The class, as a whole

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Abstract

The distribution in the relevant learning abilities of students in a class is usually not fully considered when learning strategies are employed. This article presents a case for a better conscious appreciation of the above distribution, and methods to improve the learning of all students in a class. That could lead to better retention in the program or better future contributions by the students, and better help to the Institution by future alumni.

Keywords: student abilities; distribution; whole class.

Introduction

The retention of the students in the engineering undergraduate program is a significant challenge[1] either to complete their courses in some countries, or to contribute in their chosen fields after graduation in some other countries. Engineering education or science-technology-engineering-mathematics (STEM) education in general, is traditionally addressed through straight lectures, problem-sets, laboratory work, and a final (senior)-year project. The students are assumed to possess problem solving skills to handle problems in the practice (tutorial/recitation) sessions or in the examinations that are based on the lecture material. However, some faculty members employ more effective pedagogical strategies to achieve better learning in a typical average student in their classes. A strong case has been made[1, 2] to ensure inclusion of proven learning techniques such as active learning to improve student learning.

To improve learning in students, many pedagogical strategies that have the backing of evidence such as active learning[3], which includes co-operative group learning[4], problem-based learning[5], and others have been discussed in the literature. Each strategy can be implemented in various modes; for example, active learning can be implemented through

simple calculations, think-pair-share, part derivations by students of absolutely essential quantitative information in a guided fashion, and others.

Pedagogical strategies, if and when they are employed by a typical instructor, improve the learning of the *average* student in class. Since average students are the majority in a class, such a practice provides the greatest good for the greatest number of students in a class. However, the students who possess high learning skills (who are at the right of the distribution, `right-students' or RS) and the students with limited abilities or other difficulties (who are at the left of the distribution, `left-students' or LS) are not helped much by such an approach. Significant thought was employed to arrive at the notation – LS and RS. The alternatives for LS such as `low performers', `under achievers', `weak students', `last few students in the lowest quartile', etc., have a certain hierarchy associated with them. When the students accidentally know about it, the hierarchy seems to demean and demotivate them. Thus, some term that provides a connotation of `being at the same level, but different' was sought. Left and right, in their indication of directions at the same level, seemed to denote students `being on par, but different', perception-wise, and thus they were chosen.

This author believes that the average students, LS and RS are all part of the same class, and the instructor needs to be sensitive to the needs of the entire class. Further, in some situations the number of left-students in a class could be significant and that leads to a bi-modal distribution in the learning abilities. In such situations, the LS cannot be ignored by a conscientious instructor. This paper presents methods to improve the learning of all the students in class, including the LS and RS.

Background

The observations that provided the bases for the unreferenced statements made in this paper were made while handling the undergraduate, core (required) course, transport processes in

biological systems, in the Department of Biotechnology, IIT Madras, India, over the past 7 years. The course was offered in the 4th or the 5th semester of the program. The textbook for the course [6] has a foreword by Professor R. B. Bird, University of Wisconsin-Madison.

The undergraduate program is a residential one, and less than 1% drop out; the LS usually take much longer than the usual 8 semesters to complete the program with great difficulty. The selection is highly competitive with about 0.8% success rate for the country's applicants – about 10,000 candidates are selected from 1.3 million in a two stage entrance exam.[7] Therefore, even the last entrant to the program has achieved much better compared to the relevant average student in the country's population. Thus, all our students possess basal learning skills such as knowing and understanding in mathematics, physics and chemistry (the subjects on which they are tested in the entrance examinations), although the higher level skills[8] such as applying, analysing, synthesising and evaluating could be limited in some.

Given the above, the level of instruction is reasonably high to improve learning by the average student. The high level of instruction is also to meet the expectations of the public (industry, universities, etc.,) from the average graduate from the system. However, teaching at that level poses significant learning difficulties for the LS due to the bimodal distribution in the learning abilities, and boredom for the RS. If the class activities are pitched at the LS level, the majority in class comprising of the average students, and RS, would not be benefitted. However, the LS and the RS cannot be ignored if aspects such as welfare of all students, and maximizing their future contributions are considered. This manuscript provides strategies to address such challenges, *in the same class*.

The author recognizes that there are significant differences in the details in the various systems, world-wide. However, based on the literature and his experience, the author has hope that some of the observations and strategies could be helpful to all systems, which resulted in this communication.

