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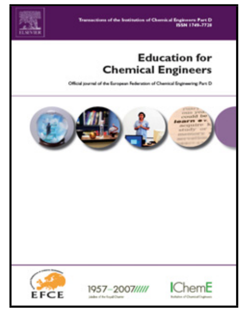

Title: Team-based Learning for First Year Engineering Students

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Team-based Learning for First Year Engineering Students

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Highlights

- Teams outperformed individuals, suggesting an effective team interaction.
- Students' perception of the team-based learning showed increasing trend as the module progressed, perhaps due to their increasing adaption to working in teams.
- The highest scores were observed for the engagement category, showing good team work, mutual respect and contribution as well as high attentiveness.

Abstract

Although it was originally developed for a business school environment to promote the benefits of small-group teaching in a large group setting, the method of the Team-based Learning (TBL) has recently been increasingly used within medical education. On the other hand, the reports on its implementation in engineering and science education are much scarcer. The aim of this work is to discuss the experience, evaluation and lessons learned from the implementation of the TBL within a Year 1 engineering module - Process Engineering Fundamentals, enrolling 115 students, and the TBL method was introduced for the first time.

To evaluate the acquired knowledge and perception of TBL, a students' performance analysis and questionnaire were completed on two occasions. It was observed that the TBL approach improved student learning, enhanced their integration and sharing of knowledge in class, supporting the implementation of this method in engineering disciplines.

Keywords: Teaching Practices, Pedagogical Innovation, Group Work, Active Learning

1. Introduction

The traditional approach of teaching engineering subjects is efficient in presenting a large amount of information to large numbers of students. However, the downside of this approach is that it fosters passive learning where students expect to be told what to learn and how to learn it (Felder, 2012), without developing the skills and enthusiasm for the course. Evidence suggests that, relative to traditionally-taught students, the students who had proceeded through the student-centred methods emerged with more positive attitudes about the quality of their instruction, higher levels of confidence in their engineering problem solving abilities, a greater sense of community among themselves, and perhaps a higher level of employability resulting partly from their extensive experience with team projects (Felder, 1995).

A large body of literature in this area addresses theory, research, practices and faculty development (Prince, 2004; Prince and Felder, 2006). The most commonly published methodologies are cooperative/collaborative learning (Cabrera et al., 2001; Maceiras et al., 2011), problem-based learning – PBL (Hmelo-Silver, 2004; Harris and Briscoe-Andrews, 2008), web-based learning (Chumley-Jones et al., 2002; Brault et al., 2007), team-based learning – TBL (Thompson et al., 2007; Lamm et al., 2014) and enquiry based learning – EBL (Levy and Petrulis, 2012; Glassey et al, 2013). Development of strong teamwork capabilities are highly required by employers in engineering sectors since engineering graduates are increasingly expected to work in team-based product and process design projects (Natishan et al., 2000). The recent study published by Zou and Ko 2012 demonstrated enhanced awareness of teamwork concepts among chemical engineering students through a three-year systematic teamwork development project. Therefore, it is not surprising that in last few decades, various group based learning methodologies have emerged in engineering education as a practical and effective approach. As evidence, undergraduate group design projects were introduced a half century ago in almost all chemical engineering courses in the world, evolving ever since due to the enormous commitment from the chemical process industry in terms of efficiency, environmental impact, safety, sustainability, and flexibility (Pekdemir et al., 2006). On the contrary to this traditional group work, such as design projects, which typically produce a paper and/or presentation, groups in TBL, PBL and EBL are more structured and actually do their group work during class time.

From all above mentioned learning methods, PBL is the most used alternative strategy within engineering education. Developed in medical education in the late 1960s, problem-based learning was a major breakthrough in curriculum reform (Frenk et al. 2010), causing many schools to adopt an alternative to then dominant teacher-centred approach. It has been described as ‘reflecting the way people learn in real life’ (Biggs and Tang 2007). PBL presents a spectrum of various different practices, but in general follows the following sequence: 1) Group analyses a given problem; 2) Group brainstorms possible solutions and hypotheses and then decides what further information is needed to solve the problem; 3) Independent study by each member of group; and, 4) Group shares gathered information and tests previous hypotheses in light of the new information. PBL delivery involves the supervision of each group by one tutor. A number of publications suggests that problem-based learning has several clear advantages over the more traditional delivery techniques, such as increased retention of information, an integrated knowledge base, the development of lifelong learning skills, an exposure to real-life experience at an earlier stage in the curriculum, increased student-faculty interactions, and an increase in overall motivation (Klegeris and Hurren, 2011). The main disadvantage of PBL lays in the fact that each group of six to ten students is supervised by one tutor, impeding its effective implementation in large classes such as first-year introductory modules with typically more than one hundred students.

