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Fostering Higher Order Thinking Skills in Engineering Drawing

GVSS Sharma[1], J. Raja Murugadoss[2], V. Rambabu[3]
[1]Department of Mechanical Engineering, GMRIT, GMR Nagar, Rajam-532127
[2]Department of Civil Engineering, GMRIT, GMR Nagar, Rajam-532127
[3]Department of Mechanical Engineering, GMRIT, GMR Nagar, Rajam-532127
[1]sharma.gvss@gmrit.edu.in
[2]rajamurugadoss.j@gmrgroup.in
[3]rambabu.v@gmrit.edu.in

Abstract: Engineering drawing is a basic engineering course, which is popularly remembered as the language of engineers and finds the applications in all the domains of engineering as well as architecture. And now due to the intervention of computing facility, it gained further momentum in the field of engineering and technology. This paper traces the development of higher order thinking (HOT) skills in the field of engineering drawing. This paper makes an attempt in proposing distinct platforms for inculcating higher order thinking skills among the engineering students, which further enables them to achieve their highest potential and prepare them to propose solutions for the real world problems. Spatial visualization coupled with an intensive practise in free-hand sketches and manual drafting which is slowly dwindling in today's era of computerization, is proposed for improving HOT skills in the domain of engineering drawing. Students' understanding of the engineering drawing course has registered a substantial improvement and is recorded in the assessment performed.

Keywords: engineering drawing, higher order thinking (HOT), outcome based education (OBE), spatial visualization (SV), perspective views

GVSS Sharma
Department of Mechanical Engineering, GMRIT,
GMR Nagar, Rajam-532127
sharma.gvss@gmrit.edu.in

1. Introduction

The need for critical knowledge in higher education always remains in demand (Madan, 2011). It is of importance that, the generated knowledge in any discipline is useful for the progress of the society by-and-large. The pedagogy related to knowledge generation and research, must focus on the innovative methodologies which critically engage the students until the desired epistemic shift is achieved (Hirst, 2005). Such a focus brings out the individuality within the pupils which ultimately brings down the desire to plagiarize. It is observed that creativity and spatial ability have a close relationship (Suh & Cho, 2020). Critical engagement of the students in the classroom calls for creativity in teaching (Sharma Sen & Sharma, 2009). With the proliferation of the number of engineering institutions, there arises the need for promoting creativity though Design-and-Make concepts along with cognitive and curricular aspects right from the high school level onwards (Khunyakari, 2015). One such domain of engineering which demands creativity and critical thinking skills is engineering drawing.

Drawing is the language of engineers. A drawing speaks better than written words and an excellent mode of communicating ideas for scientists and engineers. As soon as students enter the engineering program they are exposed to engineering drawing. This is a strategic shift from the science stream like physics, chemistry and mathematics which they learn in higher secondary school, to engineering program.

During this transition, students face various difficulties and when concepts are not understood they become dejected and form a negative impression about engineering. For this negative impression not to creep inside the young student minds, the teacher should help the students to make the journey across the drawing course smoother and free from hurdles.

Studies proved that if teachers purposely and persistently practice HOT skills like open-ended discussions, inquiry-oriented experiments and real-world problems in classroom instructions, then there stands a better chance for consequent development of critical thinking capabilities (Miri, David, & Uri, 2007). For promoting critical thinking and reflective HOT skills among students, blending of the classroom face-to-face learning with internet based learning is also proven.(Garrison & Kanuka, 2004). Higher order cognitive skills broadly comprise of question-asking (QA), problem solving (PS), conceptualisation of fundamental concepts (CFC), decision making (DM) (Leou, Abder, Riordan, & Zoller, 2006).

Engineering drawing is a unique subject unlike other theoretical engineering subjects. The infusion approach towards learning engineering drawing contributes towards critical thinking disposition when compared with the conventional drill approach (Darby & Rashid, 2017). Spatial visualization skills comprise an array of skills which infuse critical thinking among the students of engineering graphics education (Sorby, 2009a), (Sorby, 2009b). One such skill is the Purdue Spatial Visualization Test which proved helpful for improvement in 3-D Spatial Visualization skills among women engineering students (Sorby & Baartmans, 1996), (Sorby & Baartmans, 2000). Budinoff and McMains (Budinoff & McMains, 2019) observed an average increase in 9.4% in students' spatial visualization scores after rendering them training in 3D modelling skills. Rodriguez and Luis (Rodriguez &Rodriguez-Velazquez, 2019) identified spatial visualization as an important competence for successful studies in STEM fields. Einde et al. (Van Den Einde, Delson, & Cowan, 2019) assessed the impact of a mobile spatial visualization sketching app on increasing self-efficacy in learning engineering graphics courses. Apart from engineering drawing, Spatial visualization skills proved useful for explaining complex mechanical engineering concepts with ease in the classroom (Sharma & Dumpala, 2015).

