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A Test to Assess Students' Conceptual Understanding of Engineering Metallurgy Subject

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Abstract: Engineering students have misconceptions that need to be addressed to improve their understanding of the subject especially in courses that involve several interlinked concepts. While approaches such as concept inventories and concept maps have been used in the past, the present study addresses the importance of learning assessment design with a clear understanding of the conceptual difficulties faced by students. This paper describes a series of diagnostic assessments conducted to understand the most common misconceptions encountered by the Engineering Metallurgy subject students in the 3rd semester of a B.Tech. program in Mechanical Engineering. The goal of this exploratory study was to ascertain whether this diagnostic approach could help the instructor guide the students towards correct responses through multiple interventions. The primary learning interventions included live classroom lectures, asynchronous assignments, blended mode group discussion and supplementary video lectures while secondary learning interventions included periodic post-assessment reviews used for some topics. Multiple-choice questions were used for assessment and student responses were classified as correct, misconceptions or 'no basis' responses. The proposed diagnostic approach provides a framework for educators to identify best interventions suitable for specific topics and forms the basis for Outcome-Based Education. The study revealed that for 12 of the 14 topics considered in this tracking approach, a target percentage of correct responses was reached by the students while the number of 'no basis' responses were reduced significantly. The results from this study provide a basis for choosing topics where alternate learning designs could be implemented in the future.

Keywords: Misconception, Outcome-Based Education, Engineering Metallurgy

1. Introduction

Misconception refers to the student's conceptions that are different from those accepted by the scientific community. Among the engineering students, such misconceptions are often revealed during the classroom discussions. However, as they do not pose any immediate risk, they are generally ignored by the educators. Students may develop various misconceptions during their learning process, which may be due to many reasons. Moreover, these misconceptions get carried forward from fundamentals into the approach to problem solving later on. The main reasons for such an occurrence may be either wrong interpretation of the concept or misleading information gathered from an unreliable source. Identification of misconceptions help the educator to address and correct them.

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The practice of Outcome Based Education (OBE) has enabled educators to focus on developing more student-centric approaches and assessment of learning outcomes of an individual student. In such approaches, a study of misconceptions is essential for effective teaching. It is also evident from the literature that peer learning activities such as mind map, just-a-minute etc., engage and motivate the students. However, it is still a challenge to interpret and measure student conceptual understanding apart from the significant time and effort needed to track multiple student data and to classify it based on their understanding. Further, educators have to track the students' level of understanding before and after the delivery of their lectures in a systematic manner.

Available literature reveals that very often the student misconceptions about the subject are identified with the help of interviews or Multiple-Choice Questions (MCQ). One-on-one interview is generally not preferred as it is time-consuming over multiple-choice tests especially when large number of students need to be sampled. Additionally, MCQs are easy to assess and administrate. It has become even more easier with the development of educational technology tools such as Google Forms, Moodle, Plickers, Kahoot, Quizlet, Edpuzzle, Mentimeter, Edmodo, etc. Developing a diagnostic test is a simple process but unless it is planned and executed properly by the educators, there will not be any viable conclusions. However, study of literature also reveals that multiple-choice tests alone do not always indicate the student understanding levels. Several researchers have developed different strategies while deploying and assessing these tests. One of the popular strategies developed by Treagust, D.F., (1988) is a two-tier test. Broadly, the development of such a diagnostic test should essentially consist of the following three major step frameworks (Treagust, D.F., 1988) defining the content and concept boundaries, the cognitive structure of a diagnostic test, and third important step is to develop two-tier test items, of which the first tier requires a content response and the second tier requires a reason for the response. The use of the two-tier diagnostic test has been described by several authors, such as Chen, C. C. et al., (2002), Lin, S. W. (2004), Cengiz, T.Y. Z (2009), Sesli, E. & Kara, Y. (2012), Adadan, E., & Savasci, F. (2012), Adodo, S. O., (2013). However, these studies were mostly conducted for freshman students. Nevertheless, in the materials engineering course students' misconceptions have been studied in order to create a Material Concept Inventory (MCI) (Stephen Krause et al., 2003, S. Krause et al., 2003, Purzer S et al., 2009). These inventories may be cognitively biased, for example a novice student might have developed a naïve model of the concept and might focus on surface of the problem, whereas a critical thinker may be able to approach the question at a much deeper level.