Distribution in the relevant abilities

It is common knowledge that there is a distribution of student abilities in a class. For the purposes of this paper, let us take an elementary view of the abilities. Among the three domains of the Bloom's taxonomy[8], cognitive, affective, and psychomotor, let us consider only the cognitive domain. Thus, the relevant abilities are the cognitive skills – knowing, understanding, applying, analysing, evaluating and synthesising – but, as applied to the particular subject. It is known that each student has his/her areas of strength in which (s)he has easy access to the highest ability levels[9]. However, such areas may not be related to the student's undergraduate course areas. For example, a student may be skilled in music or dance, and can reach the synthesising level in it without much effort, or pick up programming/coding skills on his/her own but, may not be able to analyse a momentum transport situation such as the velocity profile in an unseen laminar flow situation even with significant effort. They may have chosen to do chemical engineering for a variety of reasons including the need for a reasonably secure job upon graduation, lack of clarity regarding their own strengths, and others.

A good first approximation is a normal distribution of the above abilities in a class (Figure 1 – A). Usually, there are variations; e.g. if the class contains a higher-than-usual number of extraordinarily bright students with varying abilities, the distribution has a longer tail toward the right. On the other hand, if the class contains a large number of students with limited abilities of different levels, the distribution has a longer tail toward the left. In some situations there are bi-modal distributions which reflect a significant number of students with widely different abilities (Figure 1 – B). For example, when there is multiple course entrance standards, bi-modal distributions could arise. There could also be other kinds of skew – a larger number of students with closely-spaced, higher abilities (a high-B-average

distribution), a larger number of students with closely-spaced lower abilities (a low-C-average distribution), and others.

An ideal aim of the instructor for the entire class could be to facilitate a shift, of say, the normal distribution to the right, which also has a smaller standard deviation, as shown in Figure 1 (C).

Course period

In almost all undergraduate engineering education systems, the course period is fixed – say, a year (rare, nowadays), a semester or a quarter. In fixed-time systems, it is difficult to aim for every student in class to reach the same, high level of achievement, mastery learning[3], to successfully complete the course. Therefore, the different levels of `satisfactory' achievements are recognized through grades. A failure grade is awarded for `less-than-satisfactory' achievement. If the system allows for mastery learning, then one could set the bar high (it may not be exactly the same for everyone) that everyone needs to reach to complete a course; however, we do not have such a system in engineering education in most parts of the world, although attempts have been made to induct mastery learning[3] or its variant, competency based learning[10].

Right students

The RS need not necessarily have CGPAs on the higher side in their class, although many do. Higher CGPAs could also result from an `optimization' approach by students with lower ability or lesser work levels. But, the RS possess the relevant abilities mentioned above. Usually, the RS do not need help with the regular aspects of a course. Their attention in class, their methodical follow-up of the material discussed in class, their smart (not necessarily hard) work, combined with their other abilities help them to understand the course

information, and to apply the principles toward solving closed-ended problems. They know when to ask the instructor for help toward better appreciation of the course. However, they are not experienced in the course material, and hence they may not necessarily reach on their own, the higher learning levels including analysing, evaluating and synthesising. The inability to reach higher learning levels leads to boredom in some RS, and a feeling of unfulfilled potential.

To better fulfil the RS potential, and to encourage students to contribute to developments in the field in the future, challenging exercises can be assigned. The developments in the field could include new knowledge through research or new applications/innovations, or a better comprehensive view, which is communicated through book-writing. Some examples of challenging exercises are challenge problems[11], creativity exercises[12] (both for extra credit), and the choose-focus-analyze (CFA) exercise[13] (please see the Appendix A for some background). If such exercises carry a good weight, say 20 to 30% toward the final grade, it can also be ensured that the grades reflect the learning extent. In the interest of fairness, such exercises need to be assigned to the entire class, and they are a learning experience for all in the class. However, they are expected to better benefit the RS. Also, when the CFA exercise was made optional, no student did it. This experiment showed that students did not want to burden themselves with a challenging class exercise without 'tangible' benefit even though they appreciate it when it is an assigned exercise that counts toward the grade. Many students have expressed their unsolicited appreciation for the CFA to the author and his colleagues when they were still in the program. In addition, some RS in the author's past classes who later became faculty members or key members in the industry, fondly recall the exercise when they meet or communicate (some even after 18 years). These show that the exercise has been effective. The author has counted 33 such unsolicited, fond recalls thus far.

Faculty members/instructors, usually, were RS in their classes

It is highly likely that the instructors or faculty members were RS of their own classes; they are *skilled in their chosen field,* either naturally (highly skilled) or through sustained effort (moderately skilled). Since the selection procedures for faculty members and for the programs that lead to being faculty members (say, Masters, Ph.D.) are highly competitive, it is likely that only the students who were skilled enough to perform consistently well are able to become faculty members. While this scenario is desired, it also places faculty members in a position from where they cannot appreciate the mental state or experiences of the LS. If the faculty members are aware of this fact, which is usually difficult to appreciate, and they take steps to understand the LS, it could lead to a better contribution to the learning of the entire class, as discussed in the later section on LS. Many faculty members empathize with the LS, but a true appreciation of how the LS see the course and an understanding of their psyche are needed to facilitate their learning. A way in which true appreciation for LS can be gained by the instructor is by signing up for a course in which (s)he is not skilled – say music, dance, painting, or any other aspect. When this author took classes in classical dance in which his natural skill is only moderate, the experiences proved valuable to understand the LS psyche.