Another pedagogical approach, Team-Based Learning (TBL) was firstly introduced in the literature in 1982 as a way to promote the benefits of small-group teaching in a large group setting, considerably enhancing students' engagement and their knowledge retention (Michaelsen et al., 1982). TBL is promoted as a special pedagogical approach comprising four elements for implementation (Michaelsen et al., 2004): i) strategically forming permanent teams of 5-7 members (to guarantee sufficient intellectual resources), ii) Readiness Assurance Process (pre-class individual assignment, e.g. readings, followed by in-class Individual Readiness Assurance Test, iRAT, and Team Readiness Assurance Test, tRAT), 3) developing students' critical thinking skills by using carefully-designed, in-class activities and assignments; and, 4) creating and administering a peer assessment and feedback system.

In contrast to PBL which covers many different practices, TBL is a well-defined set of practices and principles with only few variations. In TBL, one tutor simultaneously facilitates many small teams of 5-7 members, typically 20 or more. Usually material to be covered is organized into a few major units and for each of them the sequence of activities is implemented as shown in Figure 1. In the first phase, students are given pre-class individual assignments (*e.g.* readings) that are designed to familiarize students with the key concepts of that unit. Based on this preparation, in the next phase students are expected to take an Individual Readiness Assurance Test (iRAT), guaranteeing their preparation. After, students re-take the exact same Readiness Assurance Test as a team (tRAT) by coming to consensus on their answers. The role of tRAT is two-fold: 1) mutual transfer of knowledge between teammates; and, 2) motivation through competition with other teams. In the next phase, students receive real-time feedback from the instructor with clarification of concepts related to the test questions that students struggled with. The instructor can also provide feedback (*e.g.* mini-lecture) which is usually short and always very specific in corrections of any misperception. In the final stage, the team application assignments are designed for students to put course content to use by working in teams on progressively more difficult questions. It is essential to carefully design these application assignments in order to achieve the higher Bloom's levels of learning (abilities to analyse, evaluate and create) according to the so-called '4S' strategy coined by Michaelsen et al., 2008:

1) Significant problem – The application exercise should be meaningful and complex enough to motivate student to generate fruitful discussions within teams.

2) Same problem – All teams should work on the exact same problem which allows teams to compare their answers with answers of other teams. In this way, teams get more curious, assuring that students pay more attention, resulting in enhanced engagement. Mock

3) Specific choice – Although open-ended questions can lead to lively discussions, the application exercises should be designed as a specific choice questions, such as multiple-choice, calculating a parameter, creating a list, ordering items, organizing into categories, etc. Asking students to make a collaborative decision giving a specific answer simulates a read world situation in professional environment. In this way, teams learn to justify, elaborate, defend and argue for their chosen decision.

4) Simultaneous reporting – Teams should report their answers simultaneously in order to encourage accountability and prevent answer drift.

The last essential element of the team-based learning is peer-to-peer assessment, aiming to hold individuals accountable to their teams and to lessen the likelihood of social loafing. Three peer evaluation methods have been reported (Michaelsen et al., 2008) for team based learning: the Michaelsen method which forces students to differentiate among the performance of team members; the Fink method, in which students are given 100 points to divide among team members resulting in a multiplier that is used to adjust the overall course grade for a particular student; and the Koles method which incorporates both quantitative and qualitative section. Farland et al., 2013 discussed the best practices and challenges with peer evaluation.

Recently, Dolmans et al. 2015 examined similarities and differences between problem-based and team-based learning, concluding that the similarities between PBL and TBL are small group learning. On the other hand, two main differences were observed: 1) one instructor supports multiple self-managed teams in TBL, whereas each small group in PBL is facilitated by one instructor; and, 2) Mandatory pre-reading assignments in TBL with testing versus students identifying issues for self-study in PBL.