While MCI may be considered in a later study, the current study is mainly focused on developing an exploratory strategy to identify misconceptions among the engineering students on the subject 'Engineering Metallurgy', for the implementation of OBE. The goal of the study was to ascertain whether spaced assessments and review sessions helped in addressing difficult topics and therefore, improved learning, in addition to the classroom interventions. Formative assessment conducted for the engineering metallurgy subject using a multiple-choice test revealed that few students have opted for choices with no basis which possibly reflect poor preparation, guess work or lack of interest or attention. In this study, such choices are termed as `No Basis´ response to differentiate them from genuine misconceptions.

2. Methodology

Engineering Metallurgy subject is offered as a fundamental subject for third semester undergraduate students. The underlying concepts in this subject are mainly analytical and are important for higher semester course subjects. Therefore, eradicating the misconceptions in the early stage help the students to understand the concepts clearly and perform better in later semesters.

Generally, for any subject, certain Course learning Outcomes (C.O.s) are framed which are broad, and these are further subdivided into Topic Learning Outcomes (TLOs). Table 1 shows the C.O.s and individual TLOs in detail along with their levels of difficulty (Easy – E, Moderate – M, Difficult – D) and the corresponding primary learning interventions. the levels of difficulty are determined based on the number of interlinked concepts, i.e., a greater number of interlinked concepts indicates higher level of difficulty. The primary interventions are classified as 'Asynchronous Assignments', 'Live lecture', 'Blended Mode Group Discussion' or 'Supplementary Video Lectures'. Engineering Metallurgy subject has five units, for which a C.O. and few TLOs have been assigned. These C.O.s were mapped to Programme Outcomes (P.O.s) and Programme Specific Outcomes

(PSOs). OBE system emphasises mainly on the students' attainments of overall P.O.s and PSOs.

2.1. Learning Interventions:

The primary learning interventions are chosen and customized based on requirements for the topics of engineering metallurgy. The 'Asynchronous Assignment' includes lecture followed by assignment completed by the students themselves and feedback given by the instructor. 'Live Lecture' means a classroom live interactive presentation delivered through content and questions. In 'Supplementary Video Lectures' the live classroom was followed by video recording shared with students based on their request. 'Blended Mode Group Discussion' included lectures followed by group discussion where students worked in groups of 6, answering specific questions related to the topic. The 'Blended Mode Group Discussion' was chosen as the primary interventions for topics which were closer to application and where students could come up with examples of everyday application. However, many topics included a secondary intervention given in the form of review for a first-level assessment and some included two cycles of assessment and review prior to the final assessment. These are shown in the table as well.

2.2. Learning Assessments:

For learning assessment, each question in the MCQ test is mapped with their corresponding TLOs before collecting the responses.

Four tests on the Engineering Metallurgy subject were prepared using MCQ in which each student response was categorised as correct, misconception or 'no basis' types. A total of 70 students (59 males and 11 females) were considered as the test group. Four formative assessments (A1 to CA4) have been conducted for this group which covered most of the important concepts of the subject. Each of these assessments except the fourth one which will be referred to as the 'Comprehensive Assessment', were followed by review and two of the topics had two such cycles of assessment and review prior to the final formative assessment. TLOs 16 and 20 were not covered in the formative assessments. All the four formative assessments were validated by two subject expert teachers before deploying them to the students. All the responses from the students were collected using the tools Google Forms, Kahoot and Plickers for formative assessment.

2.3. Analysis:

For each of the TLOs above, the percentage correct responses for each of the tests were calculated as well as the percentage responses with higher level of misconceptions and 'no basis' responses. The sample assessment questions and students' responses are presented in Table 2 along with the levels of difficulty and classification of responses. The assessment results for each TLO scored by individual student was analysed in this manner and review sessions were planned in the subsequent class sessions. These review sessions generally included classroom discussions on the most common misconceptions by students and clarification by the instructor. Some other approaches included facilitating with detailed resources of notes and videos wherever possible. A target of a minimum of 55% correct responses was chosen for an initial analysis through these primary and secondary interventions with the tracking upto the final comprehensive assessment in terms of the percentage of correct responses, misconceptions and 'no basis' responses.

