baasanjav (2013).

EL is one of the ways in which they attain different skills. EL is part of the curriculum in our college and for each course it has a weightage of 20 marks. EL is carried out in 2 phases, Students form a team of 4 members., they can choose the

problem statements or borrow the problem statements from industry or from their professor's research or consultancy project and can work on it. The chosen topic need to be connected to all the courses they study in that semester and present the respective course's component.

In phase 0, topic finalization is done with the subject experts, in phase 1, an extensive literature review is carried out by students and they list the objectives, problem statement, proposed system and the methodology. In phase 2, students need to show the implementation, of the proposed system/technique and the evaluation is done as per the rubrics. If the proposed solution is very innovative, students can patent their ideas, otherwise students need to present their work in conference or go for publication in reputed journals. Many students have expressed that this component (EL) has really help them gain more knowledge and team work in particular has helped them to develop Higher-level thinking, oral communication, self-management, and leadership. These think about all possibilities before arriving at a solution or conclusion. These students are the most wanted by the industries, as they can increase productivity and product quality with such skilled people. Employers anticipate that their employees will need both soft and hard skills to perform complex tasks in a dynamic manner. Skilled workers for industries are important because they influence the country's economic growth. Developing skilled workers can be accomplished by raising the standards of the existing education system through EL, as it is a critical indicator of the country's development through industrial development Moursund (2006). "Knowledge is created through the transformation of experience," according to experiential learning theory (source: https://www.hays-index.com). To excel in the field of education and attain the learning outcomes, universities and educational institutions employ a variety of teaching and learning methods. Few of these approaches are collaborative, experiential, or project/problem/active learning in nature.

Keeping in mind, the learning styles of learners, Experiential learning can be facilitated using presentations, real time problem-solving, open-ended experiments, literature review, poster creation, implementation physical experimentation, and innovative methods to develop meaningful learning for engineering students. The assessment of critical thinking can be carried out using project presentations, exhibitions, evaluation by Industry experts or developing proper rubrics. The skills that must be assessed for critical thinking abilities are analysis, innovation, visualization, communication, and problem solving. NEP 2020 focuses on developing engineers who have a perfect blend of knowledge and skills and making them responsible Engineers. Several changes in the educational system have occurred in this direction. Challenges in implementing experiential learning techniques could be addressed through brainstorming and proper implementation by institutions. According to qualitative data Emmison (2000), Students necessitate a paradigm shift away from the traditional system and towards a 21st-century learning environment that encourages critical thinking.

C. Guess the Word (GW)

Showing pictures to students and asking them the word/s related to the picture would foster thinking and also good connect with the concept learned. For e.g., Fig 1, picture is shown and students are asked to guess the word/s. This is related to computer networks course (can be done for any course). The first word is burst and second is error, so it burst error a networking concept. A burst error occurs when more than two bits in a data unit transform from 1 to 0 or from 0 to 1. Say bits 0100010001000111 was sent, but 0101110101100011 was received. Fig 2: The first two words are twisted pair and second is cable, so it is twisted pair cable- is a cable for communication in which two conductors of a single circuit are twisted together to improve electromagnetic compatibility.



Fig1. Guess the word/s(two words)[Source :internet, images are under CCL]



Fig. 2. Guess the word/s(three words) [Source: internet, images are under CCL]

*D. Image analysis (IA)*

Visualization is more memorable and engaging than text analysis Garcia (2012). Visualization promotes imagination, observation, critical thinking skills and the benefits are significant. With its constant shifts in knowledge, the current global context necessitates the development of a new educational paradigm Freedman (2004), where ideas are conveyed through pictures.

Fig. 3 picture analysis

From the figure 3, (source: https://www.nytimes.com/ slideshow/2016/08/16/learning/images-from-four-years-of-whats-going-on-in-this-picture.html) each one can infer differently as the view point changes from person to person. Some of the inferences are highlighted

i) The flaws in the unplanned city
ii) Repair work on the road
iii) Busy life where people have no humanity

Inferring from an image differs from person to person, and it can be difficult to write the implication of a picture in one sentence and at the same time writing articles based on the picture is also very difficult, but a mere observation and following these steps would be very helpful in drafting the essay well.