Although it was originally developed as a teaching method suitable for a business school environment, team-based learning has attracted the interest of educators from various disciplines. This growing attention for the implementation of TBL is represented by the yearly increase in the number of related publications (Figure 2): starting from two publications in 2000 to eighty papers published in 2015, while the number of publications per year doubled in the period 2011-2015. It is also interesting to note that TBL was mostly implemented in the United State of America which is demonstrated also by the number of publications per country (Figure 3). Again, Web of Science data show that more than 75% of all the published work is from the USA, followed by Canada (6.2%), Austria (5.9%) and United Kingdom (4.5%).

The number of students in science and engineering fields is growing faster than in other fields. Since 2009, science and engineering degrees have increased by 19% in the US, slightly more than double the 9% growth rate for the other fields (DeWitt and Maciejewski, 2013). A similar trend is observed in the UK: while the enrolments on engineering courses at the beginning of the 2000s were relatively static, by 2006–2007 an upturn was evident, with an increase of approximately 23% (AUCC 2011). Just in the last year, the Engineering Department at Lancaster University (UK) experienced more than 50% growth in the number of undergraduate students. This phenomenon is usually not accompanied by the increases in institutional and teaching resources, thus challenging student-teacher relationships as well as the way of teaching and learning.

Reports on the implementation of TBL in engineering education are still scarce, despite its potential to be used as an effective instructional strategy for teaching problem-solving skills in large class formats. Furthermore, working in teams is an essential skill for undergraduate engineers. Thus, Van der Loos et al. 2009 reported about the TBL approach in design elements module, evidencing increased in-class discussion, peer-learning and attendance, as well as an improved course effectiveness based on student evaluation. The same group described an enhancement in the students' perception of the mechanical module and student performance on exams (Ostafichuk et al. 2012). Also, Price et al. 2010 from Monash University carefully engineered team-based learning exercises to develop team work, collaboration, lateral thinking and problem solving as well as, the often necessary, conflict resolution.

Thus, the aim of this work is to discuss the experience, evaluation and lessons learned from the implementation of Team-Based Learning (TBL), within a new Year 1 engineering module in the Engineering Department at Lancaster University, called Process Engineering Fundamentals. The Engineering Department has a common first year structure for all engineering students (chemical, mechanical, sustainable, nuclear and electronic engineering). The module covers process variables, material balance for processes without and with chemical reaction as well as single and multi-phase systems. The module enrolled 115 students and consisted of three one-hour lectures each week in an amphitheatre and one 2-hour practical session in a computer room (for five weeks).

2. Methodology

The team-based learning (TBL) was implemented within the Process Engineering Fundamentals (ENGR160), a Year 1 module required for all the engineering students (courses: chemical, nuclear, mechanical, sustainable, general, mechatronics and electrical engineering). The module was delivered for the first time at the Engineering Department of Lancaster University, during 2014-2015, enrolling 115 students. Team-based learning strategy was implemented according to Michaelsen et al. 2008 and Lamm et al. 2014 with some modifications.

The module comprised three 50-minute lectures each week in an amphitheatre and one 2-hour practical session in computer room (for five weeks).

2.1. Procedure

Students were divided into 18 groups: 11 groups of 6 students and 7 groups of 7 students. The module was divided in three units, giving approximately four lecture sessions per unit. As shown in Figure 1, before each unit, students were asked to individually study the reading material which was accessible via Moodle, a virtual learning online platform. At the first session of each unit, students individually took a Readiness Assurance Test (iRAT) to guarantee their preparation. The iRAT was designed as a multiple choice test, aiming to confirm that a student understood the main aspects of the material and is fully prepared to apply this to solve problems in a team group. The duration of iRAT was 20 minutes and it counted towards the final module mark. The next 20 minutes of a session were used to take the same test again as a team, the so-called Team Readiness Assurance Test (tRAT). The test answers were provided immediately afterwards and tailored feedback on the most difficult points given as a mini-lecture