Table 1 : Engineering Metallurgy COs, TLOs, Difficulty Level and Learning Interventions

C.O.s / TLOs	**COs & TLOs statement** Upon completion, the students will be able to:	**Difficulty Level**	**Primary Intervention**	**Secondary Intervention**
CO 1	Relate different engineering materials and their metallurgical properties.			
TLO 1	Classify various metallic crystal structures based on their Miller's Indices, Packing Efficiency and Density calculations.	M	Asynchronous Assignment	Review
TLO 2	Infer solid imperfections, grains and grain boundaries.	M	Live Lecture	None
TLO 3	Relate the need for various alloying elements.	E	Blended mode Group Discussion	Review

TLO 4	Illustrate types and rules to form solid solutions.	M	Live Lecture	Review
CO 2	Identify different binary alloy phase diagrams.			
TLO 5	Make use of phase rules for developing various phase diagrams.	M	Live Lecture	Review
TLO 6	Apply lever rule to interpret various phases diagrams.	M	Asynchronous Assignment	Double Review
TLO 7	Construct various binary phase diagrams.	M	Asynchronous Assignment	Double Review
TLO 8	Relate metal alloys to phase transformations with examples.	D	Asynchronous Assignment	None
CO 3	Apply the phase diagram concepts to interpret steel			
TLO 9	Construct Iron – Iron Carbide phase diagram and their reactions	D	Supplementary Video Lecture	Review
TLO 10	Classify various alloys steels and their properties	D	Asynchronous Assignment	Review
TLO 11	Construct TTT & CCT diagram	D	Live Lecture	Review
TLO 12	Infer various heat treatment process and about hardenability	D	Blended mode Group Discussion	Review
CO 4	Compare ferrous cast iron to few important non-ferrous metals/alloys and their properties.			
TLO 13	Illustrate various forms of cast iron.	M	Live Lecture	None
TLO 14	Interpret cast iron in engineering applications.	M	Blended mode Group Discussion	None
TLO 15	Outline important non– ferrous metals and their alloys such as Al, Cu, Ti.	E	Blended mode Group Discussion	None
TLO 16	Summarize the use of non – ferrous metals in the engineering applications.		Asynchronous Assignment	None
CO 5	Outline various materials such as ceramics, polymers, composites and some important advanced materials.			
TLO 17	Classify various ceramics, polymers and composites.	M	Live Lecture	None
TLO 18	Compare ceramics, polymers and composites and their applications.	E	Asynchronous Assignment	None
TLO 19	Extend the need for advanced materials.	M	Live Lecture	None
TLO 20	Illustrate few advanced materials such as special purpose materials, shape memory alloys, smart materials, nano materials.		Live Lecture	None

Table 2 : Sample questions from the multiple-choice tests

S.No.	C.O.'s/ TLOs	Difficulty Level	Question	Options	Number of Students	*Category	% Scores
1	CO2/ TLO 5	Easy	Above the following line, liquid phase exists for all the compositions in a phase diagram	Tie Line	8	N	23
				Solvus	0	M	0
				Solidus	3	M	9
				Liquidus	24	C	69
					Total 35		
2	CO 2/ TLO 6	Easy	Relative amounts of phases in a region can be deduced using	"Phase rule"	3	M	8
				"Lever rule"	32	C	89
				"Hume-Ruthery rule"	0	M	0
				"None"	1	N	3
					Total 36		

3	CO 2/ TLO 7	Moderate	The peritectoid reaction is represented by	Solid1 + Solid2 ? Solid3	36	C	78
				Solid1 + Liquid1 ? Solid2	9	M	20
				Liquid1 + Liquid2 ? Liquid3	0	N	0
				Solid1 + Solid2 ? Liquid	1	M	2
					Total 46		
4	CO3/ TLO 9	Difficult	Hypoeutectoid steels have structure of	Pearlite alone	1	N	2
				Proeutectoid ferrite and pearlite	36	C	61
				Proeutectoid cementite and pearlite	16	M	27
				Ferrite alone	6	N	10
					Total 59		

3. Results and Discussion

In this study, multiple learning interventions and assessments were used for the different topics. Figure 1 below shows the sequence of learning interventions and assessments used for the different topics. While some topics had multiple assessments and reviews, some had no assessments and review cycles prior to the comprehensive assessment. For example, TLOs 6 and 7 had two cycles of assessment and review while TLOs 9 and 10 had one cycle of assessment and review.