Average students

Clarity in delivery, good organization, employing proven techniques of learning, working out mathematical steps in good detail while doing derivations of important results, and listening to the feed-back of the learning are all crucial to be effective in facilitation of learning of the average student (and the LS; they are not crucial for the RS, although they help). This author pitches his class lectures to the average students in the interest of the greatest good to the greatest number of people in class. As mentioned in the Introduction, many well-tested

strategies including active learning, co-operative group learning, and many others are available in the literature to improve learning of an average student. Therefore, this manuscript will not focus on the average students.

Left students

Addressing the needs of LS toward facilitation of their learning is one of the highly challenging tasks that the author has faced in his teaching career of about 23 years, thus far. It took about 3 years of dedicated effort to start making a difference, and about 3 more years to obtain a certain level of confidence in the reproducibility of the approaches for effectiveness. The main reason for the challenge was the initial inability to understand and appreciate the difficulties faced by the LS. Many aspects that are taken for granted through one's own experiences as a student are invalid for LS. Thus, an intuitive approach, which is employed by many faculty members, except those who have realized that facilitation of student learning needs dedicated approaches, completely fails with the LS.

The reasons for the students to become LS seem to be one or more of the following, based on observations and informal personal conversations with the identified LS over the past 6 years. The personal conversations took place either in the author's office, when the LS dropped by to discuss after they felt confident enough, on the building corridors or just outside the Department building in the bicycle parking lot when the author initiated them with a simple, `how are things with you?' and followed up with `is anything bothering you?', `since you have done well in high school, what can be improved here so that you feel comfortable?', `everyone has a few strengths, and those are different between people', and so on. The author has spoken with all the identified LS over the past 4 years (numbers are given in Table 1), and about 90% of the LS in the 2 years before that.

1. Relatively lower learning ability levels, especially in applying, analysing, synthesising and evaluating, compared to their highly competitive classmates in the undergraduate program
2. A feeling of inferiority that they develop when they compete with the best in the country in the large, common first (freshman) year courses
3. Lower language skills (the medium of instruction is English) of some LS, which leads to a lack of understanding of the class material
4. Lower time-management skills of some LS that quickly lead to a feeling of being overwhelmed. Although many students in class do not possess good time-management skills, a lack of this skill in combination with the other reasons, significantly affects the LS
5. Psychological aspects including minor ones such as home-sickness and other major ones such as depression due to a variety of reasons, academic and personal. The instructor needs to be cautious while dealing with students with difficult mental conditions. A typical instructor is usually not trained to deal with such situations, and there is a danger that the condition may get exacerbated if not properly handled. If the instructor even suspects the potential for such situations (e.g. violent tendencies, suicidal possibilities), it is best to guide the student, preferably through institutional routes, to immediately get professional help.
6. A rebel mind-set, probably because of worldly disdain or because the student was forced into the program by parental/societal pressure. Some of these students are bright, and it is best to leave them alone after ensuring the condition, possibly in collaboration with their parents. They know that they are good, and will complete the undergraduate program with their classmates or soon after. Ultimately they do well in life in their chosen path after graduation, which could be completely different from

their undergraduate field (e.g. journalism, finance, art, public service). We will not discuss this category further. However, other students who rebel may not be bright, and will need help as discussed below, but with an extra dose of kindness and tolerance.

Due to 1 – 5 above, the LS are unable to concentrate to the needed extent, and are unable to recall, understand, or apply the appropriate knowledge, although many regularly attend classes. Although it appears that many LS attend classes as a ritual, about 10% of them do not regularly attend classes. They become demotivated, and also lose their self-confidence. Thus, they are unable to do even the tasks for which they are capable. Consequently, fear of failure and inability to do course exercises or write exams, set in. They also suffer multiple anxieties and they worry about their future. They talk of a feeling of `being in a hole'. Many of the above have also been reported in undergraduate medical students[14, 15] in some countries.

Efforts to help LS such as directly asking them to get help from the instructor or their classmates, to participate in study circles scheduled after class hours where experienced students can help them, or even asking them to meet with the instructor to discuss their difficulties were unsuccessful. Attempts to address their possibly different learning styles[16] when the LS met the instructor to discuss their difficulties were unsuccessful. A clear statement of learning objectives also did not help. The LS seem to be at a stage (psychological and otherwise) where merely knowing what is expected to be achieved does not translate into them expending the effort to achieve the expectations – they do not even feel confident about the efforts. The learning objectives also indicate the level of the course, given their International requirement and consequent status, and hence they need to be written with an average student in mind. They are usually written as, `students will demonstrate their ability to analyse …', `students will demonstrate their understanding …', and so on, which reflect the abilities expected from an average student. A differential set of

learning objectives for different parts of the class (average, LS and RS) may not be easily internationally acceptable, especially since the learning objectives enjoy a high status now.

