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EUROPEAN JOURNAL OF ENGINEERING EDUCATION, 2017
https://doi.org/10.1080/03043797.2017.1384797

Strategies to improve learning of all students in a class

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ABSTRACT

The statistical distribution of the student learning abilities in a typical undergraduate engineering class poses a significant challenge to simultaneously improve the learning of all the students in the class. With traditional instruction styles, the students with significantly high learning abilities are not satisfied due to a feeling of unfulfilled potential, and the students with significantly low learning abilities feel lost. To address the challenge in an undergraduate core/required course on 'transport phenomena in biological systems', a combination of learning strategies such as active learning including co-operative group learning, challenge exercises, and others were employed in a pro-advising context. The short-term and long-term impacts were evaluated through student course performances and input, respectively. The results show that it is possible to effectively address the challenge posed by the distribution of student learning abilities in a class.

ARTICLE HISTORY
Received 13 April 2016
Accepted 15 September 2017

KEYWORDS
Distribution of learning abilities; whole class; cooperative group learning; challenge exercises; proactive advising; sensitivity

Coll:
QA:
CE: CV

1. Introduction

Engineering education is traditionally addressed through straight lectures, problem sets, laboratory work, and a final (senior)-year project (Felder et al. 2000; Felder and Brent 2005). To improve student learning in the engineering undergraduate programme, pedagogical strategies such as active learning (Bradforth et al. 2015; Waldrop 2015; Wankat and Oreovicz 2015), which includes cooperative group learning (Felder and Brent 2007), and others exist. Each strategy can be implemented in various modes; for example, active learning can be implemented through simple calculations, think–pair–share (Lyman 1987), part derivations by students of absolutely essential quantitative information in a guided fashion, and others.

AQ1 AQ2 AQ3 A statistical distribution exists in student learning abilities (Kovas and Plomin 2007; Plomin, Haworth, and Davis 2010). In this work, the learning abilities denote the abilities in the cognitive domain of the revised Bloom's taxonomy (Anderson and Krathwohl 2001; Bloom et al. 1956) – recalling, understanding, applying, analysing, evaluating, and creating – as applied to the particular subject, 'transport processes in biological systems'. It is known that each student has his/her areas of strength/giftedness in which he/she has easy access to the highest ability levels (Gardner 1993). However, giftedness is area specific (Feldhusen 1986), and the areas of student's strength may not be related to the student's undergraduate course areas. Students may have chosen to do engineering for a variety of reasons including the need for a reasonably secure job upon graduation, lack of clarity regarding their own strengths (Sureshkumar 2001), and others.

The students who are in the middle (the 'average' or the 'mean') of the statistical distribution of learning abilities are termed 'average students' in this work. From the nature of the statistical distributions, it is also clear that most students in a class are 'average students'. However, the students who

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possess high learning skills (HLS), who are at the right extreme of the distribution, and the students who possess low learning skills (LLS) due to limited abilities or other difficulties, who are at the left extreme of the distribution, are not helped much. The academic passions of the HLS are not fulfilled (Sureshkumar 2001), whereas the LLS feel lost in the course and significantly struggle to pass (Baslanti 2008; Mysorekar 2012).

Academic advising is a critical component in ensuring student success and increased graduation rates (Fricker 2015). Proactive advising is a deliberate, structured intervention to enhance student motivation at the first indication of academic difficulty (Earl 1988; Glennen and Baxley 1985; Varney 2013). It provides students with information before they request it while simultaneously building a relationship with them (Varney 2013).

This paper shows that a judicious combination of challenge exercises and cooperative group learning, when employed in a proactive advising context, can address the challenge posed by the naturally occurring distribution of student learning abilities in a class. The overall aim is to increase the learning level of the 'average student' in class, as well as to reduce the spread of the learning levels in a class, as shown in Figure 1. An improved learning in the entire class is expected to improve the retention of the students in the programme, which is a significant challenge either to complete their courses (Waldrop 2015) or to contribute in their chosen fields after graduation (Auyang 2006). In addition, the resultant positive experience for the students is expected to improve their contributions in the future to their alma mater, as alumni (Morgan 2014).

1.1. Context

The work reported in this paper was done while handling the undergraduate core (required) course, transport processes in biological systems, in the Department of Biotechnology, at the Indian Institute of Technology Madras, India, over the past nine years between 2008 and 2016. The strategies discussed for improving LLS learning were first attempted in 2011, and were subsequently, significantly refined. The course was offered in the fourth or the fifth semester of the programme.

The language of instruction is English. The undergraduate programme is residential, with less than 1% dropout rate; the LLS usually take much longer than the usual eight semesters to complete the programme, with great difficulty. The selection to the programme is highly competitive – only the top 0.05% of the candidates are selected through a difficult entrance examination (Misra 2015). Therefore, it is reasonable to state that even the last entrant to the programme has a much better level of achievement compared to the relevant 'average student' in the country's population. The difficult entrance exam is designed to test the learning at all the levels of the revised Bloom's taxonomy

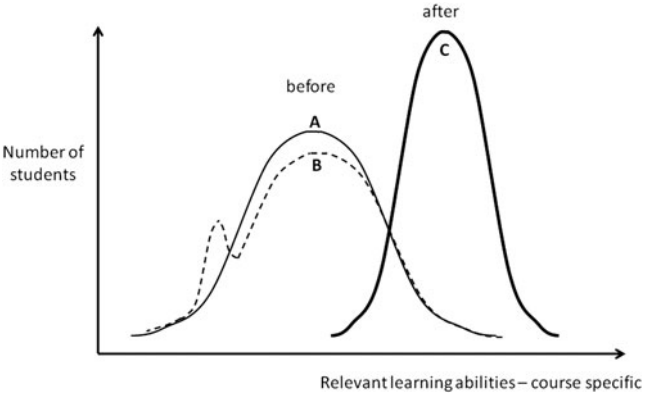

Figure 1. Distribution of course-specific abilities of the students in the class before and after the course. (A) Normal distribution, (B) bi-modal distribution, and (C) desirable distribution at the end of the course.

(Anderson and Krathwohl 2001). The revised taxonomy divided the original Bloom's taxonomy into a knowledge dimension (factual, procedural, conceptual, and meta-cognitive) and a cognitive process dimension (remember, understand, apply, analyse, evaluate, and create). Therefore, it is reasonable to consider that all the students in the programme possess basal learning skills such as remembering and understanding in mathematics, physics, and chemistry, the subjects in which they are tested in the entrance examinations. However, it was observed over 24 years in two Indian Institutes of Technology – Madras and Bombay, through the responses to the questions in the examinations, which comprised questions to test different learning skills, that the higher level skills such as applying, analysing, evaluating, and creating are limited in the LLS.

2. Literature information

In almost all undergraduate engineering education systems, a course is given over a fixed time period of an academic term, which is usually a semester or a quarter (Thomas 1966). In fixed-time systems, due to the statistical distribution in learning abilities, it is difficult to aim for every student in the class to reach the same, high level of achievement, i.e. mastery learning (Wankat and Oreovicz 2015), to successfully complete the course. Therefore, the different levels of 'satisfactory' achievements are recognised through grades (Weiss and Rasmussen 1960), and a failure grade is awarded for 'less-than-satisfactory' achievement. If the system allows for mastery learning, then the instructor could set the bar high, and need it to be reached to complete a course. However, such a system does not exist in engineering education in most parts of the world, although attempts have been made to induct mastery learning or its variant, competency-based learning (Mintz 2015). Thus, a fixed course time seems to be a constraint for mastery learning.