Importance of freehand sketching skills in problem solving and several other aspects of engineering curriculum cannot be overlooked (Uziak & Fang, 2018). Kosse and Senadeera (Kosse & Senadeera, 2011) stressed on the importance of hand-drawing and tolerancing instead of limiting the students to AutoCAD or one of the solid-modelling packages. On the other hand, if the support of modern aids like virtual reality techniques are adopted in engineering drawing, then it paves way for improvement in understanding of the subject (Romero, Maroto, Martínez, & Félez, 2007). Kimmel et al. (Kimmel, Deek, & Kimmel, 2004) proposed a problem solving approach to engineering graphics which can be applied to both manual drafting as well as CAD exercises. Huaiwen et al. (Huaiwen, Daiwei, Kaiyin, & Ding, 2013) proposed a new curriculum for engineering graphics course, which blends traditional engineering graphics with modern digital design technologies. Babu et al. (Babu, Suman, & Srinivasa Rao, 2019) focussed on the client-server environment for teaching engineering drawing based courses.

Perspective views are real-time views which find widespread applications in correction of text in three dimensional scenes (Clark & Mirmehdi, 2003), (Merino-Gracia, Mirmehdi, Sigut, & González-Mora, 2013). Another advanced application of perspective views finds in enhancing image resolution of visual surveillance cameras at public places like railway stations which are prone to crime and terrorist activities (Tarrit et al., 2018). The images from closed circuit television (CCTV) cameras often get distorted because of lens aberration (Santana-Cedrés et al., 2017). These distorted images are corrected by extracting the distorted lines and estimating their vanishing points pertaining to the perspective projections of the real-time image. These vanishing points are introduced into a lens distortion model for suitable image processing and correction. Lorenz et al. (Lorenz, Trapp, Döllner, & Jobst, 2008) proposed an interactive visualization technique for generating multi-perspective spatial views of three-dimensional landscapes and city models from the panorama maps' principles. Thus perspective views, drawings and images form an important domain for better visualization which brings in more optical clarity. In this paper, perspective views are considered as a platform for enhancing the HOT skills of the students during the learning of engineering drawing.

For any graduate coming out of the engineering program, the communication skill is one of the essential graduate qualities. In the context of outcome based education it is popularly stated as communication skills. The communication skills not only include oral and written communications but also graphical communication. Further it is a well-known fact that engineering drawing is the language of engineers. Further, this spatial visualization and perspective views, will provide an adequate scope for creative thinking and this creative thinking is one of the most wanted competency in line with 21st century skills (Gordon, 2017) . Thus, it necessitates the requirement of HOT skills in engineering drawing.

In the above literature review several authors have touched upon varied aspects of training students in engineering drawing. There emerges a research lacuna in tracing methodologies for embedding HOT skills among students during learning of engineering drawing. The present work addresses this research gap and proposes platforms for inculcating HOT skills in the area of engineering drawing and related subjects.

The structure of the paper is as follows. The paper starts with an insight into considering and selecting engineering drawing as the subject for implementing HOT skills. Then the literature review summarizes on the works carried out by different author in the related field and touches on the research lacuna. This is followed by proposing a roadmap for introducing higher order thinking skills in engineering drawing pedagogy. Spatial visualization methodology is proposed as an excellent tool for inculcating HOT skills in engineering drawing subjects among students. This is succeeded by constructing perspective views as a method for enhancing HOT skills among the students The different approaches to minimize the impediments faced by the students are consolidated. Evaluation and improvement in student success rate with pre-training in HOT skills is recorded in the next section. Finally the paper is summarized by a conclusion followed by the list of references

2. A strategy for introducing higher order thinking skills in engineering drawing

Revised Blooms Taxonomy (RBT) classifies the thinking skills broadly into two categories as:

- Lower Order Thinking (LOT) skills, and
- Higher Order Thinking (HOT) skills.

Lower Order Thinking skills mainly concentrate on the "Remember", "Understand" and "Application" aspects and whereas the Higher Order Thinking skills are targeted towards "Analysis", "Evaluation" and "Creation" facets of learning. Lower Order Thinking skills can be tested in classroom by conducting examination on the topics covered in the classroom delivery. Higher Order Thinking skills on the other hand requires the assessment that needs to be done on the basis of certain set of activities, case studies, real time industry defined problems and societal implications.

The fact that all students are not alike cannot be overlooked. In order to foster Higher Order Thinking (HOT) among the students, the first step is to join theory with practice and make the course as an "integrated" course. Another fact which has to be given due attention is that in this era of Outcome Based Education (OBE) the teacher should be a facilitator and must change oneself to fit as per the intellectual requirements of the students.

HOT must be a way of dealing situations where variety, divergence and deviations are always bound to be existing. The strategy for deploying HOT in engineering drawing is proposed in the following steps :

Step-1 : Imparting HOT skills starts with a generic cognitive approach wherein strengthening of basic and prerequisite fundamental knowledge is proposed. In engineering drawing, the basic knowledge of mathematical geometry learned in high school is a prerequisite. This is because the knowledge of geometry is crucial for spatial reasoning and thinking (Jayathirtha, 2018).