For each unit, students spent the majority of time solving application exercise which were designed according to the '4S' strategy using backwards design (Wiggins and McTighe 1998) as shown in Figure 4. In the first stage, intended outcomes of a unit should be established according to the learning outcomes for the module. In the given example, students should be able to apply knowledge on stoichiometry and material balances on multistage processes involving chemical reactions, separations and recycling. In the next stage, the team application exercise is created in such a way to assess the established learning outcomes using the 4S strategy. The given application exercise involves material balance calculations for the process composed of chemical reaction (parallel – desired and undesired reactions), separation unit and recycling system, laying the foundation for subsequent modules – unit operations, thermodynamics, reactor design and kinetics. Furthermore, it is difficult to divide tasks for individuals within the team which would cease fruitful discussions important for deep learning. Students are requested to make a specific choice by calculating various flow rates as shown in Figure 5. Depending of the application exercise, students were allowed 10 to 25 minutes to complete calculations which were followed by simultaneous answering using placards.

2.2 Assessment

Assessment was performed according to the Department's rules as presented in Table 1: Exam 60%; average of three individual readiness assurance tests $\langle \text{iRAT} \rangle$ 20%; average of three team readiness assurance tests $\langle \text{tRAT} \rangle$ 10%; and average application exercises $\langle \text{APP} \rangle$ 10%. Each team obtained a mark for the tRAT and the APP which were further used to calculate a corresponding marks for each individual member ($\langle \mathrm{tRAT} \rangle_{\mathrm{individual}}$ and $\langle \mathrm{APP} \rangle_{\mathrm{individual}}$) , according to:

$$\langle \mathrm{tRAT} \rangle_{\mathrm{individual}} = \langle \mathrm{tRAT} \rangle_{\mathrm{team}} \times (\text{Peer evaluation factor}) \quad (1)$$

$$\langle \mathrm{APP} \rangle_{\mathrm{individual}} = \langle \mathrm{APP} \rangle_{\mathrm{team}} \times (\text{Peer evaluation factor}) \quad (2)$$

The peer evaluation factor was obtained by peer-to-peer assessment using the so-called Fink method (Michaelsen, Knight and Fink 2004). At the end of the module, all the team members were asked to assess the contributions that each member of the group made to the work of the group as a whole, taking into account the level of preparation, contribution, flexibility and respect for others. Each student distributed 100 points among other team members. All the members of the team got the "peer evaluation factor", which is the sum of the points they were granted from each teammate, divided by 100. The "peer evaluation factor" is used as presented in equations (1) and (2) to adjust individual scores. An example of the peer-to-peer assessment is shown in Table 2 for a team composed of eight members. Each of team members distributed 100 points among others. In the given example, Student 1 distributed equal number of points, Student 2 gave 10 points to Student 1 and 15 points to others, Student 6 penalized Student 1 with no points, distributed 10 points to Students 3 and 4 and 20 points to others, etc. The awarded points for each member were summed and divided by 100, resulting in the peer evaluation factor, which for the given example ranged from 0.55 to 1.27 for Students 1 and 2, respectively. These were used to calculate the individual marks $\langle \mathrm{tRAT} \rangle_{\mathrm{individual}}$ and $\langle \mathrm{APP} \rangle_{\mathrm{individual}}$ given by equations (1) and (2). As an example, the team gained 75% for tRAT and 60% for APP. Thus, the highest ranked Student 1 was awarded 95.3% and 76.2% for tRAT and APP, respectively. On the other hand, the student that was awarded the lowest score (Student 2) got 41.3% and 33% for tRAT and APP, respectively. It can be concluded that there is a clear distinction in students' contributions which is reflected in their individual scores, enhancing accountability and avoiding problems associated with social loafing. Therefore, peer assessment is an incentive for students to prepare for and participate in the group work (Cestone et al., 2008), assuring accountability which is vital to the TBL. Also, students may appreciate peer review process in order to avoid additional load by having to carry their group members. Although several studies have demonstrated positive correlations regarding peer evaluation, its drawbacks include fostering distrust and high competitiveness (Levine, 2008). The process may also reduce student motivation to participate unless its rules and purpose are clearly communicated and aligned with students' expectations (Chen and Lou, 2004).

2.3. Students' performance analysis

An analysis of the results of the readiness assurance tests (RATs) and exam were performed in order to evaluate the acquired knowledge. Unfortunately, the ENGR160 is a new module at the Department, and therefore, the comparative analysis with the similar results of the previous years was not possible but the comparison with other first year modules demonstrates similar exam scores.