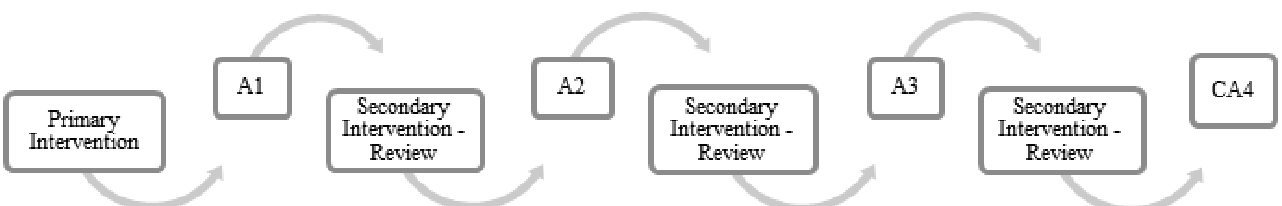

Fig. 1 : Sample Paths of Learning interventions and Assessments

One of the key results that stood out in this study was that the difficulty level as determined by the number of interlinked concepts and ideas was a larger determinant of student assessment results than Bloom's taxonomy levels in the cognitive domain of the specific path of learning interventions and assessments. This is most probably attributed to the large number of topics and nature of the arrangement of the topics in the Engineering Metallurgy course. Figure 2 shows the results of four assessments as a function of difficulty level as described above. The figure clearly shows a decrease in correct response percentages with increasing level of difficulty and this trend is observed to be independent of the type of interventions. In other words, the percentage of correct responses at the lowest difficulty level was the highest while the percentage was lowest at the highest difficulty level. The average percentage of correct responses within each difficulty level shows the decreasing trend as indicated in the figure. In the above discussion, 14 of the TLOs were selected where multiple assessment data were available with the goal of tracking student responses throughout the semester.

Figure 3 shows the tracking of percentage correct responses for the 14 TLOs selected above. The

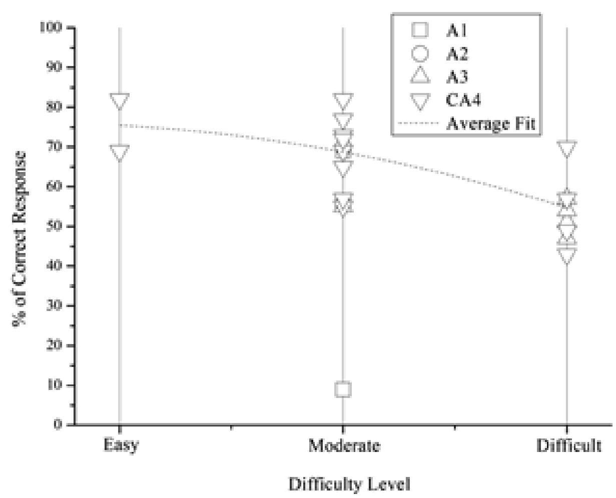

Fig. 2 : Comprehensive Assessment Results as a Function of Difficulty Level

majority of the TLOs indicate an improving trend over the different assessments and the final comprehensive assessment reaching above the minimum target.

The minimum level target of 55% correct responses is reached in the majority of the final assessments. Further, TLOs 6 and 7 with two cycles of assessment and review show a consistent improvement in the number of correct responses.

However, two of the TLOs 9 and 12 do not reach the target in spite of secondary interventions. This is understood to be the result of the difficulty level and the interlinking of concepts. Further, final assessment was comprehensive, covered more concepts and broader in scope and therefore, the topics probably require deeper interventions and alternate approaches.

Table 3 shows the tracking of percentage misconceptions and 'no basis' responses for the same 14 TLO's. There is a decrease in the percentage of the 'no basis' responses except for TLOs 6 and 10. But for TLO 6 and 10, the overall percentage of correct responses improved in these cases. TLOs 9 and 12 actually showed an increase in the number of misconceptions while TLO 14 had a large number of misconceptions in the comprehensive assessment.