Step-2 : Next to the previous step, this step involves extensive practice for dealing with the wide divergence, variety and deviations existing. In the context of engineering drawing, extensive practice of the topics not only from textual knowledge but also from the case studies pertaining to real-life scenarios are to be undertaken. Spatial visualization and perspective views are identified as unique platforms in this paper, for this extensive practice and leveraging HOT skills in the engineering drawing.

Step-3 : When skills are practiced, they become a habit and sink below the unconscious mind making a permanent connection with the existing thoughts.

Step-4 : Finally the practiced skills get embedded into the microstructure of the brain and become an usual practice.

Thus, engineering drawing is a niche area with a research lacuna unattended for the deployment of Higher Order Thinking skills. Engineering drawing is a distinctive field of engineering where the traditional methods of pedagogical techniques related to theoretical and mathematical aspects cannot be taken into consideration. This piece of work concentrates on leveraging Higher Order Thinking skills in the field of engineering drawing through the broad platforms of visualization and free-hand sketching of the perspective views.

As specified, HOT is specifically related with "analysis", "evaluation" and "creation" aspects of the Revised Blooms Taxonomy. Each of these aspects with reference to engineering drawing are discussed as follows :

- Analysis : Engineering drawing takes the shape of "analysis" when subjects like theory of machines, strength of materials, theory of structures are taught in classroom. Here engineering drawing helps in analyzing the trusses, drawing shear force and bending moment diagrams, kinematic linkages and so on.

- Evaluation : Evaluation involves a certain degree of making judgement pertaining to real-time case-studies and industry problems. Orthographic projections and isometric views in engineering drawing come into use in providing real-time solutions to the industrial case-studies.

- Creation : Creation is the pinnacle of the learning wherein there is churning of new knowledge. Designing of machine members, tools, dies, moulds, civil engineering structures, bridges, to name a few, requires the basic knowledge of the engineering drawing skills

3. Spatial visualization methodology as an excellent tool for inculcating HOT skills in engineering drawing among students

Spatial visualization (SV) is the ability to perceive and recognize the differences in views of any object without actually orienting that object in desired direction in reality. SV calls for greater imagination and is a separate field apart from general intelligence. Expertise in SV skills promotes fine motor skills like dexterity of hands, manoeuvring a vehicle in busy traffic, coordination while playing a football or hockey game and so on. SV also plays an important role in teaching and learning of anatomy in medicine. Thus, SV finds applications in wide areas like early schooling, engineering learning and pedagogy, manufacturing industries, product design and medical applications.

Spatial visualization and engineering drawing complement each other (Olkun, 2003) but they are not studied as a platform for fostering HOT skills. This work proposes integrating of the concepts of spatial visualization and engineering drawing. The following are the spatial visualization tests that help the students to improve their imagination and inculcate HOT skills in the engineering drawing domain:

A. The Mental Cutting Test (MCT)

Mental Cutting Test (Sorby, 2009a) is a part of the Special Aptitude Test in Spatial Relations that help in developing the identification of a cross section of object given the object with minimal visual information. MCT aspect helps the student in drawing the sectional views of the solids in engineering drawing. This facet of spatial visualization improves the imagination to perceive the intricate details of any engineering component without taking the cross section of that component. It trains the mind to visualize the sectional view without physically cutting or damaging the component. Mental Cutting Test finds varied applications in perceiving the inner details of complex engineering components like carburettor, engine block, engine head and transmission. It facilitates the viewing of auxiliary sections taken along the auxiliary section plane. An example of MCT is depicted in Figure 1 where a "✕" mark signifies a wrong answer and "✓" mark signifies the correct answer.

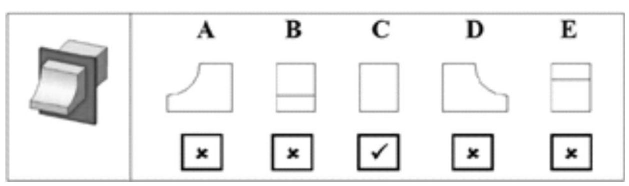


Fig. 1: An example of Mental Cutting Test

A. Mental Rotation Tests (MRT)

Mental Rotation Test (Sorby, 2009a), (Sorby, 2009b) helps in imagination of the views of the objects from north, east, west, south or intermediary directions, without physically rotating the object in reality. MRT finds its applications in programming the path of a paint line robot in an automotive sector. In ship building and aeronautical engineering, MRT helps in imagining the different views of the assembly, where, because of the magnanimity in size the assembly cannot be rotated physically frequently in desired direction everytime. It helps the students in drawing isometric views of the objects from the given orthographic projections and vice-versa. In real life situations the MRT help the persons in situations like driving a vehicle in steep curved turnings which require sufficient judgement of the position of the vehicle with respect to other vehicles and stationary objects on the road. An example of MRT is depicted in Figure 2 where, the "" mark signifies a wrong answer and "" mark signifies the correct answers for the resemblance of the extreme left master object.