2.4 Student Perception

A questionnaire comprising 18 statements related to TBL was adapted from the literature (Vasan et al., 2009) with slight modification, as presented in Table 3. Students were asked to anonymously respond twice: after the second week and at the end of the module. On two occasions, the students rated the statements using Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). In addition, two open-ended questions on positive and negative aspects of their experiences with TBL were included. The 18 questions were divided into four categories: i) Perception of TBL (statements 1, 8, 10 and 17); ii) Significance of group work (statements 9, 11 and 12); iii) Readiness Assurance Process (statements 2, 3, 4, 5, 6, and 7); and, iv) Engagement (statements 13, 14, 15, 16 and 18).

Sixty students (53%) and eighty six students (76%) responded to the questionnaire after the second week and at the end of the module, respectively.

3. Results and Discussion

Although it was not possible to compare students' performance with the similar results of the previous years, test and exam scores suggested that the student´s understanding of the material in the module was at least as good as in the similar Year 1 modules. Analysis of the readiness assurance tests presented in Table 4 indicated that the average team scores were above the average individual scores. In fact, teams outperformed individuals usually by 12%, thus suggesting effective team interactions. This is in line with the results reported by Wiener et al., 2009 for Year 1 medical students which showed that teams outperformed individuals by 16.5% higher score. Similar observation was reported by Michaelsen et al. 2004 for business students with increase of nearly 11%.

Figure 6 illustrates the difference between the highest individual member score and the team score. For the total of 18 teams, 12 teams had negative values, indicating that 67% of the teams had higher scores then their best individual team member. These results differ when compared with results reported by Michaelsen et al. 2004 showing that over 99 % percent of the TBL teams have outperformed their own best concluded by observation of nearly 1,600 teams over 20 years. In another study (Michaelsen et al., 1989) involving 222 teams, 97% of the teams outperformed their most proficient group member. This discrepancy is probably due to the fact that this study involves far smaller number of teams.

The average score of the exam was and (58.6 ± 24.4)%, respectively. As presented in Figure 7, the highest percentage of the students obtained test scores between 41-60%, which was shifted to 61-80% range for the exam scores.

Detailed results for each statement are given in Table 2 on two occasions. Out of 115 students, 60 (52%) and 86 (75%) responded to the questionnaire after the second week and at the end of the module, respectively. Average scores for each question in different categories are presented in Figure 8.

The comparison of the average scores for the statements in the Perception on the TBL category (Fig. 8 (A)) suggests that students' attitudes were reasonably good. With regard to how attitudes changed within a period of few weeks, average score increases were observed on "I learn better from TBL than from lectures" and on "I learned useful additional information during TBL sessions". After two weeks 50% of the students strongly disagreed or disagreed with the statement that they learned better from TBL then from traditional lectures. However, this percentage dropped to 38% after five weeks. An even bigger shift, from 44% to 18% of students who strongly disagreed or disagreed, was observed for Q10. It is possible that students' perception of the TBL increased due their adaption to working in teams. But, these results may also suggest that the way TBL is introduced and presented during the first session is of crucial importance as well.

The significance of group work category scored considerably more positive as it can be observed from Fig. 8 (B). They range from the average score of 3.8 for Q9, corresponding to 72% of the students who agreed or strongly agreed that solving problems in group is an effective way, to the average of 4.6 for Q12, corresponding to 98% of students who agreed or strongly agreed that the ability to work in a team is necessary to be successful as an engineer. No statistically significant changes were noted for students' attitudes about the significance of group work in two questionnaires. These positive results on the significance of group work might be due to students' awareness of the importance of professional development in terms of cooperative skills.

The scores on the Readiness Assurance process are presented in Figure 8 (C). In terms of pre-session reading, the overall average scores modestly increased. After two weeks, the average score increased by 0.4 points, corresponding to the shift from 43% to 27% of the students who strongly disagreed or disagreed. After a two-week period, 57% of the students strongly agreed or agreed that iRAT were useful learning activities (Q4), which decreased to 43% at the end of the module. On the other hand, over time, the students felt more prepared for iRATs (Q5). A high percentage of the students agreed or strongly agreed that tRATs activities allowed them to improve understandings (Q6) and were useful learning activities (Q7).