Thus, the author needed to devise ways to get insights, unobtrusively, into the LS-psyche. Based on those insights, and trial-and-error approach over the past 6 years, the following approaches seem to be effective in helping the LS improve their learning.

- The key aspect is to *unobtrusively* identify the LS as early as possible in the semester. To identify the LS, this author employs a diagnostic test (on material balances, which is reviewed in the first couple of classes in this course; the students have taken a material and energy balances course earlier in their curriculum – the test used in 2015 is given in Appendix B, as an example) that is administered in the first week of classes. The LS-identification purpose of the diagnostic test is not mentioned to the students. The diagnostic test is designed to be difficult and long to suitably identify the LS; the class averages are also lower than usual for the class. The diagnostic test identifies all LS, but can also provide false positives (up to 10%) – average students who did not do well in just the difficult diagnostic test for a variety of reasons. However, based on their interactions in class or through their performance in the first exam, it becomes clear soon after that they need not be considered as LS.
- Once identified, it is crucial that the LS are never directly addressed or unkindly commented upon in class, in front of their classmates. The LS tend to be highly sensitive, and it is imperative that the instructor gives significant importance to this fact. If any action, however well-meaning, exposes the sensitivity of the LS, all the good work toward improvement of their learning is lost. In front of their

classmates, a LS needs to be treated as an average student, without exposing the lower abilities.

- The advertised purpose of the above mentioned diagnostic test performance is its use as the basis for the formation of student groups to solve problem sets for the tutorial/recitation sessions. Based on their performance in the diagnostic test, the class is divided into 3 (number of students in each group) sets A, B, C – the highest achievers in group C, the lowest achievers in group B, and the mid-level achievers in group A, so that their performance is not immediately apparent. The students are asked to form groups of 3, and ensure that each group has one student from each of the sets A, B, and C. Thus, each group contains students with different ability levels so that the average ability level of each group is approximately the same. In addition, the group work contributes well to co-operative group learning[(4)], and is an important strategy in the effort to improve LS learning. After learning to solve the problems in the problem set, the LS are able to solve the problems, on their own, and answer relevant questions that test their understanding, when called to solve the problem on the board during tutorial/recitation classes.
- The LS usually do not turn up to meet the instructor in his/her office if (s)he directly calls them to discuss their difficulties, until the instructor gains their trust. They feel ashamed, and sometimes feel afraid to face their situation. Thus, the communication with LS also needs to happen in a sensitive fashion, until their trust is gained. The author has used the active learning periods (when students work out a small problem, part derivations of essential material, etc.,) to walk around and talk to the LS about their approaches, and also to other students. The conversations with LS included pointers such as `what is the key principle that we

are considering here?', `we need this result starting from here … how do you think we can proceed with the next step?', and others – normal questions that are posed to an average student, but with a readiness to fill-in the gap on information that an average student picks up in high school (math concepts including log, exponentials, functions, derivatives, integrals, first order differential equations, physics/chemistry priniciples, that are relevant to the particular aspects being discussed, etc.,). The LS respond well when the gaps are filled without making them realize that they should have picked up some of them in high school. Such a clarification, on a `recall' excuse on a need-basis, does not take too much time.

- During the initial part of the course, the distribution of relevant abilities needs to be discussed in class, a few times. It needs to be presented as a natural occurrence during well-placed discussions. This discussion can happen during periods of boredom in class, or when the class is looking for a break after an intense discussion on the subject. Such a discussion seems to lead to better acceptance of their situation by LS. It also seems to develop trust among LS toward the instructor and serves to emphasize that the instructor is serious about helping them.
- Once their trust is gained, it becomes much easier for the instructor to help LS with their learning. Also, when the instructor makes efforts to reach out to the LS with genuine kindness, the LS respond very well, and many of them feel comfortable to discuss their learning difficulties. It was surprising that with encouragement during informal one-to-one meetings outside the class, about 30% of the LS did reasonably well in the demanding CFA exercise, and scored even as high as 70% in it.

