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A quantitative assessment of classroom teaching and learning in engineering education

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All stakeholders are aware of the importance of measuring performance in higher education at the university/college level. Generally the performance indicators used for this purpose have focused on graduation rates and/or final examination scores, rather than the performance-enabling processes. Further, the most commonly used method for knowledge transfer is the traditional classroom teaching, which should be tracked/monitored continuously during its delivery process. It can help in the detection and correction of existing and impending problems, if any, in the teaching and learning processes. Further, the students' attitude towards learning, that is, their readiness/willingness and interest should also be taken into consideration while measuring the performance of classroom teaching.

In the present paper, the model for measuring classroom performance illustrated by Grygoryev and Karapertrovic (2005) is used to measure the performance of under-graduate Engineering students in two BTech. (Mechanical) courses, namely, fluid mechaincs (FM) and experimental methods and analysis (EMA). Classroom assessment techniques (CATs) along with the statistical process control (SPC) have been used to analyse the learning performance. Further, the data for student's readiness and interest factors are collected and their positive influences on knowledge gain are established.

Keywords: classroom assessment; knowledge gain; students' readiness and interest; statistical process control

1. Introduction

Quality of education is a mater of concern for all its stakeholders, which requires educators and educational administrators to demonstrate that educational institutions are capable of providing high-quality educational opportunities at a reasonable cost. Quality of education encompasses how the teaching and learning is organised and managed, what is the content of learning, what level of learning is achieved, what it leads to in term of outcomes, and what goes on in the learning environment (EFA report 2002). This quality is dependent on three distinct components, *i.e.* inputs, processes and outcomes (Makwati *et al.* 2003). Effective learning requires certain levels of given inputs in the 'right mix' and in situations where resources are limited, it is important to strike the right prioritisation of such inputs.

The mission of any education system is to ensure that students realise certain learning outcomes. In general, it is observed that educational outcomes are largely affected by teaching and learning

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processes. The instructor's contribution to the student knowledge-gain is considered the most important source of learning. However, according to Karapetrovic and Rajamani (1998), a student's learning is not necessarily directly proportional to instructor's teaching performance.

From the quality of education viewpoint, most of the research has been conducted on educational outcomes (*e.g.* graduation rates, final examination scores/grades etc.) rather than processes that generate such outcomes. In addition, most of the data have been collected at the end of semester/year and aggregated at the level of a department/college.

Therefore, to obtain a better quality of education along with better outcomes, main focus should be on the processes, *i.e.* the teaching and learning activities inside a classroom. The effectiveness of instructions in terms of the learning outcomes depends on a number of factors such as:

(a) the quality of instructions/lecture, that is, how well the instructor is able to communicate the basic concepts and knowledge of a particular subject to the students.
(b) students' ability to learn – the specific characteristics of learner (competence, style, role or current activity).
(c) human factors – motivation, interest, intention, readiness etc.
(d) availability of texts, reference books and class notes etc.
(e) classroom ambience

Therefore, all of the above factors should be taken into consideration as far as possible while measuring the learning outcomes or the effectiveness of instructions.

In the present work, statistical process control in combination with classroom assessment techniques (CATs) is used for measuring classroom performance. In addition to this, students' interest and readiness factors are taken into account to study their influence on students' knowledge-gain. This work is based on an on-going measurement of students' knowledge-gain as it occurs in a classroom *i.e.* during the student–instructor interaction.

All the data for this study were collected from Zakir Hussain College of Engineering and Technology, Aligarh Muslim University (AMU), Aligarh (India). The study is based on the measurement and evaluation of the process of knowledge transfer (instructor-student interaction) in instructions-based teaching of two BTech. (Mechanical Engg.) Courses offered to 4^{th} semester students.

2. Literature review

Current engineering education in many colleges and institutes, more or less, still follows the traditional instruction and knowledge delivery approach and generally is referred to as the 'instruction paradigm' (Barr and Tagg 1995). An alternative approach referred to as a 'learning paradigm' or 'constructive paradigm' has been under development mainly based on the pragmatic philosophy of education formulated by John Dewey (1916, 1933, 1938) in the early 20^{th} century. Constructivism offers some practical instructional strategies that have much to contribute to the new paradigm of education for the current information age. Some of its strategies are fairly uniformly applicable to most kinds of learning, but others are only applicable to higher-level learning in ill-structured domains.

At the heart of constructivism is the belief that each learner must construct his/her own knowledge and therefore that instruction must create an active role for the learner. Thus, according to the new paradigm, the center of education is learning, not instructions.

The learning can be classified as either active or passive. Active learning encompasses instructional methods like problem-based and project-organised learning environments, which are characterised by the following features.

(a) problem-orientation, which relates learning contents to a broader perspective and context;
(b) participant-direction, which provides learning opportunities derived from interests and experiences;
(c) inter-disciplinary learning, in which students go beyond traditional subject- related boundaries and methods in order to solve real life problems;
(d) project and group-work organisation, which provides a chance to practice work life in the engineering profession as well as develop the competencies of collaboration and management. By taking both cognitive and affective learning into consideration, the PBL model is designed to create an active learning context and to provide a chance for the development of collaboration, communication, co-operation and management of the learners (Kolmos and Graff)

The traditional lecturing-receiving approach puts the instructor at the centre of the learning environment, but the subjects of learning, that is, students play a passive role. Some recent studies in engineering education have concentrated on quality assurance and accreditation aspects, especially with reference to Europe. Augusti (2005, 2006, 2007) describes the present situation and recent advances regarding accreditation of engineering programs in Europe. In the context of making Europe 'the most competitive and dynamic knowledge-based economy in the world', a pan-European system of accreditation of engineering programs and qualifications is essential in order for European engineers to be competitive on a global scale. The EUR-ACE (EURopean ACcredited Engineer) project proposed a decentralised European system for accreditation of engineering programs in European Higher Education Area at the first and second degree levels. Gola (2005) discusses some aspects of quality assurance in engineering education with reference to Europe. Guest (2006) outlines what the 21st century holds in terms of lifelong learning and continuing professional development for engineers. Jørgensen and Kofoed (2007) presented a study in which engineering students at a Danish university developed continuous improvement (CI) and innovation capabilities through action research and experimental learning methods. The students designed and implemented solutions to self-identified problems within their educational program. The paper concludes that teaching methods based on learning-by-doing, not only support the development of CI and innovation in engineering students, but also enhances sustainability and innovation of the education itself.

Recent efforts to improve accounting education, challenged instructor to shift their focus from what they teach, to what their students learn. Along with changing course content and instructional methods, instructors have placed greater emphasis on assessment. Burrow *et al.* (2005) outline an approach based on flexible learning methods to produce computer-based formative assessment (that provides feedback to students on their learning achievement) for post-graduate students in engineering. The taxonomy adopted to ensure that the formulation of the questions addressed learning outcomes related to the development of higher order skills, is discussed. Fei *et al.* (2007) discuss the multi-mode assessment used to assess student learning in engineering graphics course. It is concluded that the reform of the examination method is important for higher-level learning. Lohmann *et al.* (2006) present a conceptual model to define global competence in engineers, a curriculum model for instilling it and an assessment model to determine if graduate engineers have attained it. It concludes with a description of a quasi-experimental research effort now underway designed to evaluate and validate these models.