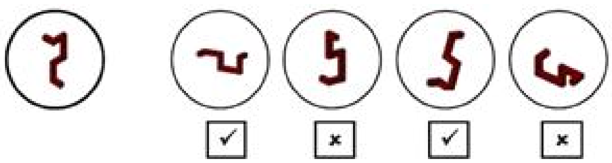


Fig. 2: An example of Mental Rotation Test

C. Purdue Spatial Visualization Test (View part) : (PSVT:V)

PSVT:V (Sorby, 2009a) helps the persons in visualizing from one view point through a glass cube. Here the physical model is kept in a glass cubicle and the different orthographic views are physically observed from front, side and top of the glass cubicle. This aspect of SV trains the students in identifying similar objects or distinguishing between dissimilar objects. PSVT:V helps in drawing the orthographic projections of the objects in first angle projection as well as the third angle projection method. An example of PSVT:V is depicted in Figure 3.

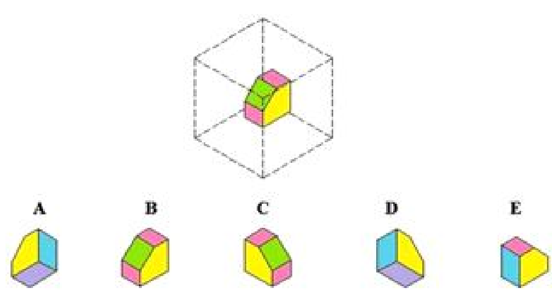


Fig. 3: An example of Purdue Spatial Visualization (view part) : (PSVT:V)

D. The Purdue Spatial Visualization Test : Visualization of Rotations (PSVT:R)

PSVT:R (Sorby, 2009a) aspect of spatial visualization trains the mind to recognize the object and its intricate shapes from any angle. This aspect of spatial visualization helps in viewing the dynamic positioning of the moving parts in union, like rotating shafts, with one another. PSVT:R helps the persons in better judgement of dynamic positioning of the moving objects with respect to each other. For example, while climbing up or getting down a spiral steps which are non-uniform in width, the person should position oneself properly in order to avoid slippage. PSVT:R also helps in performing pseudo surgery practice by medical students through augmented reality. In engineering education, augmented reality helps in comprehension of the engineering drawings and improves the understanding of the students (Olvera-García, Marín-Granados, & Ortíz-Zamora, 2019). An example of PSVT:R is depicted in Figure 4.

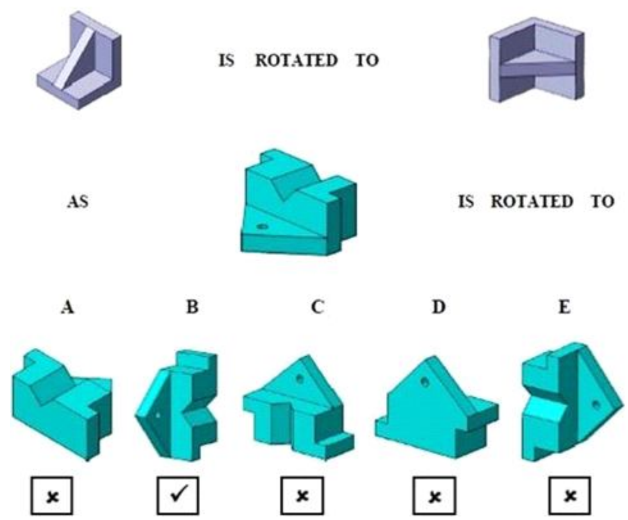


Fig. 4: An example of Purdue Spatial Visualization Test (visualization of rotations) : (PSVT:R)

E. Purdue Spatial Visualization Test (Development part) : (PSVT:D)

PSVT:D (Sorby, 2009a) helps the persons in visualizing the folding of 3D objects. This aspect of SV skill enables the students to construct the surfaces of an object and assess the overall size/dimensions and shape of the object. It helps in creating the surface topography of any engineering component. It aids in providing training for students in the product design of car body surfaces through 3D geometric modelling software packages. PSVT:D aspect of spatial visualization trains the students in development of surfaces in the engineering drawing subject. An example of PSVT:D is depicted in Figure 5.