The statistical distribution in the learning abilities, a natural occurrence in populations, is known to result from nature (Kovas and Plomin 2007; Plomin, Haworth, and Davis 2010) and nurture (Kovas et al. 2007). A set of specific genes that are termed 'generalist genes' has been established to influence cognition and learning through twin studies and multivariate genetic analysis (Kovas and Plomin 2007). However, the environment has been shown to be responsible for the differences in the manifestation of the genetic abilities (Kovas et al. 2007). The distributions of learning or performing abilities in a class are usually normal, skewed-normal, or bi-modal (McDonald 2002). When the distribution of learning abilities in a class is bi-modal or skewed-normal, the LLS or HLS could form a significant percentage of a class, which is apparent from the relevant distributions.

Students who are naturally gifted (Benny and Blonder 2016; Gardner 1993) in the course area and those who exhibit a highly effective level of self-regulation (Zimmerman 2002) or self-direction (Chou 2012) of their learning are considered HLS in this work. Gifted students of relevance here have a 'natural inner interest' (Benny and Blonder 2016) in science and engineering. They strive to better understand the underlying phenomena and to apply them (Freeman 2003; Johnsen 2004) for human benefit. The natural abilities get transformed into expertise in a particular subject or field (Gagné 2004). On the other hand, self-regulated learning (SRL) denotes autonomy and control by the students themselves to monitor direct and regulate actions toward learning (Paris and Paris 2001). Self-regulation refers to the processes of '… self-generated thoughts, feelings and actions that are planned and cyclically adapted to the attainment of personal goals', to quote Zimmerman (2000). Cognition (skills to encode, memorise, and recall information, as well as those for problem solving and critical thinking), metacognition (skills to understand and monitor one's own cognitive process), and motivation (beliefs and attitudes that determine the effectiveness of cognition and metacognition skills) are the three important components of SRL (Schraw, Crippen, and Hartley 2006). Gifted learners are believed to have a high ability for SRL (Neber and Schommer-Aikins 2002). It is recommended that the gifted students need to be provided with faster-paced and more complex learning activities compared to those available in a regular classroom (Van Tassel-Baska 2003), but establishment of such facilities is non-trivial (Benny and Blonder 2016). Furthermore,

the literature in this area usually considers strategies to address HLS who are segregated from others. However, in a realistic setting of an engineering undergraduate class, HLS are a part of a class with students of varying abilities. Detailed studies relevant to engineering undergraduates are not available in the literature on effective strategies for improved HLS learning in such a mixed set-up, although some exercises which are done only by a few students in the class for extra credit have been reported (Bullard and Felder 2007; Wankat 2013).

At the other end, students with different capability levels may turn LLS due to many reasons, as discussed later. In the population of capable and competitive students in the programme, some underachievers (Reis and McCoach 2000) whose underachievement has placed them at the bottom part of the class, underprepared students (Balduf 2009) and weak students (Mysorekar 2012), are considered as LLS in this study. Underachievers exhibit significant discrepancies between expected and actual achievements (Balduf 2009; Reis and McCoach 2000). Some of the LLS are gifted underachievers who exhibit superior scores on expected achievement evaluations but achieve much less than expected (Reis and McCoach 2000). However, underachievement is not a result of a diagnosed learning disability (Reis and McCoach 2000). Instead, it could manifest in underprepared students (Bailey, Hughes, and Karp 2003). The motivation levels in underachievers were found to be much less compared to the achievers (McCoach and Siegle 2003). Also, the goals of underachievers were found to be counterproductive to academic success (Hsieh, Sullivan, and Guerra 2007). Self-efficacy (Bandura 1989), which is understood as the student's perceived confidence to perform a task, has been directly linked to academic performance (Bandura 1997), and underachievers have been shown to have low self-efficacy levels (Fong and Krause 2014). Self-regulatory limitations may negatively affect an underachiever's personality and emotional aspects, which result in anxiety, lower self-esteem, and higher need for approval (Zimmerman and Risemberg 1997). The causes for underachievement could be both internal (student related) and external (peers, culture, family, social environment, and school environment) (Berube 1995; Schultz 2002). Underachievement is recognised as a significant challenge (Fong and Krause 2014) – it results in lower societal contributions and makes the student vulnerable to socio-psychological difficulties including depression, substance abuse, and others (McCall, Beach, and Lau 2000). Strategies to improve LLS learning in the practical setting – where they are a part of an engineering undergraduate class with students of varying abilities – are not available in the literature.

Academic advising involves a reciprocal process of good communication between a student and an advisor and is understood as a decision-making process which helps students to maximise their learning potential (Braxton et al. 2014; Fricker 2015). Academic advising could be prescriptive, in which the advisors address student queries in an authoritative fashion, or collaborative, in which students and advisors work together toward student success (Lowenstein 1999). Proactive (previously called intrusive) advising (Glennen and Baxley 1985) is a proactive process rather than a reactive one (Donaldson et al. 2016) to address student difficulties. It consists of the positive aspects of prescriptive, collaborative, and developmental approach in an outreach mode to students (Earl 1988). Proactive advising has been shown to be effective in improving retention (Donaldson et al. 2016). However, the process assumes that students would approach the advisors at regularly scheduled intervals (Fricker 2015) and does not explicitly address the students who have a difficulty in approaching advisors itself, especially in the context of engineering undergraduate education.

3. Methods

In this section, the details of the exercises and approaches that were aimed to improve the learning of HLS and LLS are presented. Also, the impact assessment means are described. Since identification of the LLS and communication with them were important aspects of the work, the means employed to discreetly and effectively identify, communicate with, and gather information from the LLS are also described.

3.1. The Choose–Focus–Analyse exercise

To better fulfil the HLS potential, a challenging exercise called the Choose–Focus–Analyse (CFA) exercise (Sureshkumar 2001) was assigned. In brief, the CFA exercise was designed to develop the skills of choice, focus, and analysis. The following assignment was made on the first day of classes. To quote from the course information sheet,

> Students need to choose a problem of relevance to industry or any human endeavour, and analyse it using the principles learnt in class. 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.

Furthermore, to make students self-reliant, the instructor unequivocally denied any help, at any stage, except if asked by the student, to opine on whether the work planned is either too less or too much. In the interest of fairness, the CFA exercise was assigned to the entire class, and it carried a significant weight (30–40%) toward the final grade.

The impact of the CFA exercise in the short term after completing the course was assessed through a survey with two questions. They were (1) Did you find the CFA exercise helpful toward improved learning in the transport course? Yes/No, and (2) If yes, can you elaborate on the ways you found it useful? The survey was e-mailed through the learning-management system (Moodle®) to the students who had completed the course in the previous three years (2014, 2015, and 2016), a total of 92 students, with a request for a quick response. To increase the number of responses from the students who completed the course in 2016 and were registered for a laboratory course offered by the author in the next semester, the class representative was requested to help. The class representative set up a spreadsheet on Google sheets (https://docs.google.com/spreadsheets/u/0/) for anonymous input from his classmates, and forwarded the input to the author. A total of 29 responses (31.2% response rate) were received over a 4-week period – 16 responses were through email, and thus the respondents were known. However, the 13 responses received through the spreadsheet set up by the class representative were anonymous.

The impact of the CFA exercise in the long term was assessed as follows: The author noted the number of past students of the course who recalled the exercise, on their own, unsolicited, when they met or communicated. The noting was done in the form of tally marks – four vertical and one diagonal for five recalls – in a sheet carried by the author in his wallet. Double counting was avoided by asking the question to the past student, 'Did we speak about this the last time we met?' A tally mark was added only when the past student said no. Although the exercise has been given in various courses handled by the author since 1996, the noting began in 2005.

3.2. LLS identification and approach

The LLS were identified through performances in a diagnostic test given after the first three lectures. The terms LLS and HLS were not discussed with students to avoid morale-related difficulties. The advertised purpose of the diagnostic test performance was its use as the basis for the formation of student groups to solve problem sets for the tutorial/recitation sessions in a cooperative group learning mode. The material for the diagnostic was based on another course that the students

had earlier taken, and the relevant essence of the previous course was reviewed in the first three lectures of the course. In this case, the previous course was on material and energy balances, and the material balances were reviewed from the perspective of transport in this course on 'transport processes in biological systems'. The diagnostic test was designed to be challenging in terms of the needed time, with an emphasis on questions that test the skills of applying, analysing, and synthesising. A sample diagnostic test is given in Appendix A1.