Assessment, as we know it is the process of systematically collecting, interpreting, and using the information to improve student learning and satisfaction (Gainen and Locatelli 1995). There are two types of assessments. First type, referred to as outcomes assessment or program-level assessment (Herring Hartwell and Izard 1992) includes large-scale efforts to periodically assess students at key points in their accounting program. Typically promoted and supported by administrators, program-level assessment uses techniques such as surveys, achievement tests, focus groups and exit interviews to identify changes that will improve students' learning in future classes.

A second type of assessment, referred to as classroom assessment (Angelo and Cross 1993) includes small-scale efforts an instructor uses continuously to assess students who are taking his or her class. Initiated and controlled by the instructor, classroom assessment uses techniques similar to those used in programme-level assessment but designed to identify changes that will improve the learning of current students before the class term ends. Because the instructors control the process, they are more likely to become involved in assessment at classroom level.

It is felt that the use of classroom assessment along with statistical process control can help both students and teachers to improve the quality of teaching and learning in classroom. The use of statistical process control in classroom assessment aids in determining whether a particular process is stable or not and assists in identifying the possible causes of variation (from various aspects) of the process and the probable areas for improvement.

A few studies on the use of statistical process control tools in monitoring educational processes and outcomes in colleges and institutions have been reported in literature.

Karapetrovic and Rajamani (1998) described a method for monitoring the quality of teaching and learning outcomes in a course taught in classroom. Data came from questionnaire, which contained 3 to 5 questions with multiple choice answers, one possible answer being 'I don't know'. Students were asked to answer the questions at the beginning of the lecture to check if they had prior knowledge of the topic to be covered in the class. They were again asked to answer the same questions at the end of the lecture. This provided a measure of the knowledge gain. The statistic of 'knowledge gain' obtained was plotted against question number on a traditional 'p' control chart. On the basis of trends of points on the chart, in-control and out-of-control situation of classroom 'teaching and learning process' was determined.

Besterfield-Sacre *et al.* (1998) described an application of standardised process control (SPC) charts for monitoring two courses. The data came from questionnaire where answers were based on a 5-point scale (1–5). For such discrete data, traditional 'p' chart was not appropriate. Therefore, the authors used two alternative non-parametric control charts. The chi-square chart was based on 'using the chi-square goodness-of –fit statistic to compare an actual distribution with theoretical distribution'. The modified 'p' chart was an extension of a traditional 'p' chart for more than two categories. For each data point, pre-survey responses were used to establish the control and the post-survey responses were plotted.

Grygoryev and Karapetrovic (2005) again presented a model for an on- going measurement of student knowledge gain as it occurs in a classroom. This paper is an extension of previous work of Karapetrovic and Rajamani (1998). In this work same course was taught by two instructors 'A' and 'B'. Instructor 'A' taught the course in fall and spring sessions, 2002 and instructor 'B' taught the same course in fall session 2002. The statistics obtained were plotted on the traditional 'p' control chart. A comparison was made in teaching and learning process of instructor 'A' and 'B'; further a comparison was made in teaching and learning process of instructor 'A' for the two semesters. The results showed that, in combination with a CAT called the 'modified background knowledge probe (MBKP)', attribute SPC charts could be used to indicate the stability of teaching and learning processes, which could then be analysed by the instructors to improve knowledge transfer.

The studies described above on educational processes, *i.e.* classroom teaching and learning have dealt with the evaluation of classroom knowledge transfer using control charts, however, the authors have not come across any studies that have taken into consideration any of the factors related to students attitude towards learning and their interest in the courses of study. Kardos (1979) stated that the most important condition for all learning is 'the interest of the learner'. It is felt that 'readiness' of students to learn and their 'interest' in the subject are important factors in the classroom learning. Therefore, in the present study one of the CATs is used along with data for 'readiness' and 'interest' for measuring the effectiveness of classroom instructions and learning outcomes. The data have been analysed by using statistical process control and other statistical techniques.

3. Methodology

3.1. *Problem focus*

This study focuses on two main questions. First, how much knowledge is being transferred by an instructor inside classroom or equivalently, how much learning is taking place in a single class? Second, how do student's readiness and interest factors affect the classroom teaching and learning process?

3.2. *Monitoring classroom learning*

There are few techniques that can be used for measuring ongoing students learning inside the class (Angelo and Cross 1993). But one should choose a technique that is easy to implement without creating any difficulty to either students or teachers. In the present study, one of the tools of CATs called background knowledge probe (BKP), designed by Angelo and Cross (1993) is used. Using a BKP, an instructor asks one or more questions before the lecture to reflect the background knowledge of students to the topic to be covered in the lecture.

Statistical process control focuses on measuring the processes and preventing the undesirable problems (Montgomery 2000). Since student's knowledge gain is a product of educational processes, it can be used as a quality characteristic for statistical process control. Angelo and Cross (1993) described 101 CATs designed to measure students' knowledge gain in the classroom. Grygoryev and Karapetrovic (2005) modified one of these CATs, the BKP to collect data on student learning. They coupled BKP with SPC; this adapted technique was called MBKP. Using an MBKP, students answered two to four objective type questions, once prior to the lecture and then again after the lecture. In the present work, an MBKP along-with readiness and interest factors is used to collect data on classroom teaching and learning outcomes.

A typical MBKP administered during experimental methods and analysis (EMA) course in undergraduate program of BTech. (Mech. Engg.) is presented in Figure 1.

Q1: When we sample from an infinite population, the standard error of the mean when the sample size is decreased from 225 to 25 is

(a) Increased by 3 times
(b) Decreased by 3 times
(c) Increased by 9 times
(d) I don't know

Q2: A random sample of size 36 is taken from an infinite population with $\mu = 63$ and $\sigma^2 = 81$. The probability of getting a sample mean greater than 66.75 is

(a) $P(Z < 2.5)$
(b) $P(Z > 2.5)$
(c) $P(Z > 0.417)$
(d) I don't know

Answer	Before	After
1		
2		

Readiness Scale(1-5) low-high	Interest Scale (1-5) low-high

Figure 1. Example of a MBKP.

Table 1. Statistics collected.

Category	Before	After	Statistic collected
1	Correct	Correct	Proportion 'Correct Before Correct After', P_{CBCA}
2	Incorrect	Correct	Proportion 'Incorrect Before Correct After', P_{IBCA}
3	Incorrect	Incorrect	Proportion 'Incorrect After', $P_{IA} = P_{IBIA} + P_{CBIA}$
4	Correct	Incorrect	

Measure/scale	1 (low)	2	3	4	5 (high)
Interest					
Readiness					

3.3. *Before and after answers*

A MBKP contains 2 to 4 objective type questions with multiple choice answers, one of them being 'I don't know'. At the beginning of each lecture, students were instructed to answer the questions in 'Before' column. Allowing 4 to 5 min to answer, students answered these questions to the best of their abilities and then put the questions aside. This provided information on the student's prior knowledge of the topic to be covered in that lecture period. At the end of the lecture, the students answered again the same questions in the 'After' column.

The responses obtained from students after collecting the MBKP are classified into four categories. Table 1 represents the four alternatives of collected statistic as explained in Appendix 'A'. For designing questions (test items) for MBKPs, the teachers concerned were asked to set objective type questions on the topics to be covered in the class. The objective of the test items was to test the comprehension of the topics covered by the students present in the class. In our opinion, all the question sets were legitimate with appropriate level of item-difficulty and item discrimination.