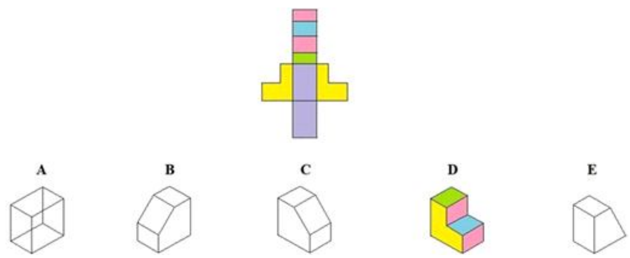


Fig. 5: An example of Purdue Spatial Visualization Test (development part) : (PSVT:D)

F. Visual Penetrative ability (VPA)

Visual penetrative ability (VPA) is the ability to visualize the three-dimensional (3-D) underground structure of folded sedimentary rocks from two-dimensional (2-D) surface clues (Alles & Riggs, 2011). It is a basic skill for any geology undergraduate student. Visual Penetrative Ability finds its widespread applications in the field of geology where the student needs to visualize and construct a three dimensional physical model of the cross section of the earth's layers of soil showing the penetration of the earth's internal underground structure. Students with poor VPA cannot visualize and understand the internal structure of the soil and hence cannot construct the 3D physical model correctly. Thus VPA enhances the capability of the student to imagine and visualize across the boundaries and can be successfully learnt by the engineering students for enhancing their application of SV skills in engineering drawing course.

G. 2D to 3D transformation

2D to 3D transformation enables the student to convert the orthographic projections into isometric views. It is one of the important aspect of engineering where student develops the skill of reading, interpreting and drawing inferences from industrial production drawings. Figure 6 depicts an instance of 2D to 3D transformation.

Thus, spatial visualization is an excellent tool for enhancing the visualization skills among the students.

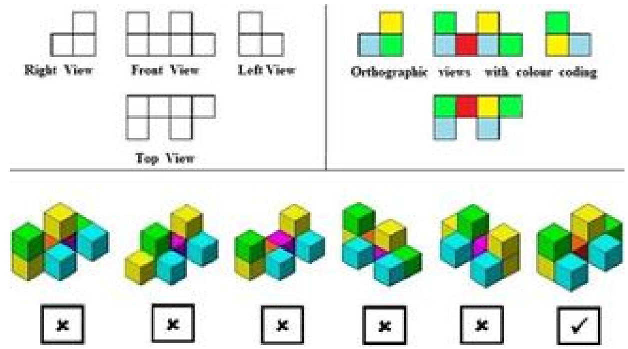


Fig. 6 : An example of 2D to 3D transformation

This is an excellent platform for enhancing Higher Order Thinking skills namely the analysis, evaluation and creation learning levels in the area of engineering drawing and allied fields

4. Perspective views as a platform for enhancing HOT drawing skills among the students

Drawing is a pedagogical tool and a part of cognitive process in visual literacy where one has to extract the required visual information. It is an integral part of the thought process and a strong medium for improving the expressiveness among the students. Manual drawings and hand drawn sketches bring in multi-dimensional benefits such as enhancing engagement among students, learning reasoning and representation in science, formulating strategy and learning to communicate (Ainsworth, Prain, & Tytler, 2011). Free-hand sketching and drawing constitutes the process of capturing the overall picture and simultaneously looking into the minute details. It involves tracing of contours, expressing perspective volume and depth through shading. Constructing meticulous drawings is an approach for capturing elusive aspects of visual experiences (Qvarnström, 2019).

Higher Order Thinking skills pertaining to drawing can be fostered through keen observation from nature and the physical surroundings. In relation to engineering drawing, the capturing and mastering of free-hand perspective views enhances the visualization capability which in turn expands the horizons of "analysis", "evaluation" and "creation" frontiers of HOT skills.

The view of the single point perspective of a natural surrounding is captured in the photograph below in Figure 7. Students are encouraged to improve their critical thinking skills, their spatial

Fig. 7: A landscape representing a single vanishing point perspective

visualization and imagination skills by observing from such natural surroundings. The point here in this paper is not to teach perspective views but to encourage students to draw free-hand manual sketches in perspective mode which improves their critical thinking towards engineering drawing.

In order to enable HOTS, students are encouraged to identify such geographic places which closely depict the perspective drawing and practice such drawings with pencil and paper. The practice can be extended to manually draw, using a pencil and paper, the house-hold articles like a simple water bottle as shown in Figure 8. The main idea is that the bottle is built up of various circular cross-sections geometrically and this concept proves to be useful in drawing the perspective views. Higher order thinking can be fostered by building up of the perspective views of the surrounding common house-hold objects. This helps the students to improve their imagination and critical thinking skills. This HOT can be extended further to other common household articles like utensils, tables, chairs and so on.

The conversion of textual isometric views into perspective views also enhances the visualization and imagination capability. Any standard text book on engineering drawing consists of numerous examples of isometric view. It is suggestible for students to practice conversion of these isometric views into perspective views manually, as this fosters HOT skills and enables them to expand the horizons of thinking capacity. Manual conversion of one such isometric view into perspective views, on pencil and paper, is shown in Figure 9. Further to this, the sketch of surrounding habitats like high rise buildings also can be captured for improvement in HOT skills.