3.3. Group formation

The need to form groups to promote cooperative learning was explained to the class. Based on their performance in the diagnostic test, the class was divided into 3 or 4 (number of students in each group) sets A, B, C (or D) – 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 were asked to form groups of 3 (or 4) and to ensure that each group had one student from each of the sets A, B, and C (or D). Thus, each group contained students with different ability levels so that the average ability level of each group was approximately the same. When the number of students in class was not a multiple of 3 or 4, the needed number of groups had one more student.

3.4. Communication with LLS

The LLS usually did not meet the author in his office when he directly called them to discuss their difficulties, until the author gained their trust. The communication with LLS needed to happen in a highly sensitive fashion, at least until their trust was gained. To build trust, the author used the active learning periods (when students worked out a small problem, part derivations of essential material, etc.) to walk around and talk about their approaches to the LLS and also to other students. The conversations with LLS 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 (mathematical concepts including log, exponentials, functions, derivatives, integrals, first-order differential equations, physics/chemistry principles, that are relevant to the particular aspects being discussed, etc.). The LLS responded well when the gaps were filled without making them realise that they should have picked up some of them in high school. Such a clarification, with a 'recall' excuse on a need basis, did not take an unacceptable amount of additional time.

Once their trust was gained, it became much easier for the author to help LLS with their learning. Also, when the author made efforts to reach out to the LLS with genuine kindness, the LLS responded well and, with time, felt comfortable to discuss their learning difficulties.

3.5. Reasons to become LLS

The LLS were interviewed, discreetly, to assess the reasons for them to become LLS in the context of engineering undergraduate education with high entry standards. The interviews were conversational in nature and were conducted in an informal tone. The conversation notes were made immediately after the interviews. The conversations took place after the students seemed to feel confident enough either in the author's office when the LLS came to discuss or on the building corridors or just outside the Department building in the bicycle parking lot. 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?', and others. The LLS were also assured with statements such as 'everyone has a few strengths, and those are different between people', and others, to make them comfortable during the conversation.

The author spoke with all the identified LLS over the past five years (numbers are given in Table 1) between 2012 and 2016, and with about 90% of the LLS in the two years before 2012. The direct verbal conversations that contributed to data in this work happened once with each LLS, although the non-verbal and discreet verbal interactions with them in class happened from the time of their identification. The notes were made immediately after the above direct verbal conversations. The notes were analysed to consider whether the LLS responses fitted under following heads: (1) feeling of inferiority (Baslanti 2008), (2) time-management difficulty (Balduf 2009; Mysorekar 2012), (3) language difficulties (Mysorekar 2012), (4) other psychological difficulties (Mysorekar 2012), and (5) a rebel mind-set.

3.6. Examination design

The examinations were designed with the last LLS in mind. The criterion for earning the minimum pass grade was set as the ability to meet the learning objectives that related to recall and understanding. The recall and understanding of that knowledge were 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% weight was given to questions that tested recall and understanding. The remaining part of the examination comprised closed-ended problems at varying degrees of difficulty to address the non-LLS students. A typical final examination, which was used in the course given in 2016, is provided in Appendix A2.

4. Results and discussion

4.1. Impact of the CFA exercise on learning

The responses to the survey on the CFA exercise received from the students who completed the course in 2014, 2015, and 2016 are presented in Table 2. A significant majority, 96.6%, of the respondents said that the CFA exercise was helpful toward improved learning. Only one negative response was received.

The reasons provided by the respondents for their improved learning are also given in column 3 of Table 2. The reasons are different for each student, although some common factors can be interpreted from the responses. The common factors that seem to be present in a significant fraction of the responses include working on a real-world topic of personal interest to the student and an opportunity for in-depth study of the course material. It is interesting that a student who earned a

Table 1. Number of students with LLS in the author's course, transport phenomena in biological systems, between 2012 and 2016 when strategies to improve LLS learning were implemented.

Year	Total no. of students in class	No. of LLS identified	No. of LLS who passed	Comments
2012	55	16	15	
2013	53	11	9	
2014	20	3	3	Students in the new programme registered for the course. All the LLS in the batch could not register for the course due to programme rules[a]
2015	36	11	11	
2016	30	9	9	

[a]The curriculum for the new programme placed the course in the fifth semester, whereas earlier, it was in the fourth semester. According to the rule, the students who have not passed all their courses until the second semester cannot register for fifth semester courses. Thus, the students who had backlogs until the second 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 fourth semester. This changed the composition of only the 2014 class (the first batch in the new programme) because there were no students who (earlier) had backlogs. From 2015 onwards, the students who cleared their backlogs became eligible to register for the course, and hence the composition became closer to the usual.

AQ9 **Table 2.** The responses of students who completed the course between 2014 and 2016 to the survey regarding the CFA exercise.

The questions in the survey:
Q1: Did you find the CFA exercise helpful toward improved learning in the transport course? [Yes/No]
Q2: If yes, can you elaborate on the ways you found it useful?

S. No	Q1 response	Q2 response (quoted)	CFA marks (max: 100)	Grade
1	Yes	It forced me to analyse a particular topic from its root.	Anon	Anon
2	Yes	Enhanced learning. Promoted original thought. Encouraged student to research beyond curriculum.	Anon	Anon
3	Yes	It made us to look into the real-life application of principles studied in class. It gave us a mathematical understanding of real-life systems. It gave an intuitive idea of modelling a real-life system for solving many problems. It increased the analytical way of thinking and finding solutions to a problem.	Anon	Anon
4	Yes	Searching for ideas for CFA as well as going further with each idea has deepened my understanding of the core concepts of the course and their applications.	Anon	Anon
5	Yes	It asked us to work on a different kind of problem not offered in usual coursework. Other than that it was an amazing learning curve for me and personally, I learned Latex because of it which I wanted to for a long time.	Anon	Anon
6	Yes	Firstly, this course is really different in any manner may the way it has been taught examples taken videos shown everything is really useful and there is so much to learn in everything. The main part I liked was this course motivated the concept of learning till the end rather than marks gaining which improved the quality of course unlike the other courses even if we have much interest finally we end up mugging for marks. I learnt many things without mugging but understanding each concept clearly and thoroughly another important thing was textbook even if we miss classes the text book was very clear and easy to read and understand in my case. CFA was more efficient because of all these factors which were done in the course.	Anon	Anon
7	Yes	CFA exercise for normal general purpose is fine to do. Through this, we learn how the basic general things work. But I didn't find it improving my knowledge towards transport course and also considering it too seriously isn't necessary.	Anon	Anon
8	Yes	I always wanted to work on a project related to diabetes, ever since I joined biological engineering. But the push to do the necessary was never there and neither was there much confidence in myself to work on a project like that. The barrier broke when I started working on CFA. Everything looked vague and felt like it will go nowhere. But after starting to work on it for a couple of days and thinking it through properly, it seemed simple to solve. Though there were a couple of assumptions I had to make while doing the exercise, now I have the confidence that I can manage reading a lot of research papers, absorb and combine all the knowledge to analyse what is required.	Anon	Anon
9	Yes	First of all, it gave of glimpse of applying class room knowledge to real-life problems. I personally liked it because it was designed to build up the knowledge in a particular subject rather learning everything and not having a clear-cut big picture of it. All other courses also have this type of projects but the importance allotted was incomparable with CFA. This is a great platform for the students who wish to learn the subject genuinely and get something out of it at the end.	Anon	Anon
10	Yes	We were made to choose our own topic so we could pick a topic of our interest and work on it rather than doing something half-heartedly.	Anon	Anon
11	Yes	In my two years here, this was one of the most useful exercises I've ever been a part of. It was designed perfectly to motivate the student and to get them to understand the process of scientific enquiry as we were required to delve deeper into whatever topic we had chosen. The fact that we were not pushed into picking topics that were limited to a specific field was one great part of the exercise. Even though we had difficulty settling on one topic in the beginning, we ended up picking topics we really cared about and actually enjoyed reading up and working out the problems. The format in which the paper was required to be submitted in encouraged me to try and understand what academic writing looks like. Personally, I've been more of a creative writer all my life but as a student pursuing a career in science, this was a great learning experience for me. As an undergraduate in an intensively competitive environment, the CFA exercise was a great boost of confidence and morale.	Anon	Anon
12	Yes	It helped think deep into a topic, and helped improve analysing skills.	Anon	Anon
13	Yes	I improve my knowledge, skills, and understanding.	Anon	Anon