3.4. *Readiness and interest factors*

How much students actually learn in a class depends not only on the quality of instructions but also on student's attitude towards learning and their interest in the subject. Data on theses factors are desirable confidently to estimate the effectiveness of a lecture in contributing to knowledge gain.

In the present study, two factors are taken into account. Firstly, student's readiness is used to assess his or her willingness and attitude towards learning. Secondly, student's interest in the course based on its instructor's teaching ability also affects learning process. Students' readiness and their interest in the topic of the lecture delivered on a particular day were collected on a 5-point scale (low–high). Each MBKP contains a 'readiness' and 'interest' factors table with a scale of (1–5) as shown in Figure 1 where 1 = very low; 2 = low; 3 = moderate; 4 = high; 5 = very high.

At the beginning of each lecture, students were instructed to answer the questions in 'Before' column and fill the readiness and interest column with the appropriate scale factor (1–5). They were given 4 to 5 min to do this.

3.5. *Data collection*

The present study was conducted in the Department of Mechanical Engineering, Zakir Hussian College of Engineering & Technology, Aligarh Muslim University, Aligarh (India). The study was limited to two B. Tech. (Mechanical Engg.) courses, *i.e.* Fluid Mechanics (FM) and Experimental

Methods and Analysis (EMA), both 4^{th} semester courses. Approximately 25–35 students attended the lectures in each of two sections in these courses.

The course on Fluid Mechanics was taught by two instructors A_1 and B_1 to two different sections A and B, of 4^{th} semester BTech. (Mech. Engg.). All the questions distributed in both sections were designed by instructor A_1. In total, nine MBKPs were administered during the semester in each section for FM course. The course on Experimental Methods and Analysis (EMA) was taught jointly by two instructors C and D together in both sections of 4^{th} semester BTech. (Mech. Engg.). Lectures delivered by instructor C related mainly to the concepts of error analysis, probability, statistical distributions and experimental data analysis techniques, while instructor D dealt with various types of measurement techniques. Both instructors were offering the course third time in succession. All questions were designed jointly by both instructors. Total eight MBKPs were administered in each section for EMA course.

4. Results and discussions

4.1. *Relative performance*

The relative performance of students of each section in a course can be seen by plotting the statistics (P_{IBCA} or P_{IA}) against the question number on the same 'P' control chart (Appendix B). On the basis of pattern of trend lines of $P_{IBCA}$and P_{IA} statistics, it can be judged whether the relative performance of students in both sections is similar or not.

When comparing the charts for P_{IBCA} and P_{IA}, the following criterion has been used to indicate the differences in performance based on these fractions.

(1) If the difference in the corresponding P_{IBCA} and the corresponding P_{IA} values of two sections for any question of a course is less than 0.15 simultaneously, then the performance is considered to be similar or nearly similar for that question.
(2) If this difference is more than 0.30 simultaneously, then the performance is considered to be noticeably different for that question.

4.1.1. *Fluid mechanics (FM)*

Figures2(a) and (b) represent the standardised P control chart for P_{IBCA} and P_{IA} statistics respectively for the fluid mechanics course. It can be seen from P_{IBCA} control chart as shown in Figure 2(a) that point 12 for section B is lying on LCL and few others (1, 10 for section A; 1, 16 and 18 for section B) fall below the LCL indicating out-of-control condition. Similarly, it can be seen from P_{IA} control chart as shown in Figure 2(b) that some points (10, 18 and 20 for section A; 6, 12, 16 and 18 for section B) exceed the UCL (see Appendix B).

Thus, the process of knowledge transfer is not in statistical control in either section for the fluid mechanics course. As discussed before, according to equation (1) in Appendix A.

$$P_{IA} + P_{IBCA} + P_{CBCA} = 1$$

A high value of P_{CBCA} indicates that many students did not learn anything new, that is, did not benefit from the lecture. When P_{CBCA} is high, other two statistics (P_{IA} and P_{IBCA}) will be relatively low and vice-versa. Generally P_{CBCA} is found to be low (about 80% of the time), then the sum of the values of P_{IA} and P_{IBCA} will be slightly less than or nearly equal to one. If P_{IBCA} is high, P_{IA} will be low which indicates that there is sufficient knowledge transfer. For low P_{IBCA}, P_{IA} will be high, indicating poor knowledge transfer.

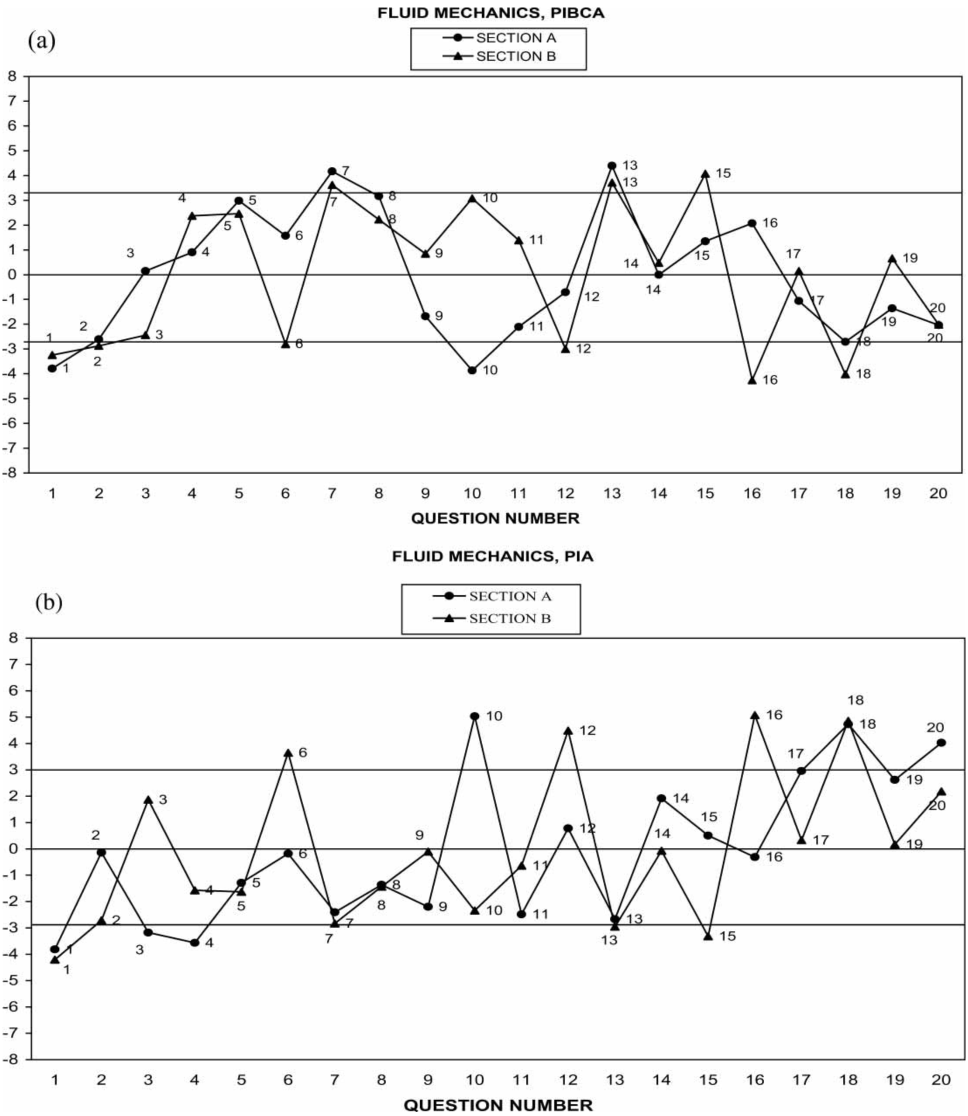

Figure 2. Standardised P control charts for fluid mechanics course.