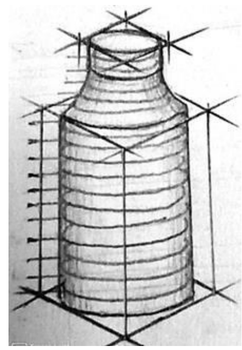
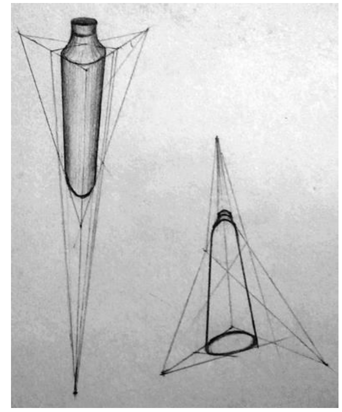
ISOMETRIC VIEW OF A BOTTLE	PERSPECTIVE VIEWS OF A BOTTLE
	

Fig. 8: Manually drafted isometric and Perspective views of a common household article like water bottle

It is emphasized here that there should be no time limit imposed for practicing such drawings from real life scenarios. This method of learning from real-life shall certainly develop the real-time higher order thinking skills in engineering drawing among the students.

Manual mode of technical drawing imparts value addition in terms of personal achievement , enjoyment and transferable skills (McLaren, 2008). In this era of computerization, manual drafting is thought to be redundant and "old fashioned". It is of grave concern that learning must involve a deeper understanding of concepts and not just a mere training in commands and syntax to use the software package. The findings suggest that characteristics such as accuracy, co-ordination, visualization and personal discipline are learned better from the experience of traditional manual drafting and it is observed that the students after training appreciated the approach through manual drafting.

It is strongly recommended that students must first develop their free-hand sketching and drawing skills by mimicking the scenic beauties of nature, as these skills shall enhance the observation and imagination ability of the students (Coutts & Dougall, 2005). A short training for students in this area prior to teaching engineering drawing shall generate interest among the students and help them to analyze, evaluate and create their own engineering drawings in future. Further to this, a pre-requisite for learning engineering drawing would be a short term course in the fundamentals of mathematical geometry which the students have learned in their high school. This shall strengthen their basic knowledge and minimize their efforts in learning engineering drawing. Another important aspect is that in today's era of computerization it is of importance that students should first make themselves master over the drawings with pencil, paper and drafter and then proceed for the learning of advanced drafting and geometric modelling softwares. In other words, students are strongly advised to learn the concepts of engineering drawing using pencil and paper and then shift to computer-aided geometric modelling. Doing vice-versa would be of no benefit and may lead to hindering in their thinking and visualization capabilities. This progressive approach shall make them to think critically and enhance their visualization capability.

5. Approaches to minimise the impediments faced by students while deploying Higher Order Thinking skills

Engineering drawing is the pre-requisite for learning subjects like machine drawing, production drawing, civil engineering drawings, architectural drawings and electrical machine drawings. The orthographic projections, isometric views, perspective views, development of surfaces are some of the main topics to be stressed upon. Generally at the beginning of the engineering course, the engineering drawing is relatively a new subject to the student. Hence for better understanding, following are the aspects to be taken care of for minimizing the difficulties faced by the students :

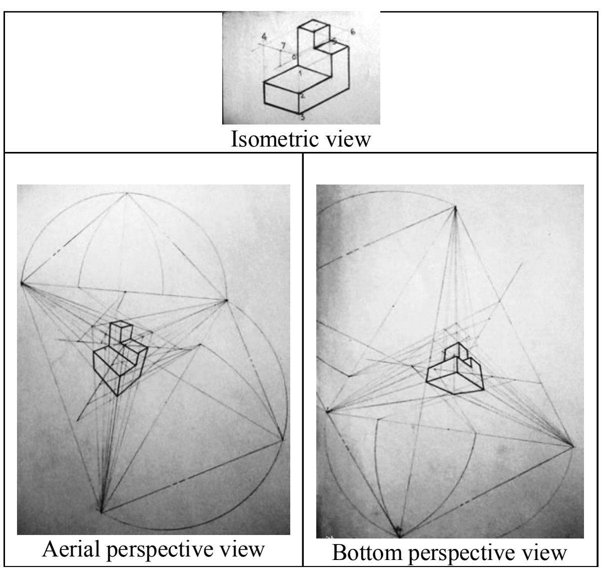


Fig. 9: Conversion of textual isometric views into perspective views through manual drafting

- Selection of updated and proper drawing instruments. Older instruments must be replaced with modern tools, like a drafting mechanical pencil of 0.5mm and 0.7mm pencil leads instead of traditional pencil which needs to be sharpened time and again.

- Inculcation of the spirit of visualization of the surrounding objects from the view point of engineering drawing. While practising engineering drawing, the world surrounding us must be seen and perceived from the angle of the engineering drawing. For example, we see many objects surrounding and making our world on day-to-day basis. These objects must be perceived from orthographic projections of elevation, plan and side views.