14	Yes	The project involved applying concepts taught in the course to any problem. Practising and applying concepts generally leads to better and faster understanding.	91	S
15	No	CFA is a good concept; however, the execution in my opinion was not proper. Yes we get almost the whole semester to do it, but by the time we begin to understand the course enough to attempt a challenge like CFA, it is too late. Therefore, no I did not find it beneficial in this case, rather detrimental. I do not know the answer to this problem, but it needs more time to do in the manner that is expected. More than the constraints of a single semester course allow. Lastly, statistically only a couple of students will require such extensive understanding of the course in question, this fact makes it difficult to develop the enthusiasm to do a CFA on it.	66	B
16	Yes	I have learned a lot from the course (Transport phenomenon) which you taught us. The CFA exercise plays an important role in the course as it brings all the applications together to complete that exercise and also we get to know where to apply the different parameters or applications at their perspective sites. At the starting level of the course I knew very few conceptual things, but by the end of the course I come up with a problem statement and along with its solution and got to know lot of applications and theory. Yes, it was and it will be very helpful for a student to be assigned with such CFA exercises.	59	D
17	Yes	CFA is a very good exercise to learn more about the fundamentals behind Transport phenomena as well as its use in a relevant or different area where people generally don't think about applying transport phenomena. By doing this exercise, I improved my ability to discover, focus and analyse with deep thoughts. I can say that I have never done any project like CFA project before or after the course Transport phenomena and I feel that every student should do this exercise at least once during his graduation.	96	S
18	Yes	I am able to apply the topics it into day-to-day life activities. I had a great time in doing that course. I did CFA on 'A study on Concentration profile of food in Intestine'	65	C
19	Yes	The CFA exercise made us apply the concept learnt in class in real-world problems. It gave us an opportunity to be creative while choosing the problem we wanted to work upon. It made us realise that biological equations could also be applied in other phenomena. It made us thorough with the concepts and solidified the concepts in our minds.	84	B
20	Yes	Though it is a different story that I did not do justice to the exercise, it definitely helped me understand the basics regarding the course, for example what all factors one needs to take into account while modelling something as simple as blood flow in the human body or some phenomenon as complex as diffusion of a drug across the surface of a tissue. How to apply engineering principles and mathematical approaches to the human body is also something I learned from this course. I had previously thought that it would not make sense, applying mathematics to the human body, given the difficulties of the ever-changing micro and macro environment of the human body, and on using differential equations to model the same, there would be more variables than equations to quantify the exact parameters. CFA and the course convinced me that taking certain assumptions into account would give me conditions that are very much close to reality. I think CFA is a good exercise that can be included in any kind of coursework, where it helps you apply concepts taught in class by yourself. It also encourages you to make mistakes and rectify the same or suggest possible solutions, if not fix those mistakes. plagiarised	0 D	
21	Yes	(1) It made me look into the assumptions and such details of the chosen concept, in order to apply it to the topic I selected. This gave me a better understanding of the concept. Also, discussing with friends each of their selected projects and their approaches and application of concepts for solutions made the concepts more tangible and workable, as compared to being equations in texts made for solving certain problems. (2) On applying the concept, and trying to solve the problem I chose, I could think of issues that may not be solved by the concept with its initial assumptions alone. It made me look for solutions for these issues; be it more assumptions to reduce it to a problem solvable by the concept, or integrate other concepts to solve the problem. This exercise, therefore, gave me a taste of real-life problem solving, where a fragile solution can be found the easy way with more assumptions, or looking for ways; learning and broadening the perspective to obtain a more robust result. (3) Though I have been applying the concepts learnt in courses to solve direct questions in assignments previously, this exercise gave me a wider experience. It made me condense a real-life problem into an objective form. This enlightened me to the fact that how a problem is defined affects the	80	A

(*Continued*)

Table 2. Continued.

The questions in the survey:
Q1: Did you find the CFA exercise helpful toward improved learning in the transport course? [Yes/No]
Q2: If yes, can you elaborate on the ways you found it useful?

S. No	Q1 response	Q2 response (quoted)	CFA marks (max: 100)	Grade
		quality of, and the method followed for the solution. (4) Looking for appropriate problems, and the solutions in literature, opened up a whole world of creative problem solving. I came across very creative approaches used to solve real-life problems, and this, in my opinion, inspired and motivated creative thinking towards problems. (5) The research for the whole project was a great self-study experience. Being methodical and the step-by-step approaches that I developed for this exercise in this third year course helped me in my further internships and projects.		
22	Yes	(1) CFA allows us to choose our own project topic and then work on that. This helps one to develop courage for pursuing ones' own ideas (2) The fact that fundamentals of transport phenomenon could be applied by many on non-obvious applications showed the depth in which students understood these concepts	90	S
23	Yes	The CFA exercise helped me gain in-depth knowledge of the course. I would try and refer to books and internet which helped me grasp a better knowledge of the subject. This was the first time I could have actually studied something in class and used it to solve some real-life questions, no matter how trivial it was.	85	A
24	Yes	Indeed the CFA was very helpful to me as it allowed me to think more practically using theoretical concept in class (course). It also helps think out of the box and made learning more interesting.	72	C
25	Yes	Ways CFA was useful to us are: Independent fixation of problem statement, while keeping in mind the feasibility in mind. This exercise is necessary as before starting a research project, we are supposed to do similar analysis. Complete independence for student and thus confidence building involved. Such exercise make student responsible as a whole semester is given and if students do not start early it might affect quality thus their grades. Helps choose an important as well as favourite part of the course and take it forward to think beyond the curriculum Creativity is involved as it is not just a project but a story. Overall, CFA was a unique experience in learning.	77	A
26	Yes	To be frank the education system in India is such that it expects students to reproduce whatever is in book or other source. It doesn't encourage students to be innovative. The CFA exercise which we did last semester helped me think a lot on my own and come up with few ideas. In the process I learnt a lot about many things which I have never heard of before and became more knowledgeable about the course. Without CFA exercise I don't think I would have become this knowledgeable. The exercise boosted a bit of confidence within myself too.	88	B
27	Yes	First of all, it gave of glimpse of applying class room knowledge to real-life problems. I personally liked it because it was designed to build up the knowledge in a particular subject rather than learning everything and not having a clear-cut big picture of it. All other courses also have this type of projects but the importance allotted was incomparable with CFA. This is a great platform for the students who wish to learn the subject genuinely and get something out of it at the end.	91	B
28	Yes	My CFA exercise was on projectile motion of laminar jets of a fluid. Research and derivation of formulas for the exercise have contributed highly to my understanding of laminar flow of fluids and their behaviour. Even before deciding on this topic, I had went through dozens of different ideas to do my CFA exercise on and I had researched them thoroughly. All of them were on different parts of the course and trying to build a CFA exercise on it has helped establish my basic understanding of each core concept in the course.	93	A
29	Yes	CFA to me was a first-hand experience of what it takes to carry out novel and meaningful work. The open-endedness of the exercise helped me appreciate the art involved in formulating a relevant research problem. In retrospect, working independently on my problem while struggling hard at times was crucial to help me understand that most real-world problems are not straightforward. However, appropriate formulation and execution pays off at the end.	93	S

Note: Grading system: S, A, B, C, D, E, and failure.
Anon: anonymous.

zero in the CFA exercise because he plagiarised responded positively to the survey (S. No. 20) – it also indicates his generosity. Also, the only student who responded negatively (S. No. 15) felt that although the concept was good, the execution was not proper.