It is observed from the patterns of P_{IA} and P_{IBCA} for fluid mechanics course that for some course concepts, relative performance is similar or nearly similar *i.e.* points 1, 2, 5, 7, 8, 13, 14, 17, 18, and 20 on both P_{IBCA} and P_{IA} charts. Further, knowledge transfer is worse for some course concepts (related to question 2, 18, and 20) and better for some other course topics (related to questions 5, 7, 8 and 13) in both sections. Knowledge transfer for a unit of course is said to be worse when P_{IA} statistic for that unit is high and P_{IBCA} is low. It is said to be better when P_{IBCA} statistic for a unit is high and P_{IA} is low.

The question 18 is related to the concept of the 'change in discharge when a pipe is replaced by two pipes connected in parallel combination'. For this question, for sections A and B the P_{IBCA} is found to be 0.2571 and 0.1389, respectively. The high proportion of 'Incorrect After' answers in both sections (0.7429 and 0.8611) indicates that students had difficulty to learn this concept well during the lecture. The reason behind high proportion of 'Incorrect After' is that the topic related to question 18 was explained briefly in both sections.

For some course concepts, relative performance is similar in the two sections and better than other concepts. It is observed from Figure 2(a) that data points 7 and 13 fall above the upper control limit, indicating a more effective knowledge transfer. The questions 7 and 13 are related to the topics of 'Velocity potential in irrotational flow' and 'momentum equations' respectively.

The question 1 is related to the concept of 'Law of mass conservation'. The P_{IBCA} for sections A and B is 0.1154 and 0.1724, respectively. As a result point 1 lies below the lower control limit on P_{IBCA} chart suggesting poor knowledge transfer. However, the corresponding P_{IA} values are not high (0.0 and 0.069 respectively). The reason for low values of both P_{IBCA} and P_{IA} is that P_{CBCA} is high indicating that many of the students had prior knowledge of the concepts covered in this class.

For certain points, relative performance is noticeably different, as illustrated by points corresponding to questions 6, 10 and 16. These questions are related to the concepts of 'streak and path lines'; 'stream function' and 'power transmission through a pipe', respectively. The reason for poor performance of students of section A (point 10) and section B (points 6, 16) is that the respective topics were discussed briefly near the end of the lecture class.

4.2. *Experimental methods and analysis (EMA)*

Figures 3(a) and (b) represent the standardised P control chart for P_{IBCA} and P_{IA} statistics respectively for the EMA course. It is seen from P_{IBCA} control chart (Figure 3(a)) that the point 10 for section B is lying on LCL and few others (4, 12 and 13 for section A) fall below the LCL indicating out-of-control condition. Similarly, it is seen from P_{IA} control chart (Figure 3(b)) that some points (4, 12 and 13 for section A; 10 and 14 for section B) exceed the UCL. Thus, the process of knowledge transfer is not in statistical control in either section for this course also.

For some course concepts, relative performance is noticeably different, as illustrated by points for question nos. 4, 11, 12, 13, 16, 17, and 18 on both P_{IBCA} and P_{IA} charts. For some other course topics, relative performance is similar or nearly similar *i.e.* points 1, 2, 3, 5, 7, 9, 10, 14, 19, and 20 on both charts. Knowledge transfer is comparatively worse in both sections for the course topics related to question 3, 7, 10, 14, and 20.

It was found that topics related to Questions 4, 12, and 13 were covered in section A briefly in a hurry near the end of the lecture resulting in poor performance of the students, as shown in Figures 3(a) and (b).

The responses to questions 14 and 20 related to the topics of 'force measurement' and 'hot wire anemometer' indicate poor knowledge transfer ($P_{IBCA} = 0.25$ to 0.33; PIA $= 0.52$ to 0.71) in both sections. Theses topics were covered hurriedly near the end of semester.

Questions 3, 5, and 7 are related to the concepts of Poisson and sampling distributions. The low values of P_{IBCA} in section A (0.24–0.28) and B (0.26–0.44) respectively for these questions indicate that students in both sections found it difficult to learn these concepts well during the lecture. The possible reasons for it are as follows:

(1) Some of the students who attended the lecture had diploma background and no previous exposure to statistics. Statistics is generally introduced in either class 12th or BTech 1st semester. Therefore, some of the students felt that this topic was a new concept.
(2) Many students did not learn these concepts well because they had low interest in such topics.
(3) Generally, students feel that statistic is a difficult subject. Further, they do not study the subject regularly and do not solve the problems given as home assignments.