The "agree" responses dominated the Engagement category (Figure 8 (D)). No statistically significant changes along time were noted for the statements Q13 (My team worked well together), Q14 (I contributed meaningfully to the TBL discussions) and Q18 (There was mutual respect for other teammates' viewpoints). The decrease of 0.3 points was observed for the statement Q15 (Most students were attentive during TBL sessions). More detailed analysis reveals that the decline from 61% to 41% for the students who strongly agreed or agreed was reflected in the increase of "neutral" responses but no change was observed for the "disagree" responses. On the other hand, the increase of percentage of students who strongly agreed or agreed from 55% to 70% was observed for the statement Q16 (I paid attention most of the time during the TBL sessions).

The average score for all questions in the end of module was 3.50 out of 5 which is comparable with average score of 3.14 out of 5 for alike first year module calculated from the report by Wang and Mott, 2015.

Approximately, 69% and 55% students responded to two open-ended questions ("what did you like most' and 'suggestions for improvement") after two weeks and at the end of module questionnaires, respectively. Most of the positive responses involved comments on benefits of working in teams, knowledge sharing, engagement and deep learning. Many students enjoyed team discussions and chance to get to know their colleagues better. They valued the opportunity to learn about how other people solve problems and a chance that someone else in a group knows and can teach them. The TBL method "forced" many students to read the material and learn and that was much more engaging than only following lectures.

The most disliked was the pre-session reading, and some students would prefer to have a lecture and then applications in a team. Some students stated that they were against working in groups as they felt forced and would prefer to work and learn at their own pace. Many students pointed out the problems associated with participation: some people are not involved in the group discussion or do not concentrate.

Conclusions

There is a growing interest in the implementation of the team-based learning which is demonstrated by the increasing number of publications in the recent years, covering mainly medicine, health and life science disciplines. This study reports on the benefits of the team-based learning implemented for the first time within the -Year 1 engineering module at the Engineering Department of Lancaster University. Analysis of the readiness assurance tests showed that the teams outperformed individuals by an average of 12%, suggesting an effective team interaction. Students' perception of TBL showed scores from 2.6 to 3.4 of 5 increasing as the module progressed, perhaps due to their increasing adaption to working in teams. The significance of the group work category scored considerably more positive, ranging from 3.7 to 4.6 of 5, suggesting students' awareness of the importance of professional development in terms of cooperative skills. In respect to the effectiveness of the readiness assurance process, less than 20% of the students strongly disagreed or disagreed that the tests were useful learning activities. The highest scores were observed for the engagement category, showing good team work, mutual respect and contribution as well as high attentiveness.

Limitations of this work include the ability to generalize results since this study took place at a single university and in one module. Nevertheless, this experience and evaluation demonstrate potential benefits of TBL in a first year engineering module.

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Caption to Figures

Figure 1. Team-based learning procedure.

Figure 2. Number of publications on team-based learning from 2000 to 2015 (*Web of Science*^{TM} July 2016). Search word: "team-based learning" as topic for each year.

Figure 3. Number of publications on team-based learning for different countries from 2000 to 2015 (*Web of Science*^{TM} July 2016). Search word: "team-based learning" as topic for each country.

Figure 4. Example of backward design for TBL unit.

Figure 5. Example of answer sheet.

Figure 6. The difference between the highest member score and the team score.

Figure 7. Exam scores.

Figure 8. Average score for the statements in different categories: (A) – Perception on the TBL; (B) Significance of group work; (C) Readiness Assurance Process; and, (D) Engagement. Offered scores were strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5).