The marks earned out of 100 for the CFA exercise, from the author's records, are provided in column 4, for the students who had identified themselves. Their course grades are provided in column 5. Contrary to expectations that only the HLS would appreciate the exercise, students with widely varying performances in the CFA exercise and grades in the course felt that the exercise improved their learning. Among the respondents who had identified themselves, 25% had earned the highest grade in the course, S, 25% – A grade, 25% – B grade, 12.5% – C grade, and 12.5% – D grade. Also, as discussed in a later section, some of the identified LLS had scored as high as 79% in the challenging CFA exercise.

The above indicate the impact of the CFA exercise on the student learning in the short term. As described in Section 3, to assess the impact of the CFA exercise in the long term, tally marks were made when a past student recalled it, on his/her own without being prompted by the author, when the past student met or communicated with the author. Thus far, 41 students in the author's past classes have recalled the exercise when they met or communicated. About 90% of the past students who recalled the exercise had become faculty members or key members in the industry, and they continue to serve in those positions. The longest period between the course and the recall has been 18 years, thus far. The above shows that the CFA exercise has been effective in the long term.

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 appreciated it when it was an assigned exercise that counted toward the grade.

4.2. Identification of LLS and communication

The set of students with the least performance, among the sets drawn to form tutorial groups, were considered as LLS. They usually scored 35% or less in the diagnostic test, with the 2014 batch being an exception. The diagnostic test successfully identified all students with learning difficulties, but the identification criterion provided false positives (up to 10%), i.e. 'average students' who did not do well in just the difficult diagnostic test for a variety of reasons. However, through their interactions in class or through their performance in the first exam, it became clear soon after that they need not be considered as LLS. The actual number of LLS, after correction, is given in Table 1.

The author realised the following through trial and error, over a period of three years between 2011 and 2013: Once identified, it was crucial that the LLS were never directly addressed or unkindly commented upon in class, in front of their classmates. The LLS are highly sensitive, and it was imperative that the instructor gave significant importance to this fact. In front of their classmates, LLS needed to be treated as 'average students', without exposing the lower abilities. If any action, however well-meaning, exposed the sensitivity of the LLS, all the good work toward improvement of their learning was lost, and the LLS retreated further into their shells.

During the initial part of the course, the distribution of relevant learning abilities was discussed in class, a few times. It was presented as a natural occurrence during well-placed discussions. This discussion happened during periods of boredom in class or when the class was looking for a break after an intense discussion on the subject. Comparison of the qualitative student responses to the author's attempts to relate to the LLS in the years with and without the above discussions implied that the discussions lead to better acceptance of their situation by LLS. They also seemed to develop trust among LLS toward the instructor and served to emphasise that the instructor was serious about helping them.

Furthermore, the efforts to help LLS 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 helped them, or even asking them to meet with the instructor to discuss their difficulties were unsuccessful. Attempts to address their possibly different learning styles (Felder and Brent 2005) when the LLS met the instructor to discuss their difficulties were unsuccessful. A clear statement of learning objectives (Bonner 1999; Thambayah 2011) and their repetition at frequent intervals also did not help the LLS, although it seemed to help the rest of the class. The LLS seemed to be at a stage (psychological and otherwise) where merely knowing what is expected to be achieved did not translate into them expending the effort to achieve the expectations. Conversations with LLS revealed that they did not even feel confident (Bandura 1997) about their efforts. Therefore, the communication methods given in the Section 3.4 were formulated.

4.3. Reasons for students to become LLS

Since the selection to the programme is highly competitive (Misra 2015), slow learners (Murray and Bloom 1960) are not part of the student population. To better understand the reasons for low performance by students who entered the programme through a highly competitive selection process, the identified LLS were interviewed in an informal tone, as detailed in Section 3.5.

All the LLS have mentioned during the above mentioned conversations that they were unable to concentrate to the needed extent, and some of them seemed to be unable even to recall, understand, or apply the appropriate knowledge, although 90% of them regularly attended classes – they probably attended classes as a ritual. It was observed that they became demotivated and also lost their self-confidence (Bandura 1997). Thus, they were unable to do even the tasks for which they were capable. It was observed that consequently fear of failure and inability to do course exercises or write exams set in. Based on the conversations, they also seemed to suffer multiple anxieties and worried about their future. They talked of a feeling of 'being in a hole'. Many of the above have also been reported in low-performing undergraduate medical students (Mysorekar 2012; Padmavathy, Patil, and Pani 2009) in some countries.

Analysis of conversation notes made as described in Section 3.5 showed that 56 out of the 64 LLS (87.5%) mentioned that they felt significantly inferior (Baslanti 2008) to the others in their class. They seemed to develop the inferiority feeling when they compete with the best in the country in the large, common first (freshman) year courses. About 34% had difficulties with effective time management. Lower time-management skills (Balduf 2009; Mysorekar 2012) quickly lead to a feeling of being overwhelmed. Although many students in class did not possess good time-management skills, a lack of this skill in combination with the other reasons seemed to significantly affect the LLS. About 14% faced significant language difficulties (Mysorekar 2012) because their instruction until the higher secondary school level (pre-college) was not in English or they had not developed the language skills to the needed extent.

About 50% indicated other psychological difficulties, which included minor ones such as homesickness (Mysorekar 2012) and other major ones such as depression due to a variety of reasons, academic and personal. The author needed to be cautious while dealing with students with difficult mental conditions because 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 author even suspected the potential for difficult situations (e.g. violent tendencies, suicidal possibilities), he guided the student, through institutional routes, to immediately get professional help. About 6.5% of the identified LLS between 2010 and 2016 needed professional help.

Four LLS out of 64 displayed a rebel mind-set, and they were handled with an extra dose of kindness and tolerance. Such a handling was sufficient to help them be successful in the course. A small percentage (estimated at 10%) of students among the many with a rebel mind-set, probably because of worldly disdain or because the student was forced into the programme by parental/societal pressure, became LLS. An estimated 40% of the students with a rebel mind-set were bright, and as observed over the past 24 years, they completed the undergraduate programme with their classmates, or a semester or two after. They have also been observed to do well in life in their chosen path

after graduation, which was completely different from their undergraduate field (e.g. journalism, finance, art, public service). However, the remaining about 60% of the students with a rebel mind-set may not be bright, and some of them become LLS.

4.4. Impact of the relevant strategies on LLS learning

As mentioned in Section 3.3, groups with approximately the same ability levels were formed for solving problems in the tutorial/recitation sessions. The group work contributed well to cooperative group learning (Felder and Brent 2007) and was an important strategy in the effort to improve LLS learning. Many LLS regained their confidence and improved their problem-solving skills when they solved problem sets in groups. After learning to solve the problems in the problem set through group work outside the classroom, the LLS were able to solve the problems on their own and answer relevant questions that tested their understanding, when called to solve the problem on the board during tutorial/recitation classes. The tutorial group to solve a particular problem on the board was selected by drawing lots, and the author called the LLS in the group to solve the problem on the board. About 70% of the LLS were able to do also the simpler problems in the examinations, and earn D or C grades; the lowest pass grade was E.

It is common practice in quantitative courses to use examinations that have only numerical closed-ended problems, with varying degrees of difficulty (Felder 2002). However, closed-ended problem-solving requires at least applying and analysing (higher level) skills. Therefore, the examination was designed as detailed in Section 3.6. The author discussed the examination design in class a few times to enable LLS to appropriately prepare their exam strategies. However, some LLS attempted the most difficult question first in the in-semester exam and lost out on time to do well in the questions they could handle. To help such LLS, the author, after making sure that he had gained their trust, directly advised LLS, in private, to ensure that they answer the direct questions first, before attempting the more difficult problems.