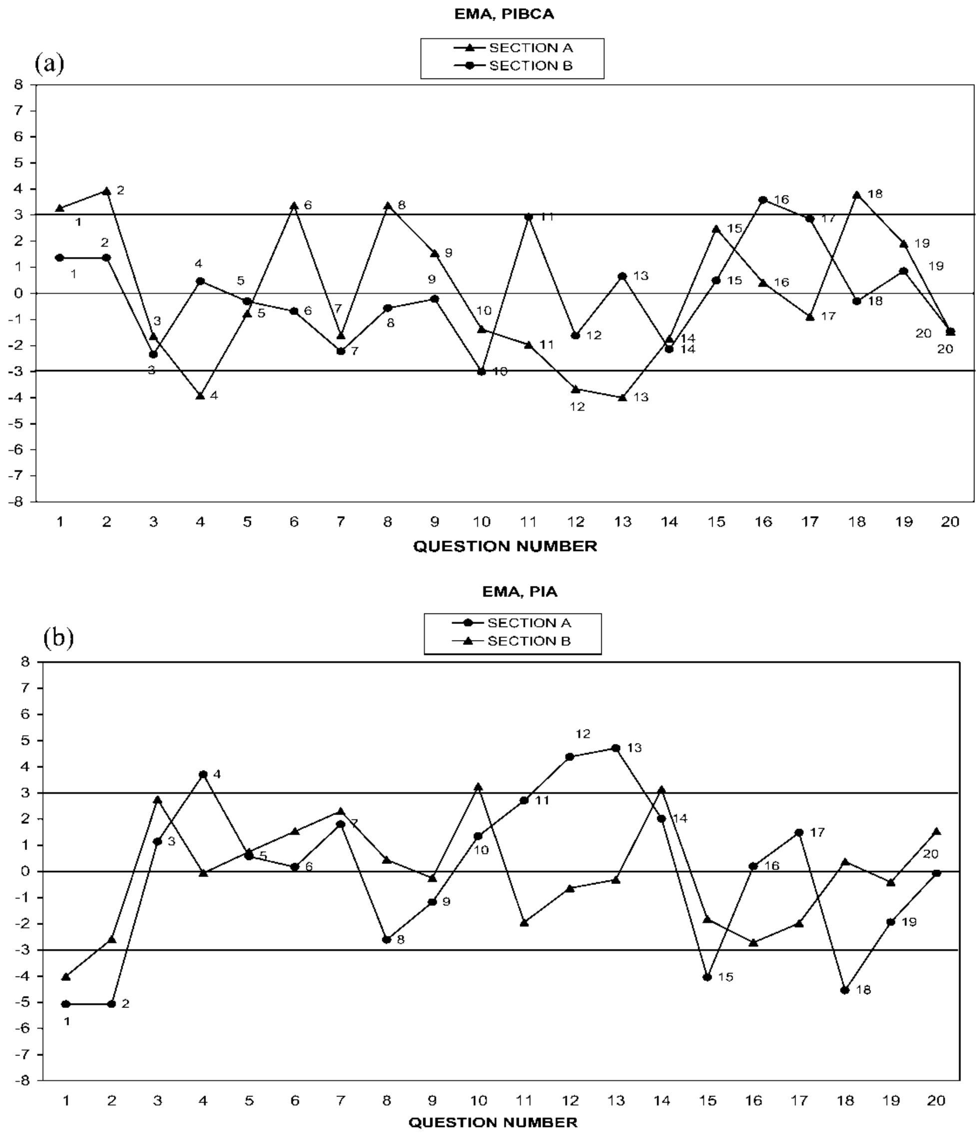

Figure 3. Standardised P control charts for EMA course.

Table 2. Data sets used in FM.

Data set	Instructor	No. of question	Total sample size	Estimated process P_{IBCA}	Estimated Process P_{IBIA}
Section A	A_1	20	646	0.4861	0.3205
Section B	B_1	20	655	0.4733	0.3710

4.3. *Absolute performance*

Even if the relative performance of students in both the sections (A and B) for courses FM and EMA is similar, it does not necessarily mean the absolute performance of students of both sections is same. It is observed from Tables 3 to 5 that there is no statistically significant difference

Table 3. Absolute difference in performances of sections A and B for FM course.

Statistic	Section A	Section B	Absolute difference	Weighted p	Z	Statistically significant?
P_{IBCA}	0.4861	0.4733	0.0128	0.4796	0.4620	No
P_{IBIA}	0.3205	0.3710	−0.0505	0.3459	−1.915	No

Table 4. Data sets used in EMA.

Data set	Instructors	No. of question	Total sample size	Estimated process P_{IBCA}	Estimated process P_{IBIA}
Section A	C & D	20	586	0.4118	0.4330
Section B	C & D	20	623	0.4735	0.4093

Table 5. Absolute difference in performances of sections A and B for EMA course.

Statistic	Section A	Section B	Absolute difference	Weighted p	Z	Statistically Significant?
P_{IBCA}	0.4118	0.4735	−0.0617	0.4525	−2.1525	No
P_{IBIA}	0.4330	0.4093	0.0237	0.4208	0.833	No

($\alpha = 0.01$) in P_{IBCA} and P_{IBIA} statistics of sections A and B for FM and EMA courses. It indicates the same learning effect on students of sections A and B. Recalling that $P_{IA} = P_{CBIA+}\ P_{IBIA}$ as shown in Table 1, and since the value of P_{CBIA} is low in comparison to P_{IBIA}, the analysis here is performed using P_{IBIA} instead of P_{IA}. The justification of doing so is that for FM and EMA courses, $P_{CBIA} = 0.0$ (25% and 30% of time respectively) and varies between 0.0–0.167 (FM) and 0.0–0.228 (EMA) rest of the time whereas $P_{IBIA} \approx 0.0$–0.75 (FM) and 0.06–0.83 (EMA).

4.4. *Effect of human factors on knowledge gain*

Learning experience can be made more effective by the intervention of some factors such as taking into account the specific characteristics of the learner (competence, style, role, or current activity) as well as human factors (motivation, interest, readiness, intention etc.). Motivational factors play an important role in the readiness of students to learn. Individuals are driven by desires that make them act, or that inhibit their actions. Reiss (2000) has proposed a theory of motivation that relies on 16 basic desires that represent the basic drivers of a person's actions. These drivers are combined differently depending on the individual, and contribute to the definition of a person's identity and personality. One of these desires- the curiosity – directly relates to the eagerness to learn. Individuals whose curiosity basic desire is very developed do not need any other external stimulation to engage into learning activities and sustain them. People for which the curiosity desire is underdeveloped will have more difficulties to engage spontaneously into a learning activity, and other drivers will have to be used to engage them into learning (Nabeth *et al*. 2004).

Knowles (1985) advances convincing evidences that people who take the initiative in learning (proactive learners) learn more things and learn better than do people who sit passively waiting to be taught (reactive learners). Self-confidence, self-efficacy (strength of a person's belief that (s)he is capable of successfully performing) play an important role in people motivation, and in their dedication to learning activities and to achievement behaviors that produce better quality outcomes (Nabeth *et al*. 2004).

Goal-orientation theory proposes that students adopt a certain orientation to learning and achievement that is instrumental in motivating learning behaviours. The orientation adopted will, in turn, influence the ways in which a student approaches and responds to academic demands. This approach is supported by the findings of a research study (Ames and Archer 1988) in which the students who perceived an emphasis on mastery goals in the classroom reported using more effective strategies, preferred challenging tasks, had a more positive attitude towards the class, and had a stronger belief that success follows from one's effort.

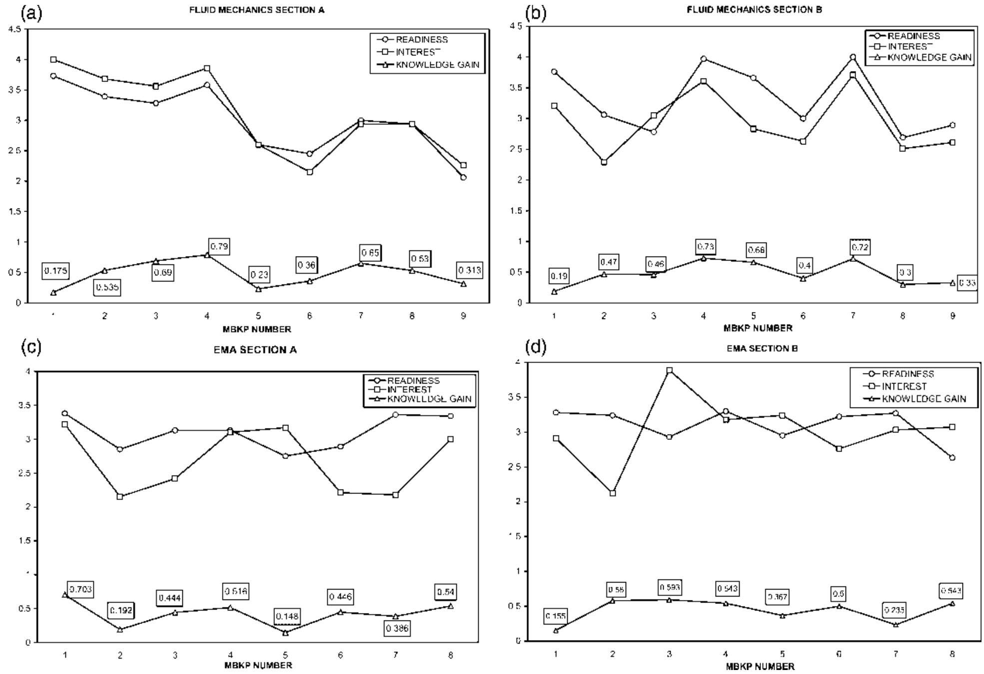

Figure 4. Readiness, interest and knowledge gain versus MBKP number plots.