- The examination (question paper) design is another key aspect to improve LS learning. It is common practice in quantitative courses to use examinations that have only numerical, closed-ended problems, with varying degrees of difficulty. However, closed-ended problem-solving is an applying/analysing (higher level) skill. Instead of using examinations with only closed-ended problems, the instructor needs to first be clear about the minimum knowledge that the student needs to gain to pass the course. The recall and understanding of that knowledge can be tested through appropriate direct questions or `what is the difference between …' type of questions; e.g.`what is the difference between laminar and turbulent flows?', and `what is the difference between flux and driving force?'. About 30% of the examination can have such questions, so that the student who answers only them, and gets about 30% in the CFA can get a minimum pass grade (say, `E'). The remaining about 70% of the examination can have closed-ended problems at varying degrees of difficulty. On the other side, to keep the RS interested, it helps if about 20% of the paper consists of problems that require high learning skills to answer. Such a design also results in well-balanced examinations in systems that can accommodate a significant variation in the total marks that determine the course grade.
- The above design is with the last LS in mind. Many LS regain their confidence, and improve their problem solving skills through co-operative group learning[(4)] when they solve problem sets in groups. About 70% of the LS are able to do also the simpler problems in the exams, and earn D or C grades.
- The author has discussed the examination design in class, a few times. The discussion helps most LS to appropriately prepare their exam strategies. However, some LS try the most difficult question first, and lose out on time to do

well in the questions they can handle. To help such LS, the author, after making sure that he has gained their trust, has directly advised LS, in private, to ensure that they answer the direct questions first, before attempting the more difficult problems.

The above approaches, designed through trial and error over 5 to 6 years, have significantly helped LS to improve their learning. The distributions of student percentages in the diagnostic test and in the total marks that determined the grades, in a representative class (2015) are presented in Figure 2. The diagnostic test data (course-start) was bi-modal, and the same trend was retained in the total marks (course-end), as expected. However, only two students in a class of 36 were in the 0 to 30% range at course-end (their marks were close to 30%) starting from about 11, at course-start. Without the strategies to improve LS learning, a disturbingly significant fraction of the class was seen in the 0 to 30% range at the course end, about 7 years ago. Further, all the identified LS were able to pass the course. The relevant data in the past 4 years are presented in Table 1.

After completing the undergraduate program, it may be best for the LS to choose careers that match their strengths. With the above methods of proactive advising[17] combined with due consideration to the human elements (kindness, empathy, understanding, etc.,), the process of graduation can be made less traumatic for LS, especially when it is too late to drop out of the program. The kindness they experience in the process would possibly have a lasting effect on them, and that can be positive for all concerned. There are significant practical consequences too; It is known[18] that students who feel good about their alma mater, and can do, help the Institution, as alumni. The help could include better engagement with the Institution, financial gifts, and other means. Efforts toward reducing the negative feelings in learning in LS, and providing suitable opportunities to the average and RS to improve their learning

would increase the possibility of students associating positive feelings toward their alma mater.

Conclusion

It is possible to address the learning needs of all the students in class, the average student, RS and LS, through appropriate strategies that are fair for the entire class.

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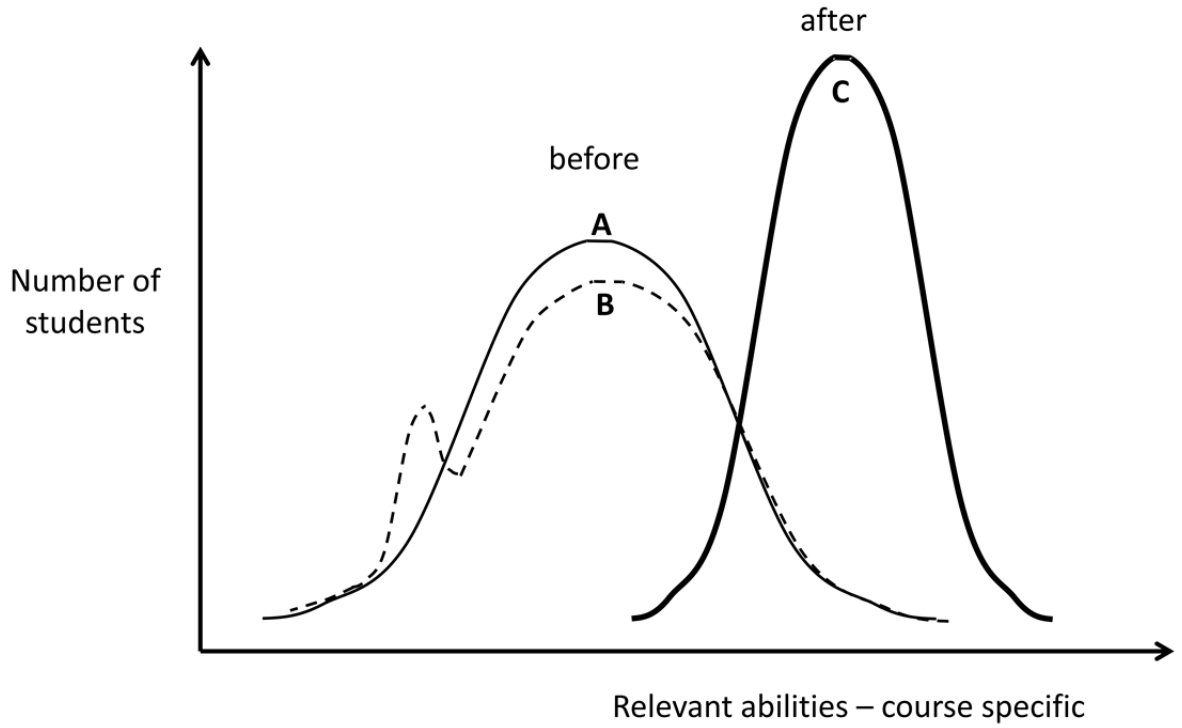