- Spending time in knowing about the concepts even outside the prescribed syllabus. Syllabus is only an outline for showing the direction. For gaining true knowledge students must explore outside the prescribed syllabus and also refer to as many books as possible and also make use of the internet optimally.

- 2D drafting software application in the domain of engineering drawing as a support to drafter, paper and pencil approach. Computer aided drafting also helps in accuracy of the drawings and makes the students employable by grooming them to be industry ready.

- Coaching of students in application oriented approach in their respective engineering discipline so that engineering drawing cuts across the branches as an interdisciplinary tool

- Taking aid of the Computer aided geometric models and physical models to explain the concepts of engineering drawing. Apart from giving illustrations through CAD models, the faculty should also demonstrate the cross-sectional views of the parts and assemblies through real-time physical models.

- Imparting real-time training to the students by suggesting examples of daily usage objects that make our world. In other words making engineering drawing as a way of life.

- These are the few vital aspects which percolate deep into students' thinking and help in minimising the impediments faced by them while deploying HOT skills in engineering drawing.

6. Proposed evaluation methods and scores registered by students

Evaluation patterns and methods that can be adopted to examine HOT skills among students of engineering drawing are :

Method-1 : An open book exam/ drawing of the live objects, buildings, bridges etc. without any time-limit and may span upto 3 days to 1 week.

Method-2 : A comprehensive exam wherein open-ended questions are declared few days before the examination and students are expected to spend some quality time and perform a survey for finding the answers.

Method 3 : A live project-based exercises comprising of a full semester through augmented sheet work exercises. One such example of augmented exercise is formulation of blue-prints of the production drawing of engineering components. The first year engineering students are exposed to advanced level of engineering work with the intention of triggering and expanding the horizons of their thinking levels as they try to explore the various branches of engineering domain. This is done because it is believed that effective learning occurs when students are challenged just beyond the level they can do on their own (Delson Van Den Einde, Cowan, & Mihelich, 2019).

Method 4 : A full semester internship at product manufacturing industries like an automobile power train manufacturing unit wherein the student is trained in tool design, development, process design involving understanding of the complex production drawings

Method 5 : Senior students taking classes to junior batch in the course of engineering drawing, as it is proven fact that the best way of learning is through teaching others

Studies have been conducted on a set of 240 students of first year engineering program and their percentage of marks in the evaluation are recorded during pre-training without HOT skills and pre-training with HOT skills in engineering drawing predominantly based on the first three above enumerated methods. Comparative studies are undertaken among two sets of students of 120 students each. One set of students were trained in spatial visualization skills, imparted knowledge of perspective views and revised the fundamentals of geometry. They were examined based on the above enumerated methods for assessment of HOT skills. Whereas the other set of students were deprived of all the above stated methods and were straight away taken through the engineering drawing coursework. It is to be emphasized here that the basic philosophy of introducing HOT is to understand the depth of the meta-cognitive skills of the learners in graphical communication. The responses of the students are captured with the assessment tool, involving spatial visualization and perspective drawings, to understand the learners' abilities on graphical communication.

It is to be clarified that the evaluation pattern for the students comprised of tests involving the skills of analysis, evaluation and creation aspects through augmented sheet work involving exercises from all other domains of engineering including electrical, electronics, civil and mechanical engineering programs. The concept of augmented exercises has been structured to be in addition of part and parcel of the regular work in an engineering drawing course work. These augmented sheet work and exercises are announced in the class at the beginning of the semester. The students are at liberty to answer the augmented exercises on their own through self-learning mode gradually as the semester progresses, with the direction of insights gained from the tutor's pedagogical instructions in the classroom. It is once again stressed here that the objective of exposing the students to advanced level of engineering work (through augmented experiments) is to trigger and expand the horizons of their thinking levels relating to higher order thinking. This is based on the pedagogical approach of Zone of Proximal Development (ZPD) which is based on the belief that effective learning occurs when students are challenged just beyond the level they can do on their own (Delson et al.2019).

The pedagogical tool for training students in engineering drawing comprised of a blend of manual as well as software-based drafting. Manual drafting was used for first half of the course work ie., for the first 2 months, and 2D software package AutoCAD was used for second half of the course work for the last two months of the academic calendar. One group was exposed to an extra 3D geometric modeling software package while the other was deprived of it. In this way both manual as well as computer-based drafting is exposed to the students

The time-table for the engineering drawing lab course comprised of two slots, one in the morning session and another in the afternoon session. The morning session comprised of an extra hour making it as a four-hours at a stretch session whereas the afternoon session comprised of traditional 3 hours session. This additional one hour in the morning slot was concentrated for improving the imagination and visualization capability of students through training in the HOT skills through spatial visualization tools and perspective drawing methodology enumerated in this work. Students were encouraged to think beyond their normal capacity in the morning slot. This non-uniform slot design helped in comparison of students with pre-training in the morning slot and without pre-training in afternoon slot. Also for better management and time-utilization, a second person was attached to the primary course faculty. These two teachers would take the engineering drawing course together hand-in-hand to make the journey of the students along the course work of engineering drawing smoother and enriching.