Table 6. Coefficients of variation for FM and EMA courses.

Courses	Section A			Section B		
Factors	Readiness	Interest	KG	Readiness	Interest	KG
FM	0.18	0.23	0.45	0.16	0.17	0.41
EMA	0.11	0.18	0.43	0.08	0.16	0.38

Table 7. Correlation coefficient and confidence intervals (95%) for correlation coefficients for Courses FM and EMA.

Course	FM		FM (Excluding 2 Points)		EMA	
Factors	r	Confidence intervals for r	r	Confidence intervals for r	r	Confidence intervals for r
Knowledge Gain V/S Readiness	0.450	$-0.02 < \rho < 0.76$	0.840	$0.81 < \rho < 0.95$	0.614	$0.16 < \rho < 0.85$
Knowledge gain V/S Interest	0.430	$-0.05 < \rho < 0.75$	0.810	$0.53 < \rho < 0.93$	0.550	$0.08 < \rho < 0.83$
Interest V/S Readiness	0.80	$0.0 < \rho < 0.83$	0.80	$0.51 < \rho < 0.93$	0.530	$0.05 < \rho < 0.82$

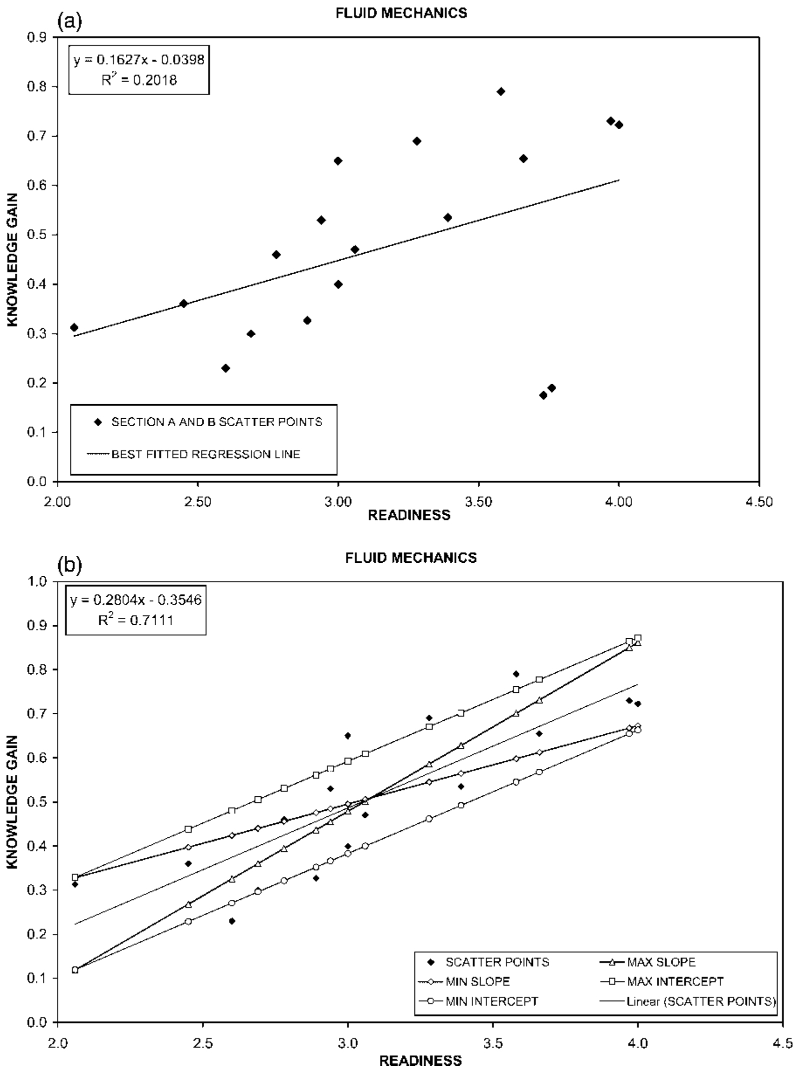

Figure 5. Scatter and best fitted line plots for knowledge gain versus readiness.

According to Nabeth *et al.* (2004), some level of autonomy, the feeling of control, and the possibility to decide on goals to pursue that fulfil some profound objectives that are meaningful in the life of the learner, appear to have a positive influence on the effectiveness of learning.

Keeping the above arguments in mind, it was decide to collect data on students' readiness and interest towards learning and study their influence on classroom knowledge gain. Some of the factors which affect students' readiness are – their physical health, state of rest and relaxation, fulfilment of basic needs (all essentials) and willingness to learn (optional). Interest, on the other hand, is considered to be influenced by the instructor's style of teaching, course/lecture content and schedule of lecture (time of the day) etc. The results obtained are discussed in the following.

4.4.1. *Fluid mechanics (FM)*

Figures 4(a) and (b) represent the readiness, interest and knowledge gain versus MBKP number plots for sections A and B, respectively for fluid mechanics. It is observed from the patterns of

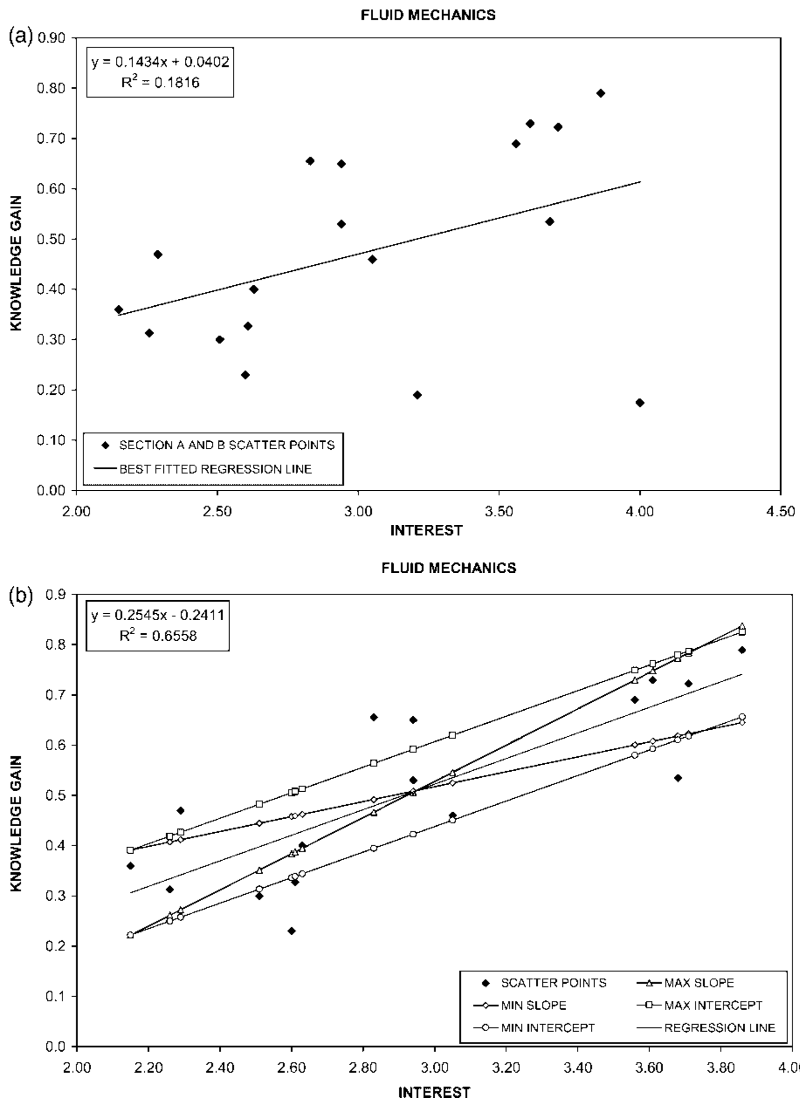

Figure 6. Scatter and best fitted line plots for knowledge gain versus interest.