The student performance in the 2016 final examination is presented in Figure 2. The student performance in the 2010 final examination is also given in the same figure for comparison; 2010 was the last year during which no strategies were consciously employed for improved LLS learning, although the author began talking to the LLS during that year. It can be seen from Figure 2 that in 2010, about 23% of the students earned less than 30% and 10% earned less than 20%. In contrast, in 2016, only

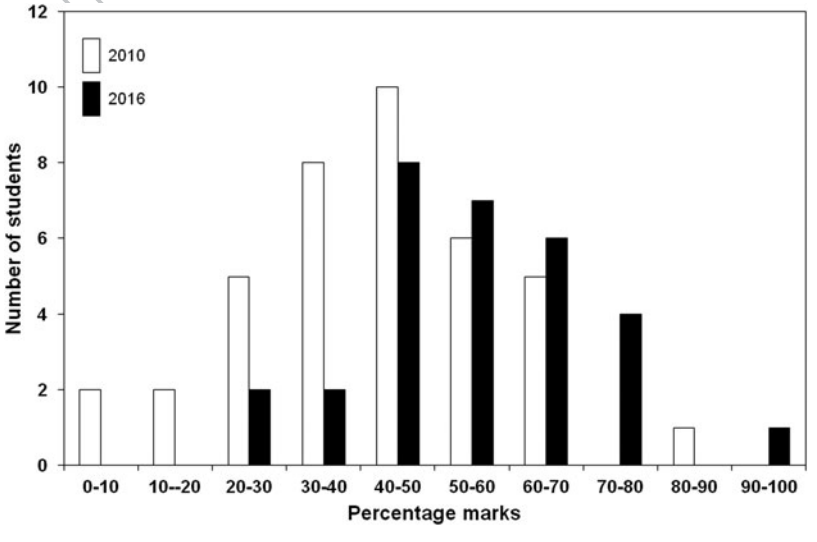

Figure 2. Frequency distribution of student percentages in the end semester exam in 2010 (unfilled bars) and 2016 (filled bars).

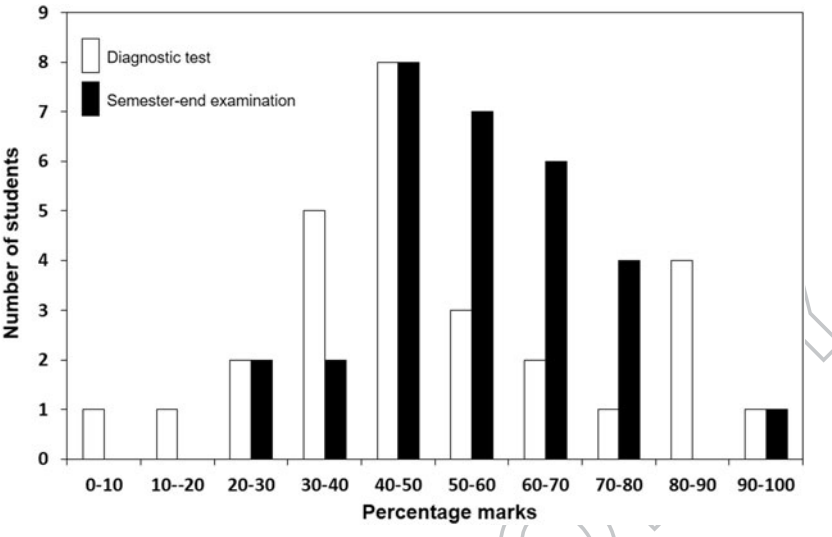

Figure 3. Frequency distribution of 2016 student percentages in the beginning of the course as assessed through a diagnostic test in the first week (unfilled bars) and in the semester-end examination (filled bars).

6.7% of the students earned less than 30% and none earned less than 20%. This shows an improved learning by LLS, and the performance distribution moved to the right.

To consider the improvement in the same year, the 2016 performances in the final examination and the diagnostic test are compared in Figure 3. The figure shows that about 14.3% of the students earned less than 30% in the diagnostic test, whereas only 6.7% of the students earned less than 30% in the final examination – about a 2-fold reduction.

Furthermore, the overall aim of this work as mentioned in Section 1 was to improve the learning level of the 'average student' in class and to reduce the spread of the distribution in the learning extents of students in the class. The performance in the end semester exam, an indicator of the learning extent (Figure 3), shows that the mean value of the distribution increased from 48.5 in the diagnostic test to 55.9 in the end semester exam. More significantly, the standard deviation of the distribution reduced from 25.7 in the diagnostic test to 14.7 in the end semester examination, a 42.8% reduction.

Moreover, the strategies to improve LLS learning seemed to be effective in unexpected ways. It was surprising that with the encouragement during informal one-to-one meetings outside the class about 30% of the LLS did reasonably well and earned more than 50% in the demanding CFA exercise. The highest earned by a LLS in the CFA exercise thus far has been 79%.

In addition to improved LLS learning, the discussed strategies could lead to better retention of students in the programme. After completing the undergraduate programme, it may be best for the LLS to choose careers that match their strengths. With the above methods of proactive advising (Varney 2013) combined with due consideration to the human elements (kindness, empathy, understanding, etc.), the process of graduation can be made less traumatic for LLS, especially when it is too late to drop out of the programme. 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 (Morgan 2014) 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 LLS and providing suitable opportunities to the average and HLS to improve their learning would increase the possibility of students associating positive feelings toward their alma mater.

5. Conclusions

It is possible to address the challenge posed by the distribution of student learning abilities in a class and simultaneously improve the learning of students including those with HLS and LLS. Student input showed that the CFA exercise had a significant impact, both in the short term and in the long term. The reasons for students who were selected through a competitive selection process to turn into those with LLS were better understood. Strategies to unobtrusively identify and communicate with the students with LLS were effective in moving the distribution of marks in the semester-end examination, especially at the lower end, to the higher side.

Acknowledgements

The author thanks Professor K. P. Madhavan for his insightful input to improve the manuscript and Professor Nandita Madhavan for her input. The author also acknowledges the input received from his colleagues, Professors Karthik Raman, Sanjib Senapati, and Smita Srivastava.

Disclosure statement

AQ10 No potential conflict of interest was reported by the author.

Notes on contributor

G. K. Suraishkumar received his B.Tech. in Chemical Engineering from IIT Madras, Chennai, India, and his Ph.D. from Drexel University, Philadelphia, U.S.A. He has contributed methods through journal publications 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 has developed videos, NPTEL online video courses, and MOOCs. He and his research group have contributed to 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 the first formal Department Head of each.

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References

Anderson, L. W., and D. R. Krathwohl. 2001. *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. New York: Addison Wesley Longman.

Auyang, S. 2006. *Engineering – An Endless Frontier*. Cambridge: Harvard University Press.

Bailey, T. R., K. L. Hughes, and M. M. Karp. 2003. *Dual Enrolment Programs: Easing Transitions from High School to College (CCRC Brief)*. New York: Community College Research Center.

Balduf, M. 2009. "Underachievement Among College Students." *Journal of Advanced Academics* 20: 274–294.

Bandura, A. 1989. "Human Agency in Social Cognitive Theory." *American Psychologist* 44: 1175–1184.

Bandura, A. 1997. *Self-efficacy: The Exercise of Control*. New York: W.H. Freeman.

Baslanti, U. 2008. "Investigating the Underachievement of University Students in Turkey: Exploring Subscales." *International Journal of Progressive Education* 4: 40–56.