Figure 1: The distribution of course specific relevant abilities in of the students in the class before and after the course. (A) normal distribution (B) bi-modal distribution (C) desirable distribution at the end of the course.

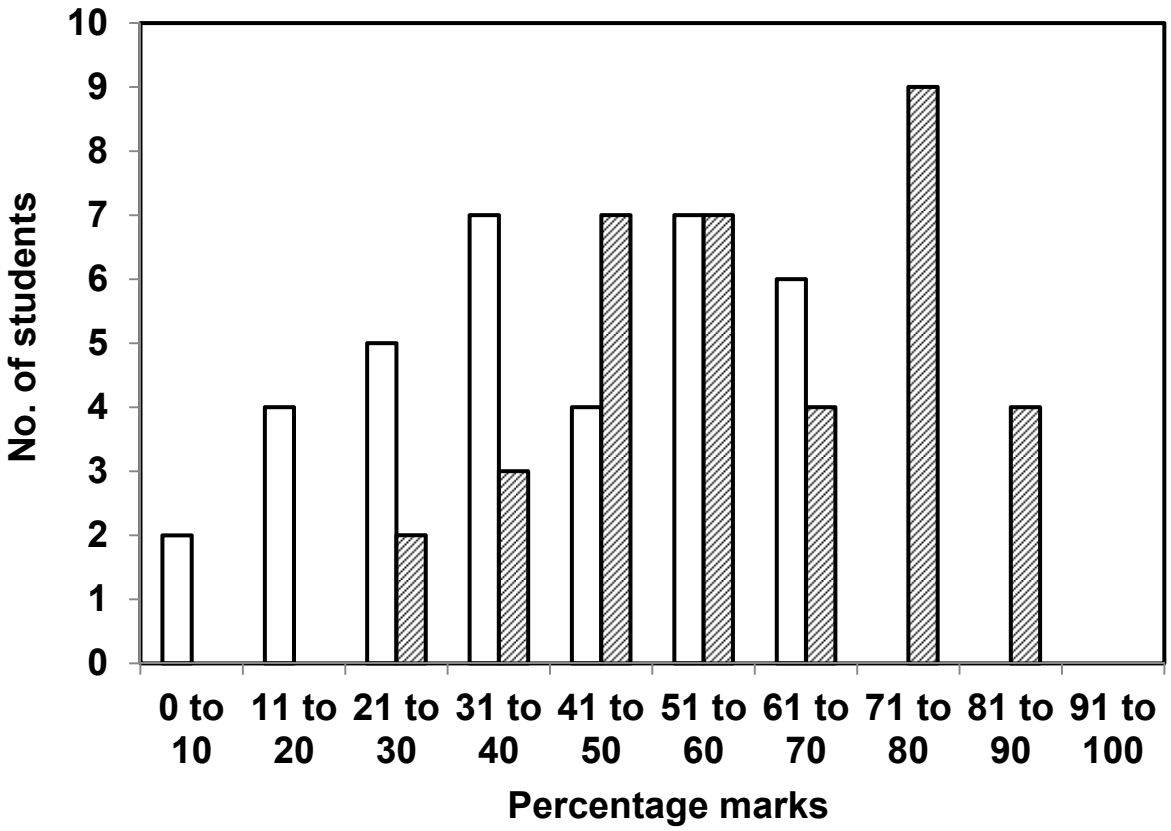

Figure 2: Frequency distribution of student percentages in the beginning of the course as assessed through a diagnostic test in the first week (unfilled bars) and at the end of the course, the overall marks that decided the grades (shaded bars).

Tables

Table 1: LS information in the author's course, transport phenomena in biological systems, over the past 4 years

Year	Total no. of students in class	No. of LS identified	No. of LS who passed	Comments
2012	55	16	15	
2013	53	11	9	
2014	20	3	3	Students in the new program registered for the course. All the LS in class could not register for the course due to program rules.*
2015	36	11	11	

* The curriculum for the new program placed the course in the 5th semester, whereas earlier, it was in the 4th semester. According to the rule, the students who have not passed all their courses until the 2nd semester cannot register for 5th semester courses. Thus, the students who had back-logs until the 2nd semester could not register for this course from 2014 onwards, whereas earlier, they could register for the same course because it was offered in the 4th semester. This changed the composition of only the 2014 class (the first batch in the new program) because there were no students who (earlier) had back-logs. From 2015 onwards, the students who cleared their back-logs became eligible to register for the course, and hence the composition became closer to the usual.