Image analysis steps (source:.https://www.tutorphil.com/blog/how-to-write-analysis) Step 1: Detect and categorize the components. when analyzing an image. Step 2: Recognize Symbols and Associations must comprehend what the artist is try to depict. Discover connections and links. Step 3: Generate the Thesis. The main goal of this step is to produce an argument that will help you inscribe an essay. The objective of writing a visual analysis is to determine and divulge the image's internal significance to the reader. The image could be inferred in a variety of ways. Step 4: Finish the Thesis statement Step 5: Write the body of the Essay. Step 6: Write the paper's introduction, inference and summary. This method is more effective to write the report from image analysis.

*E. Design thinking (DT)*

DT is an approach where user experience is considered and the problems are solved innovatively. There are many instances in literature in which DT has helped to solved complex problems or give simple solutions to existing problems. For e.g., Ladies in Rajasthan, North Karnataka, and other dry areas used to carry water on their shoulders or waists for 2 kilometers. This was a serious concern for Nilkamal, and an idea striked to him, and thus he introduced rotating plastic cans, which can easily carry 45 Liters of water.

Another example came from a farmer who used to grow watermelons (oval shaped) and sell them to a shopkeeper. However, the shopkeeper refused to purchase all of the watermelons and instead purchased only a few watermelons due to a lack of storage space. Figure 4 shows the square shaped water melons. The farmer had to carry many watermelons back home, so he considered the shape of the watermelons and genetically bred square-shaped watermelons so that the shopkeeper could buy many watermelons.



Fig. 4. Square shaped water melons[Source: internet, images are under CCL]

The ideas can come from any one, it's only a matter of concern or the necessity.

Creativity is the act of bringing new and innovative ideas to life. Novelty in solving problems or giving simple and efficient solution to existing problems is the main aim of DT. Invention: the creation of a novel concept or idea. Innovation is the process of transforming a novel idea into a commercial success or widespread application. For example, the wheel is an invention, whereas the car or jeep is an innovation.

DT is a multidisciplinary framework for approaching difficult problems that can be applied to almost any situation. It isn't just about art or technology. Empathy, problem definition (Point of View), ideation, prototyping, and validation are the five stages of design thinking. DT is taught to second-year students of our college. The themes and domains are shared with the students, they have the complete liberty in choosing the theme and are sole responsible for fetching the problems from the society, identify the issue, find the stakeholders, and empathize with them in person or online. A five-step process is followed for DT.

Empathy: To create meaningful innovations, one must first understand the users and their needs. After empathizing, they create empathy maps that depict the persona's likes, dislikes, gain/pain points, and so on.

Define: The only way to create the right solution is to frame the right problem.

Ideate: It's not about coming up with the best idea; it's about having as many options as possible, even if some of them are outlandish. They use different tools like story board, brain storming, mind map, brain walk, How Now Wow matrix to come up with the best idea to solve the identified problem.

Prototype: Construct to think and test to learn. They build the prototype.

Testing: Testing allows to learn about the solution and validating the prototype to see if it meets the needs of the users. Decisions are made based on what customers require, not on existing facts or perception. DT is a tool for capturing practical information with societal concerns, not just a benchmark for future projects.

*F. Problem based learning (PBL)*

PBL is a problem-driven approach to learning. In the

course, students work collaboratively to solve open-ended research problems. This motivates them to learn. PBL motivates students to solve complex real-world problems, improves learner-facilitator interaction, and exposes students to new ways of thinking. This motivates students and instils in them the ability to deal with complex problems. PBL is a teaching method in which students learn by doing (source: https:// www.pblworks.org). Students learn how to apply classroom knowledge to real-world problem solving. According to the fundamental concept of PBL, real-world problems inspire and provoke serious thought in students as they acquire and apply new knowledge in a problem-solving context. PBL proponents argue that it helps students develop critical thinking and collaboration skills that are necessary in the workplace. It also assists students in integrating knowledge from various STEM disciplines.

Steps to take when practicing PBL: Determine the desired learning outcomes in Step 1. Step 2: Design the case studies, that includes real world problems relevant to the course. Case studies should be interesting, thought provoking, drive students towards lifelong learning. Step 3: Include PBL – Initially make them very comfortable about the problem to be solved and expose them to this process, by giving them solve easy problems so that they become confident. Step 4: Research and Inquiry — Small-group brain walk sessions in which participants generate ideas for PBL research. Step 5: Product Performance - A product presentation based on expertise and research data analysis. Step 6: Evaluation - Using rubrics, assess and reflect on one's own products/performance.