Benny, N., and R. Blonder. 2016. "Factors that Promote/Inhibit Teaching Gifted Students in a Regular Class: Results from a Professional Development Program for Chemistry Teachers." *Education Research International* 2016: 11. doi:10.1155/2016/2742905.

Berube, B. N., ed. 1995. *What Educators Need to Know About Underachievement and Gifted Students (Practitioners' Guide A9712)*. Storrs: University of Connecticut, National Research Center for the Gifted and Talented.

Bloom, B. S., M. D. Engelhart, E. J. Furst, W. H. Hill, and D. R. Krathwohl. 1956. *Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook I: Cognitive Domain*. New York: David McKay.

Bonner, S. 1999. "Choosing Teaching Methods Based on Learning Objectives: An Integrative Framework." *Issues in Accounting Education* 14: 11–39.

Bradforth, S. E., E. R. Miller, W. R. Dichtel, A. K. Leibovich, A. L. Feig, J. D. Martin, K. S. Bjorkman, Z. D. Schultz, and T. L. Smith. 2015. "Improve Undergraduate Science Education." *Nature* 523: 282–284.

Braxton, J. M., W. R. Doyle, H. V. Hartley III, A. S. Hirschy, W. A. Jones, and M. K. McClendon. 2014. *Rethinking College Student Retention*. San Francisco, CA: Jossey-Bass.

Bullard, L. G., and R. M. Felder. 2007. "A Student-centered Approach to Teach Material and Energy Balances. 1. Course Design." *Chemical Engineering Education* 41: 93–100.

Chou, P. 2012. "Effect of Students' Self-directed Learning Abilities on Online Learning Outcomes: Two Exploratory Experiments in Electronic Engineering." *International Journal of Humanities and Social Sciences* 2: 172–179.

Donaldson, P., L. McKinney, M. Lee, and D. Pino. 2016. "First-year Community College Students' Perceptions of and Attitudes Toward Intrusive Academic Advising." *NACADA Journal* 36: 30–42.

Earl, W. R. 1988. "Intrusive Advising of Freshmen in Academic Difficulty." *NACADA Journal* 8: 27–33.

Felder, R. 2002. "Designing Tests to Maximise Learning." *Journal of Professional Issues in Engineering Education and Practice* 128: 1–3.

Felder, R. M., and R. Brent. 2005. "Understanding Student Differences." *Journal of Engineering Education* 94: 57–72.

Felder, R. M., and R. Brent. 2007. "Co-operative Learning." In *Active Learning: Models from the Analytical Sciences*, edited by P. A. Mabrouk, ACS Symposium Series 970, 34–53. Washington, DC: American Chemical Society.

Felder, R. M., D. R. Woods, J. E. Stice, and A. Rugarcia. 2000. "The Future of Engineering Education. II. Teaching Methods that Work." *Chemical Engineering Education* 34: 26–39.

Feldhusen, J. F. 1986. "A Conception of Giftedness." In *Identifying and Nurturing the Gifted: An International Perspective*, edited by K. A. Heller and J. F. Feldhusen. Toronto: Hans Huber.

Fong, C. J., and J. M. Krause. 2014. "Lost Confidence and Potential: A Mixed Methods Study of Underachieving College Students' Sources of Self-efficacy." *Social Psychology of Education* 17: 249–268.

Freeman, J. 2003. "Scientific Thinking in Gifted Children." In *Science Education: Talent Recruitment and Public Understanding*, Vol. 38 of NATO Science Series, 17–30. New York: IOS Press.

Fricker, T. 2015. "The Relationship Between Academic Advising and Student Success in Canadian Colleges: A Review of the Literature." *College Quarterly* 18: 1–15.

Gagné, F. 2004. "Transforming Gifts into Talents: The DMGT as a Developmental Theory." *High Ability Studies* 15: 119–147.

Gardner, H. 1993. *Multiple Intelligences: The Theory in Practice*. New York: Basic Books.

Glennen, R. E., and D. M. Baxley. 1985. "Reduction of Attrition Through Intrusive Advising." *NASPA Journal* 22: 10–14.

Hsieh, P., J. R. Sullivan, and N. S. Guerra. 2007. "A Closer Look at College Students: Self-efficacy and Goal Orientation." *Journal of Advanced Academics* 18: 454–476.

Johnsen, S. K. 2004. "Definitions, Models, and Characteristics of Gifted Students." In *Identifying Gifted Students: A Practical Guide*, 1–22. Waco: Prufrock Press.

Kovas, Y., C. M. A. Haworth, P. S. Dale, and R. Plomin. 2007. "The Genetic and Environmental Origins of Learning Abilities and Disabilities in the Early School Years." *Monographs of the Society for Research in Child Development* 72: vii–160.

Kovas, Y., and R. Plomin. 2007. "Learning Abilities and Disabilities." *Current Directions in Psychological Science* 16: 284–288.

Lowenstein, M. 1999. "An Alternative to the Developmental Theory of Advising." *The Mentor*. Accessed February 21, 2017. http://dus.psu.edu/mentor/old/articles/991122ml.htm.

Lyman, F. 1987. "Think-Pair-Share: An Expanding Teaching Technique." *MAA-CIE Cooperative News* 1: 1–2.

McCall, R. B., S. R. Beach, and S. Lau. 2000. "The Nature and Correlates of Underachievement Among Elementary Schoolchildren in Hong Kong." *Child Development* 71: 785–801.

McCoach, D. B., and D. Siegle. 2003. "Factors that Differentiate Underachieving Gifted Students from High-achieving Gifted Students." *Gifted Child Quarterly* 47: 144–154.

McDonald, M. 2002. *Systematic Assessment of Learning Outcomes: Developing Multiple-choice Exams*. London: Jones and Bartlett.

Mintz, S. 2015. "Competency-based Education 2.0." Accessed April 10, 2016. https://www.insidehighered.com/blogs/higher-ed-beta/competency-based-education-20.

Misra, A. 2015. "Report of the Committee to Examine the JEE System." Accessed February 21, 2017. https://www.iitsystem.ac.in/Media-uploads/f4a3dc378b6c47b433a7184d3b5.pdf.

Morgan, R. B. 2014. "Factors that Lead Millennial Alumni to Contribute to their Alma Mater." Dissertations, Paper 839.

Murray, W. I., and I. Bloom. 1960. "Characteristics of Slow Learners and Pupils of Normal Intelligence Referred to a Child Guidance Clinic." *Journal of Education Research* 54: 43–48.

Mysorekar, V. V. 2012. "Need for Mentorship to Improve Learning in Low Performers." *National Medical Journal of India* 25: 292–293.

Neber, H., and M. Schommer-Aikins. 2002. "Self-regulated Science Learning with Highly Gifted Students: The Role of Cognitive, Motivational, Epistemological, and Environmental Variables." *High Ability Studies* 13: 59–74. doi:10.1080/13598130220132316.

Padmavathy, K. M., S. Patil, and S. P. Pani. 2009. "Unravelling the Secrets of High Performance to Help Low Performers." *South East Asian Journal of Medical Education* 3: 65–66.