readiness, interest and knowledge gain as shown in Figures 4(a) and (b) that for high values of interest and readiness, knowledge gain is generally high (MBKPs 4, 7 for both sections). When one of the factors or both are low, the corresponding value of knowledge gain is generally low (MBKPs 5, 6, 9 for section A; 2, 3, 6, 8, 9 for section B). However, for MBKP 1, knowledge gain appears to be low, even though interest and readiness values are high (3.5 to 4.0). This is because in this case P_{CBCA} (0.637) is high, resulting in P_{IBCA} statistic to be low (0.173) in accordance with equation (1).

4.4.2. *Experimental methods and analysis (EMA)*

Figures 4(c) and (d) represent the readiness, interest and knowledge gain versus MBKP number plots for sections A and B, respectively for EMA course. It is observed from Figure 4(c) that

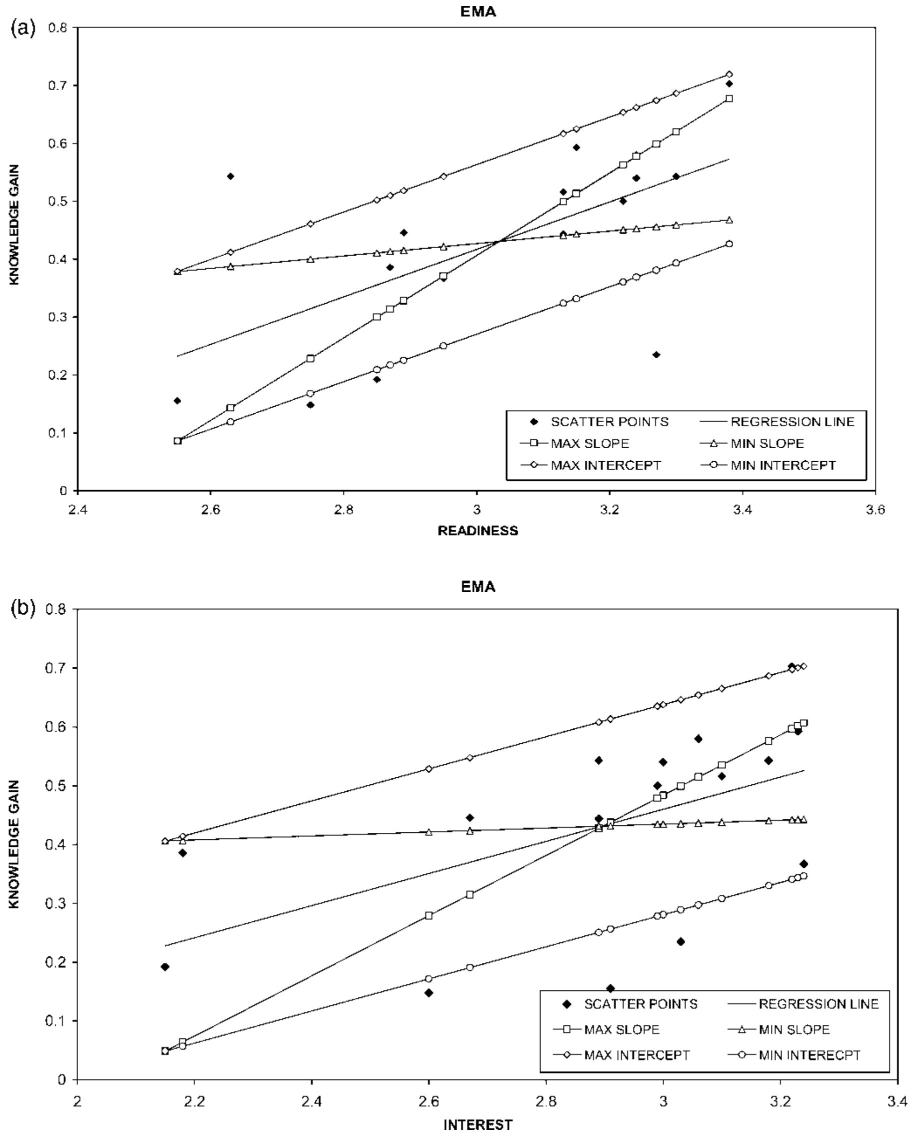

Figure 7. Scatter and best fitted line plots for EMA course.

knowledge gain pattern is generally following the same trend as that of interest and readiness patterns. It means that for high value of interest and readiness, knowledge gain is high (MBKPs 1, 4, 8). When one of the factors or both are low, the corresponding value of knowledge gain is low (MBKPs 2 and 5). In section B (Figure 4(d)), knowledge gain and readiness show comparatively less variation. Interest variation is also less except at MBKP Number 2 and 3. Table 6 lists the values of coefficients of variation for each course.

4.4.3. *Statistical analysis for testing relationship between readiness, interest and knowledge gain*

In order to determine relationships, if any, between knowledge gain, interest and readiness factors, scatter plots, best fitted lines and correlation coefficients (r) are used. Table 7 lists the values of

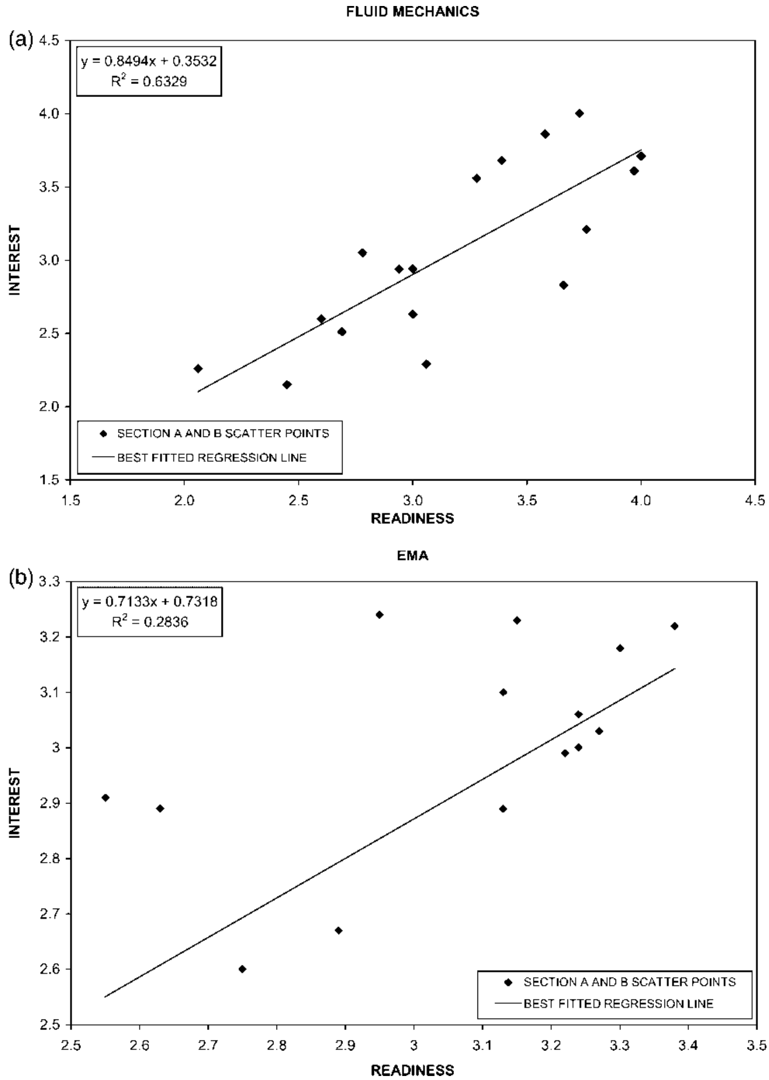

Figure 8. Scatter and best fitted line plots for Interest versus readiness for section A and B combined.