PBL is practiced in our college. Here one case study is discussed about PBL for the course Foundations of computer system design. Learners must form groups and are encouraged to seek out problems in society by speaking with various people. Students must work on the problem for one month before the first round of discussions with the relevant teachers. Following this discussion, students must decide on the necessary components, software, and hardware tools. Then, from morning to evening, an event called "Productathon" is held during which student groups must implement and demonstrate their work (PBL) to a jury of experts. The rubrics that have already been shared with students are used for evaluation. PBL promotes diverse thinking, critical thinking, creative problem solving, self-management and leadership skills.
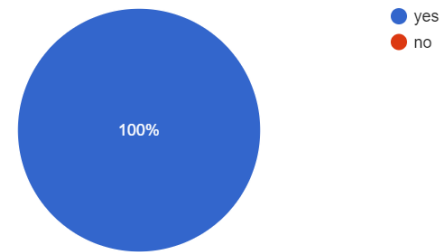
## II. RESULTS AND DISCUSSION

All the mentioned techniques from section II. A to F were conducted for undergraduate Engineering students of our college. Students expressed their sincere appreciation for conducting these activities and feedback was taken from these students. Around 53 responses were received.

Figure 5

depicts the responses submitted by the students for
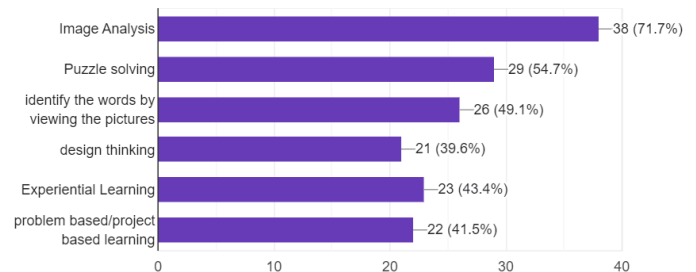
whom this activity was conducted.

Do you like the activities conducted in the class as part of computer networks.
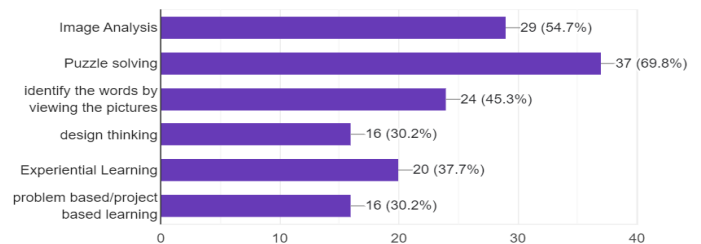
53 responses



Which activity helped for enhancing analytical skills?
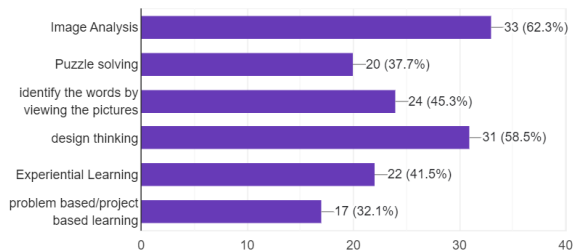
53 responses



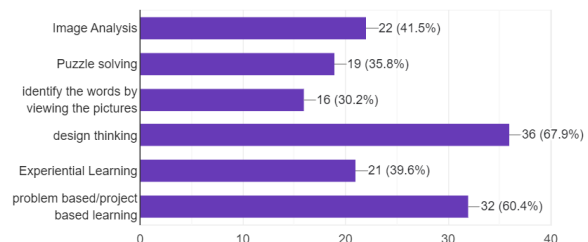Which activity helped for enhancing Logical skills?

53 responses



Which activity helped for enhancing creativity/imagination skills?
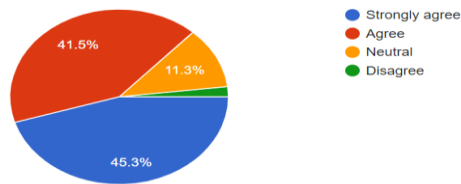
53 responses



Which activities contribute for life long learning skills?