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Appendix A: The Choose-Focus-Analyze (CFA) exercise

Excerpted from: Sureshkumar, G.K., A Choose-Focus-Analyze Exercise in ChE Undergraduate Courses", *Chem. Eng. Ed.*, 35, 80–84 (2001)

Most open-ended problems tend to have the limitation that they have been assigned by the instructor. Therefore, the creativity aspect becomes limited to finding various solutions to a particular, instructor assigned, and thereby, instructor limited, problem. Usually, there are several students who are inherently more creative than the experience-honed instructor, and such an exercise does not fulfil the academic passions of those students.

The following assignment was made during the discussion of the course information material, which was handed out to students, on the first day of classes:

Students need to choose a problem of relevance to industry or any human endeavor and analyse it using the material and energy balance principles (or thermodynamics principles, for the thermodynamics course) learned in class. This is an open-ended problem, which has been designed to improve the choice, focus and analysis skills in students. The evaluation will be based on

Originality in approach	15%
Focus level	15%
Depth of analysis	20%
Quantum of work	20%
Original contribution	20%
Presentation (mainly communication)	10%

A concise report (in the format that you think would best communicate your work) submitted

a week before the last day of classes will be evaluated strictly based on the criteria given above. It will help if the problem is chosen well in advance (within the first four weeks) and sufficient time, distributed throughout the course duration, is devoted.

Each student needed to perform the exercise individually, and it carried either a 15% or a 20%weightage towards the final grade. Further, to make students self-reliant, the instructor unequivocally denied any help, at any stage. The inputs from the instructor were strictly limited to two aspects, for this particular exercise:

1. if the student decided to visit an industry (visiting the industry was not necessary) then, an introductory letter was provided. But, the letter alone may not guarantee admission into an industry – a fact that was clearly stated to the students (the fact that more than 75 students over the past four years have managed to visit the industries for this exercise indicates their relevant abilities – native, or developed for this exercise)
2. after focusing on the problem for analysis, if the student desired to know whether the problem was `too small' or `too large', then the instructor would give his opinion on that aspect alone.

However, the instructor was readily available to clarify the other aspects of the course such as class material, concepts and problem sets.

Appendix B: Sample diagnostic test

Indian Institute of Technology Madras
Department of Biotechnology
BT 3011 Tutorial 1 and diagnostic test for group formation

- Communicate your approach (carries significant weightage) and assumptions clearly.
- 11th August 2015; duration: 50 min Max. marks: 100

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1. An ineffective lecturer uses two chalk pieces to fill a black board of 1m X 5 m. At the end of the class, the board is erased. The chalk piece can be considered cylindrical with a diameter of 1 cm and length, 7.5 cm. Each chalk piece weighs 3.5 g, and when discarded, its length reduces to 2 cm. After the board is erased, what is the average area concentration of the chalk dust in g cm^{-2}, in the vicinity of the board, which can be taken as 15 cm from the board on the floor. Assume that the dust taken away by the duster and the amount lost while writing consists of 85% of the chalk used, and the remaining is present in the vicinity of the board.

[Marks: 15]

2. Sometime after 2.5 mmoles of a drug are injected in to the blood stream of a human being, its concentration becomes uniform in the blood. For effectiveness, the drug concentration in the blood needs to be above 100 μM and below 500 μM to avoid side effects. When the blood flows through the kidney, 1% of the drug is removed, and the blood supply rate to the kidney is 1.5 L min^{-1}. Taking the total volume of blood in the human body to be 5 L, prescribe a dosage for the drug.

[Marks: 30]

3. For an analysis of oxygen supply to a bioreactor of broth volume V, an effective system for writing the oxygen balance is usually (broth – bubbles). Also, it is assumed that the volume of bubbles is negligible compared to the volume of the broth. In addition to aeration, if the decomposition of H_2O_2 by catalase present in the cells is used to provide oxygen, in situ in the bioreactor, write a material balance on oxygen for the system, (broth – bubbles). A first order reaction with a rate constant k can be assumed for H_2O_2 decomposition. Also, the mass rate of oxygen supply through aeration in this case, can be represented as $\dot{I} = k_L a \left(C^*_{O_2} - C_{O_2}\right) V$ where $k_L a$ is a constant under the given conditions of operation, $C^*_{O_2}$ is another constant, and C_{O_2} is the concentration of dissolved oxygen in the broth.