correlation coefficients (r) and 95% confidence intervals for correlation coefficients for each course. Confidence intervals are also calculated for slope and intercept for the various linear relationships.

(1) Knowledge gain versus readiness. Figure 5(a) represents the scatter diagram between readiness and knowledge gain, with the best fitted regression line for FM course. The value of correlation coefficient (r) is found to be 0.449, indicating a moderate degree of relationship. Figure 5(b) shows the scatter plot with the best fitted line after excluding two extreme points (possible outliers) which are far away from regression line in Figure 5(a). Trend line now shows a better linear relationship between knowledge gain and readiness. A higher value of r (0.843) shows a stronger relationship between the two variables. Thus, as the readiness increases, knowledge gain increases. The 95% confidence intervals for slope and intercept

are also shown in Figure 5(b). Similarly, Figure 7(a) (see later) represents a moderate degree of linear relationship for EMA course (r = 0.614).

(2) Knowledge gain versus interest. Figures 6(a) and (b) represent the scatter plots with best fitted regression line for the two situations discussed above in (1) for FM course. A moderate linear relationship between two variables is indicated. If two points (outliers) are excluded from the plots, r value improves from 0.4261 to 0.81. The 95% confidence intervals for slope and intercept are also shown in Figure 6(b). Similarly, Figure 7(b) represents a moderate strength of the linear relationship (r = 0.55) between knowledge gain and interest for EMA course.

(3) Readiness versus interest. Figures8(a) and (b) represent the scatter plots with best fitted regression line for FM and EMA courses, respectively. A higher value of r (0.80) shows a stronger relationship between the two variables for FM course. Similarly, a moderate linear relationship (r = 0.53) is indicated for EMA course.

5. Conclusions

(1) The present study illustrates a model for continuous monitoring, controlling, and improvement of teaching and learning outcomes in an engineering classroom. Monitoring and measurement of teaching and learning performances is required for continuous improvement of educational outcomes.

(2) The application of this model in teaching and learning process of two courses shows a number of out-of-control points on standardised P control charts that should be investigated in detail. For difficult to understand topics, the teacher should formulate a new strategy to teach it next time so that students are able to understand it better.

Others, showing lack of interest in the class, have to be motivated. They may be invited for a discussion during the semester for an appraisal of their problems. If a proper introduction to the course, covering its scope, utility, application and content etc is given at the beginning of a semester by a senior teacher, it is hoped that it should motivate students to do well in that subject.

(3) The present study also attempts to address the effect of readiness and interest factors on knowledge gain achieved in the class. It can be observed from the trends of readiness, interest and knowledge gain plotted against the MBKP number for the two courses that there exists a positive linear relationship between them.

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Appendix A

Statistics calculated

(1) Proportion 'incorrect after' (P_{IA}). It includes students who have 'incorrect' or 'I don't know' answer to any question after the lecture. It is denoted by P_{IA}. It includes both 'Correct Before, Incorrect After' *i.e.* P_{CBIA} and 'Incorrect Before, Incorrect After' *i.e.* P_{IBIA} statistics. If P_{CBIA} statistic is consistently small, it can be assumed that lecture was not the cause of confusion. If this statistic is consistently large, the instructor needs to check quality of both the lecture delivered as well as questions of MBKP.

P_{IA} statistic represents the students who did not benefit from the lecture or failed to learn material during the lecture. The theoretical target for P_{IA} statistic is 0%, meaning that all students in every lecture would give the correct answer to every question. However, this value is rarely achieved practically. Looking from quality control point of view, zero % defective output rarely occurs in practice.

(2) Proportion 'incorrect before, correct after' (P_{IBCA}). It includes students who did not know the answer to the questions before the lecture, but knew correct answers after the lecture. It is denoted by P_{IBCA}. This statistic provides a measure of the teaching effectiveness of an instructor in terms of the student's learning that occurred inside the classroom due to the lecture.

(a) Theoretically P_{IBCA} statistic should be 100%, meaning that no student knew the material prior to the lecture, but all of them knew it after the lecture, but P_{IBCA} seldom reaches 100%. This is because
(b) Some of the students may have prior knowledge of the material.
(c) Some topics remain hard to learn for the students.
(d) Some students may not be interested in learning.

(3) Proportion 'correct before, correct after' (P_{CBCA}). It includes students who knew the answer both before and after the lecture. The high P_{CBCA} is not a desirable situation, since it indicates that many students did not learn anything new from the lecture. The P_{CBCA} can be computed from P_{IA} and P_{IBCA} as

$$P_{IA} + P_{IBCA} + P_{CBCA} = 1 \tag{1}$$

Statistical principles of MBKP

(1) The underlying assumption behind the MBKP is that the statistic obtained from any of the 'Before & After' answers is based on the Binomial Distribution.
(2) It is assumed that the process of instructions and teaching is uniform throughout the course delivery.

According to the binomial distribution, probability of getting x success in n trails is

$$P(x) = {}^{n}C_x p^x (1-p)^{n-x} = b(xn, p) \tag{2}$$

In the present study, the outcome of interest is knowledge gain in a lecture class. We assume that the probability that a student will be able to answer any particular 'B & A' question correctly is p. In addition to this, we assume that the probability of a student answering a 'B & A' question correctly is independent of any another student's answer. Therefore, each student's answer to a particular 'B & A' question is a realisation of Bernoulli trial with parameter p.

Appendix B

SPC charts

In the present work, standardised attribute chart is used to plot the P_{IBCA} and P_{IA} statistics. This chart has the centre line set at zero and upper and lower control limits set at +3 and −3 respectively. The sample statistic plotted on the chart can be calculated using the following formula (Montgomery 2000)

$$Z_i = \frac{p_i - \bar{p}}{\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}}} \tag{3}$$

Here, P_i is the sample proportion (P_{IA} or P_{IBCA}), $\bar{p}$ is the process fraction non-conforming and n_i is the sample size (number of students attempting i^{th} question).
The criterion for determining out-of-control condition is as follows.

(1) P_{IBCA} statistic: If a point lies or falls below the lower control limit for P_{IBCA} statistic, this may be an indication of out-of-control condition as the statistic is of the type, higher the better.
(2) P_{IA} statistic: If a point lies or exceeds the upper control limit for P_{IA} statistic, this may also be an indication of out-of-control as it is of the type, lower the better.

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