Paris, S. G., and A. H. Paris. 2001. "Classroom Applications of Research on Self-regulated Learning." *Educational Psychologist* 36: 89–101. doi:10.1207/S15326985EP3602_4.
Plomin, R., C. M. A. Haworth, and O. S. P. Davis. 2010. "Genetics of Learning Abilities and Disabilities: Recent Developments from the UK and Possible Directions for Research in China." *Behavior Genetics* 40: 297–305.
Reis, S. M., and D. B. McCoach. 2000. "The Underachievement of Gifted Students: What Do We Know and Where Do We Go?" *Gifted Child Quarterly* 44: 152–170.
Schraw, G., K. J. Crippen, and K. Hartley. 2006. "Promoting Self-regulation in Science Education: Metacognition as Part of a Broader Perspective on Learning." *Research in Science Education* 36: 111–139.
Schultz, R. A. 2002. "Illuminating Realities: A Phenomenological View from Two Underachieving Gifted Learners." *Roeper Review* 24: 203–212.
Sureshkumar, G. K. 2001. "A Choose-Focus-Analyze Exercise in ChE Undergraduate Courses." *Chemical Engineering Education* 35: 80–84.
Thambayah, A. 2011. "On the Design of Learning Outcomes for Undergraduate Engineer's Final Year Project." *European Journal of Engineering Education* 36: 35–46.
Thomas, G. I. 1966. *Extended School Year Designs: An Introduction to New Plans of School Organization Which Can Result in Financial Economies and Provide More Education for All Pupils*. New York: University of the State of New York.
Van Tassel-Baska, J. 2003. "Selecting Instructional Strategies for Gifted Learners." *Focus on Exceptional Children* 36: 1–12.
Varney, J. 2013. "Proactive Advising." In *Academic Advising Approaches: Strategies that Teach Students to Make the Most of College*, edited by J. K. Drake, P. Jordan, and M. A. Miller, 137–154. Manhattan: NACADA: The Global Community for Academic Advising.
Waldrop, M. M. 2015. "The Science of Teaching Science." *Nature* 523: 272–274.
Wankat, P. C. 2013. "Challenge Problems." *Chemical Engineering Education* 47: inside cover.
Wankat, P. C., and F. S. Oreovicz. 2015. *Teaching Engineering*. 2nd ed. Purdue: Purdue University Press.
Weiss, R. M., and G. Rasmussen. 1960. "Grading Practices in Undergraduate Education Courses: Are the Standards Too Low?" *The Journal of Higher Education* 31: 143–149.
Zimmerman, B. J. 2000. "Attainment of Self-regulation: A Social Cognitive Perspective." In *Handbook of Self-regulation*, edited by M. Boekaerts, P. R. Pintrich, and M. Zeidner, 13–39. San Diego, CA: Academic Press.
Zimmerman, B. J. 2002. "Becoming a Self-regulated Learner: An Overview." *Theory into Practice* 41: 64–70. doi:10.1207/s15430421tip4102_2.
Zimmerman, B. J., and R. Risemberg. 1997. "Self-regulatory Dimensions of Academic Learning and Motivation." In *Handbook of Academic Learning: Construction of Knowledge*, edited by G. D. Phye. San Diego: Academic Press.

Appendix A1: Sample diagnostic test

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

- Communicate your approach (carries significant weightage) and assumptions clearly.
- 8th August 2016; duration: 50 min Max. marks: 100

1. Many students in hostels use liquid mosquito repellents. A normal refill containing 35 ml of the repellent lasts for 45 nights (12 hours a night). Supposing a student switches it on at 19:00 hrs, what will be the concentration of the repellent in the room at 7:00 hrs the next morning. Dimensions of the room are $1.5 \times 2 \times 3$ m^3. Assume that the windows and doors are shut and the ceiling fan acts as a stirrer to maintain a uniform distribution of repellent in the room. [Marks: 30]

2. 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 $\dot{l} = k_L a(C^*_{O_2} - C_{O_2})\, V$ 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: 30]

3. A chemostat (continuous stirred tank bioreactor) is sometimes used in the bioindustry to produce bioproducts. The feed (inlet) stream consists of nutrients for the cells to grow and the outlet stream consists of cells, products and unreacted nutrients. The difference in densities of the input and output streams can be considered negligible. The concentrations of substances in the outlet stream are the same as those inside the bioreactor, at steady-state.

The cells produced are a major interest, because cells are the actual factories producing the product – higher the cell concentrations reached, better the product produced, usually. The rate of cell formation, r, can be given by a first-

order expression, $r = \mu x$, where μ is the specific growth rate (with units of time^{-1}) and x, the cell concentration (mass of cells per unit volume) at any time.

The volume of the chemostat is V and there are usually no cells present in the feed stream (sterile feed). The dilution rate, D, is defined as the ratio of volumetric flow rate at the inlet to the volume of the bioreactor. What is the relationship between the specific growth rate and the dilution rate, when the chemostat is operating at steady-state? [Marks: 40]

Do your Best. Good luck.

Appendix A2: Sample final examination

Indian Institute of Technology Madras
Department of Biotechnology
BT 3011 Transport Phenomena in Biological Systems, End-semester exam

- Open-notes (**only** self-notes and pre-approved tables/graphs) exam.
- Communicate your approach (carries significant weightage) and assumptions clearly.
- 15th November 2016; duration: 3 h Max. marks: 100; Weight: 35%

1. A. Succinctly, differentiate between

(i) laminar and turbulent flows in a pipe
(ii) Newtonian fluid and Bingham plastic
(iii) work done in mechanical terms and in electrical terms
(iv) charge conservation and Ohm's law
(v) Newton's law of viscosity and Fourier's law [marks: 6 × 5 = 30]

2. An orifice meter is to be installed in a 10 cm line to measure the water flow rate. The maximum expected flow is 75 m^3 h^{-1}. The manometer used to measure the differential pressure is to be filled with mercury and water is to fill the leads above the surfaces of mercury. If the maximum manometer reading is to be 2 m, what diameter (to the nearest mm) should be specified for the orifice? (b) what will be the power required to operate the meter at full load? [marks: 10]

3. In a certain cell type, the distribution of K^+, Na^+ and Ca^{2+} determine the electrical characteristics of its membrane.

(a) Represent the membrane as a suitable electrical circuit
(b) When there is no net charge transport across the cell membrane, what is the relationship between the intracellular and extracellular concentrations of the above ions?
(c) For this case, derive an expression for the resting potential in terms of the conductances and Nernst potentials of the ions involved. [marks: 5 + 5 + 5 = 15]

4. Show, step-by-step, that the equation

$$\frac{\partial(\rho v_x)}{\partial t} = -\left(\frac{\partial(\rho v_x v_x)}{\partial x} + \frac{\partial(\rho v_y v_x)}{\partial y} + \frac{\partial(\rho v_z v_x)}{\partial z}\right) - \left(\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}\right) - \frac{\partial p}{\partial x} + \rho g_x$$

can be written as

$$\rho \frac{Dv_x}{Dt} = -\left(\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}\right) - \frac{\partial p}{\partial x} + \rho g_x. \quad \text{[marks: 5]}$$

5. The cone-and-plate viscometer consists of a stationary flat plate, upon which is placed a small volume of the liquid to be tested, and an inverted cone, which is lowered into the puddle until its apex just contacts the plate. The cone is rotated at a known angular velocity, Ω, and the viscosity of the fluid is determined by measuring the torque required to turn the cone. The angle between the conical and flat surfaces is small, say about half a degree.

(a) write the components of the equation of motion in spherical coordinates taking the flow to be entirely tangential and the relevant boundary conditions.
(b) if the cone and plate are maintained at different temperatures, T_1 and T_2, respectively with T_2 being higher, set-up the equations to find the steady-state temperature profile in the fluid while the viscosity is being determined. There is no need to solve the equations. [marks: 15 + 10 = 25]

6. In a bio-industry, a shell and tube heat exchanger used to heat process water with condensing steam at atmospheric pressure, consists of Schedule 40 standard steel pipes with 1.58 cm inside diameter, and 0.65 cm wall thickness. Calculate the heat flux at a point in the heat exchanger where the water temperature is 27 °C. The heat transfer co-efficient inside

the pipe is 12 KW (m^2 °C)$^{-1}$, and that of the shell side is 14 KW (m^2 °C)$^{-1}$. The thermal conductivity of steel is 50.2 W (m^2 °C)$^{-1}$. The fouling layer inside the pipe has a conductivity of 0.5% compared to that of the pipe material, and its thickness is about 2% of the pipe thickness. The fouling layer on the shell side has a conductivity of 1% compared to that of the pipe material and its thickness is about 1% of the pipe thickness. [marks: 15]

Do your best. Good luck.