[Marks: 40]

4. Through suitable explicit material balances express the relationships between the metabolites in the figure on the other side in terms of the stoichiometric matrix, reaction rate and state vectors.

[Marks: 15]

Do your Best. Good luck.

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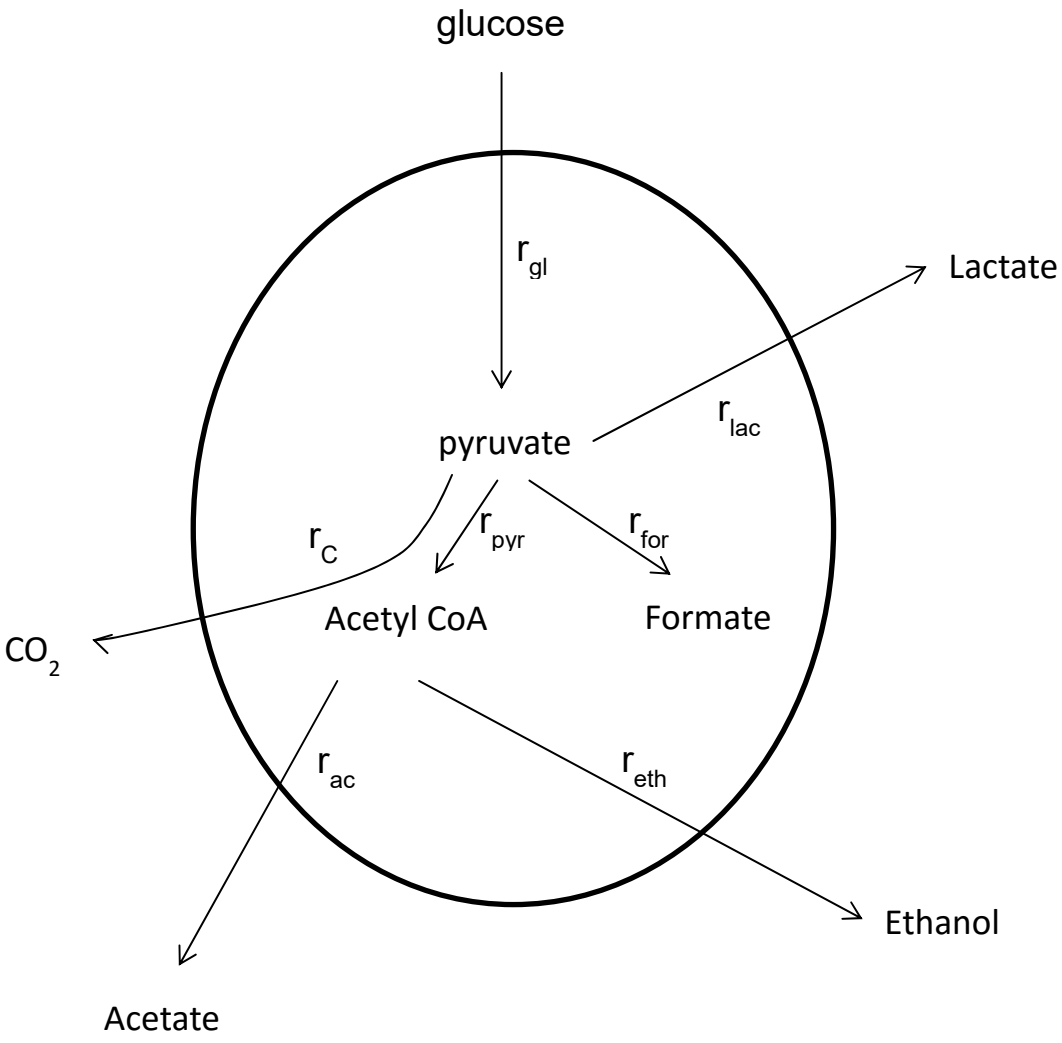
glucose
r_{gl}
Lactate
r_{lac}
pyruvate
r_C
r_{pyr}
r_{for}
Acetyl CoA
Formate
CO_2
r_{ac}
r_{eth}
Ethanol
Acetate

Short biographical sketch

G. K. Suraishkumar received his B.Tech. in Chemical Eng. from IIT Madras, Chennai, India, and his Ph.D. from Drexel University, Philadelphia, USA. He has contributed methods to improve student learning in courses, laboratories, and to improve technical writing. He has authored a book titled Continuum Analysis of Biological Systems: Conserved Quantities, Fluxes and Forces, and developed video/on-line courses and MOOCs. His research group and he have contributed novel research findings related to the technological aspects of reactive species. He has also significantly contributed to the start-up of two Departments of Biotechnology at IIT Madras and IIT Hyderabad, respectively, as their first formal Department Head.