The final assessment was designed to test the preparedness of the student before the summative assessment. Therefore, it was more comprehensive than the earlier assessments and this explains some of the results in the previous paragraphs. However, alternate approaches on learning design involving concept maps in combination with multiple assessments and reviews will be planned for TLOs 9, 12 and 14.

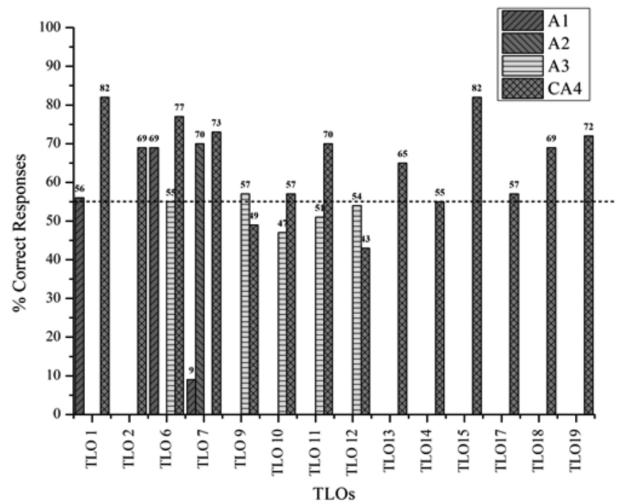

Fig. 3 : Tracking Percentage Correct Responses over the Learning Paths.

Table 3 : Tracking Percentage Misconceptions and 'No Basis' responses for the 14 TLOs

*TLOs	Primary Intervention	Level of Difficulty	% Misconception & No Basis Responses							
			A1		A2		A3		CA4	
			M	NB	M	NB	M	NB	M	NB
TLO 1	Asynchronous Assignment (A.A.)	Moderate	19	25	-	-	-	-	4	14
TLO 2	Live Lecture (L.L.)	Moderate	-	-	-	-	-	-	12	19
TLO 6	Asynchronous Assignment (A.A.)	Moderate	27	4	-	-	42	3	0	23
TLO 7	Asynchronous Assignment (A.A.)	Moderate	91	0	21	9	-	-	8	18
TLO 9	Supplementary Video Lecture (SVL)	Difficult	-	-	-	-	19	24	38	13
TLO 10	Asynchronous Assignment (A.A.)	Difficult	-	-	-	-	42	11	27	16
TLO 11	Live Lecture (L.L.)	Difficult	-	-	-	-	19	30	30	0
TLO 12	Blended mode Group Discussion (BGD)	Difficult	-	-	-	-	28	18	42	15
TLO 13	Live Lecture (L.L.)	Moderate	-	-	-	-	-	-	21	14
TLO 14	Blended Mode Group Discussion (BGD)	Moderate	-	-	-	-	-	-	45	0
TLO 15	Blended Mode Group Discussion (BGD)	Easy	-	-	-	-	-	-	12	6
TLO 17	Live Lecture (L.L.)	Moderate	-	-	-	-	-	-	25	18
TLO 18	Asynchronous Assignment (A.A.)	Easy	-	-	-	-	-	-	31	0
TLO 19	Live Lecture (L.L.)	Moderate	-	-	-	-	-	-	20	8

4. Conclusions

A systematic approach to tracking learner misconceptions in different categories using multiple assessment and learning interventions was discussed. Such an approach shows promise in dealing with subjects with multiple concepts and difficulty levels.

Tracking percentage correct responses, misconceptions and 'no basis' responses provides insights to the instructor for learning design, helps identify topics to implement alternate learning interventions in subsequent course offerings and further helps quantify the effectiveness of learning design approaches involving multiple interventions.

The conceptual complexity of the topic and the assessment has a larger impact than Bloom's taxonomy classification, on the student journey towards correct understanding of the learning outcome.

Out of 14 topics, 12 topics had above 55% of correct student responses in the comprehensive assessment and 12 of the topics had reduced 'no basis' responses.

In the majority of the topics, the students were guided towards the correct responses in the comprehensive assessment. Multiple assessments and reviews helped increase the percentage of correct responses (TLOs 6 and 7).

The tracking of the three categories of student responses helped the instructor identify the topics for alternate learning interventions in the future.

The study also points to the need for describing the conceptual difficulty of topics using an alternate framework such as the SOLO taxonomy in order to help learning design.

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