Table 1 depicts the scores of the students. Figure 10 and Figure 11 shows the normal distribution curves without and with pre-training respectively. It is evident that the curve of pre-training with HOT skills is skewed towards higher end of the marks thereby recording an improvement when compared to pre-training without HOT skills which is skewed towards lower end of percentage marks. As the percentage of marks is a higher-the-better characteristic, hence skewness towards the higher end of percentage shows a positive sign. Through pre-training with HOT skills, the class average percentage has shown a growth from 25.58 percent to 59.13 percent.

Table 1 : Performance of the students without pre-training and with pre-training in HOT skills

Percentage of marks scored	No. of students without Pre-training in HOT skills	No. of students with Pre-training in HOT skills
0	0	0
5	4	0
10	5	0
15	14	0
20	22	2
25	30	1
30	25	2
35	10	0
40	1	5
45	0	11
50	7	17
55	2	3
60	0	32
65	0	20
70	0	8
75	0	13
80	0	1
85	0	5
90	0	0
95	0	0
100	0	0

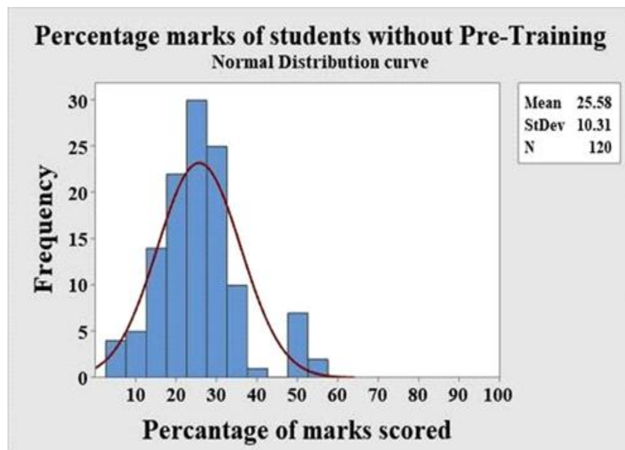


Fig. 10 : Percentage marks of students without Pre-Training in HOT skills

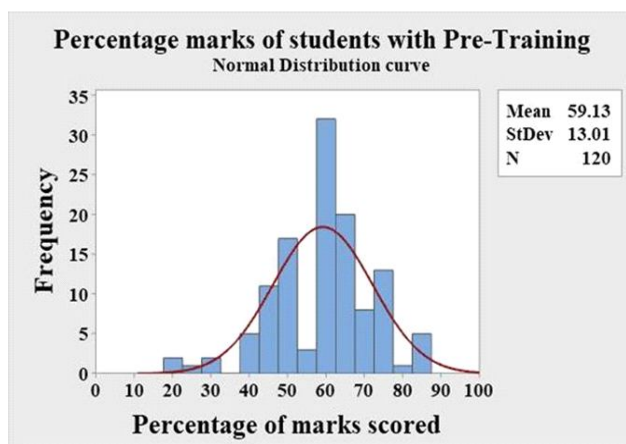


Fig. 11 : Percentage marks of students with Pre-Training in HOT skills

7. Conclusion

Engineering drawing is unlike any other regular engineering subjects. It requires inculcation of certain degree of imagination and spatial visualization. This work discusses the finer aspects of the engineering drawing pedagogy. It discusses about about the implementation of the Higher Order Thinking skills among the students in the field of engineering drawing. This paper discusses about using spatial visualization and perspective views as the two major platforms for leveraging Higher Order Thinking skills in the engineering drawing course. The difficulties faced while learning engineering drawing are discussed. Focus is set on mastering the free-hand sketching skills before taking the grip over the CAD software. A delicate balance in free-hand sketching and CAD software is the key to success in fostering Higher Order Thinking skills in the engineering drawing and allied subjects. This work can be further extrapolated to other drawing related courses like, machine drawing, production drawing, electrical drawing and architectural drawing. The further scope lies in the horizontal deployment of the approaches proposed in the paper across the other engineering courses.

Be it engineering services sector or core manufacturing sector, the engineering drawing has got its own importance. Engineering services sectors, like Information Technology (IT), in one or the other way have to support for improving the processes for core industries. Persons with a combination of core domain engineering knowledge plus IT tools, shall always be preferred when compared to a person with only sole knowledge in IT tools. Thus, in this today's fast changing world, cross functional team work is the key to success. Person with the basic knowledge of engineering drawing goes by and far an extra mile when compared to others. This is because of the fact that drawing is the language of engineers and is irreplaceable.

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