53 responses

compare the traditional teaching methods versus 21st century
teaching in terms of achieving higher order skills
53 responses



- Strongly agree
- Agree
- Neutral
- Disagree

41.5%
11.3%
45.3%

On a scale of 1 to 5(5 being the highest and 1 the lowest), rate how
these activities contribute towards learning the course effectively.
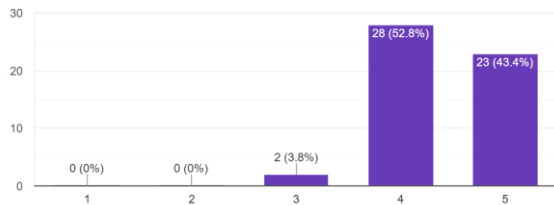53 responses



Fig. 5. Responses for the feedback

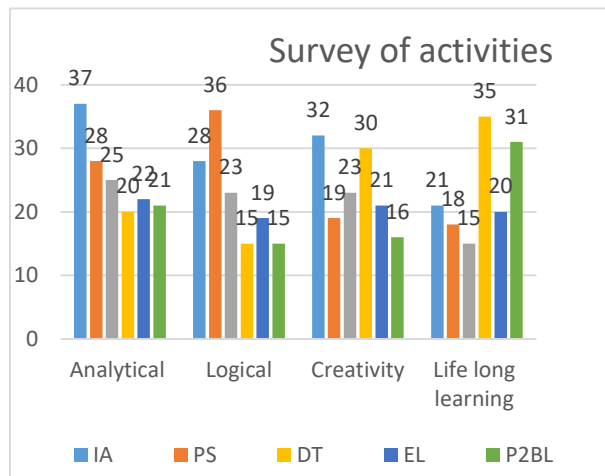The graphical results of the feedback from students are shown in figure 6.



Fig. 6. Graphical representation of feedback

Inference from the feedback: Majority of students believe that IA, GW, and PS improve analytical skills, while PS improves logical skills and IA and DT foster creativity. Lifelong learning skills are greatly enhanced by DT and PBL. Students who excelled in these activities were also found to have a background in co-curricular/extracurricular activities such as dance, music, sports, and so on. These students' test scores have significantly improved because their approach to problem solving is completely different. As a result, liberal arts education is critical in engineering education.

Table 1 depicts the correlation of techniques with different features responsible for critical thinking skill enhancement.

Table I: Techniques mapped with features

| Sl. No. | Techniques | Features promoting critical thinking skills |
|---|---|---|
| 1 | Visualization | Communication, Writing /articulation skills, computational thinking, imagination and conceiving all possible perspectives |
| 2 | Puzzle Solving | Logical thinking Enhanced Visual-Spatial Reasoning, Higher IQ |
| 3 | Guess the word | Improved visualization, Recalling, Analytical, Logical and Creativity |
| 4 | Experiential Learning | Self -learning, problem solving, societal concern, real-world problem-solving skills, literary skills, report/article writing |
| 5 | Design thinking | Societal concern, solving ill-defined and unsolved problems, improving user experience, Create innovative solutions |
| 6 | Problem based learning | Reinforcement of better understanding of course concepts, discussion, pitching ideas Creativity and innovation |

### III. CONCLUSION AND FUTURE WORK

Integrating liberal arts/active learning into the curriculum enhances students' lifelong learning experiences. It causes prospective students to think from a variety of perspectives and not only encourages critical thinking in students but also provides a platform to participate enthusiastically in these activities. Their involvement in this learning process has expanded their problem-solving abilities, and made them critical thinkers. Always Students should be made part of the teaching learning process and that is possible with these techniques. Team dynamics open new forums in which each one learns to be co-operative, leader, collaborator and self- learner. They develop the ability to apply course content to real-life scenarios. Inter/multi -disciplinary research, complex problem-solving, presenting concepts, imagination and reflection, are some of the benefits of practicing and inculcating techniques such as PS, EL, IA, GW, DT, and PBL in the curriculum. This paper attempts to demonstrate some of the techniques used in engineering

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education to improve critical thinking. This helps in achieving most of the graduate attributes.

FUTURE WORK:

 More research with few more case studies is needed in the future to quantify and validate the acquired knowledge. This research will encourage educators to incorporate liberal arts, either implicitly or explicitly, into the engineering curriculum. The strategies presented here will serve as a bridge for the paradigm shift from traditional teaching to 21st century skills in order to implement National Education Policy 2020.

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