Figure 1

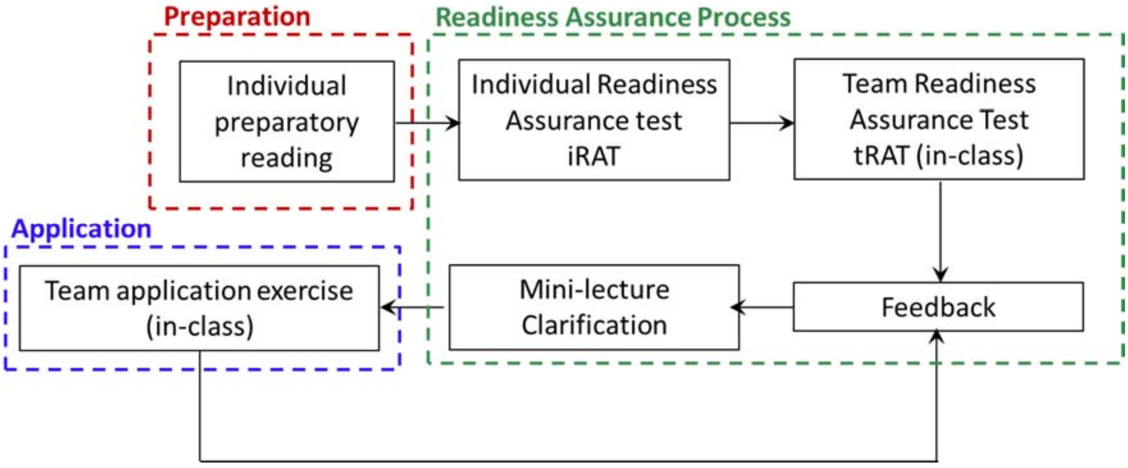
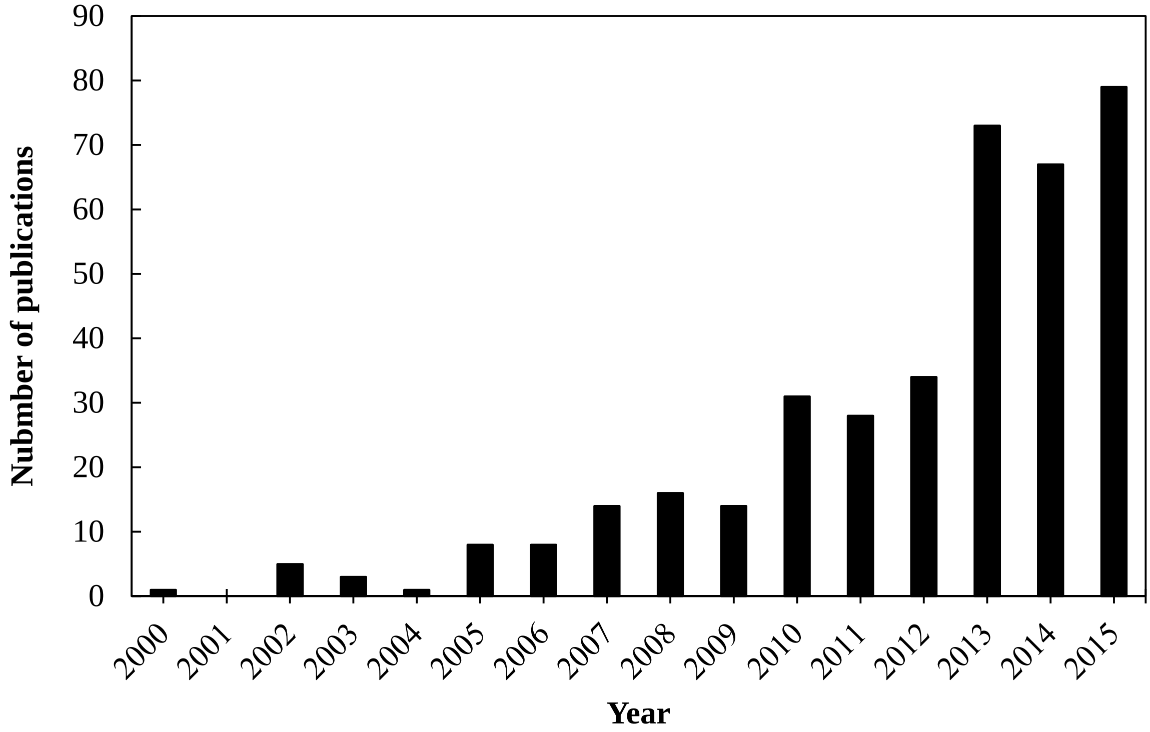

Preparation
Readiness Assurance Process
Individual preparatory reading
Individual Readiness Assurance test iRAT
Team Readiness Assurance Test tRAT (in-class)
Application
Team application exercise (in-class)
Mini-lecture Clarification
Feedback

Figure 2



90
80
70
60
50
40
30
20
10
0
Nubmber of publications
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year

Figure 3

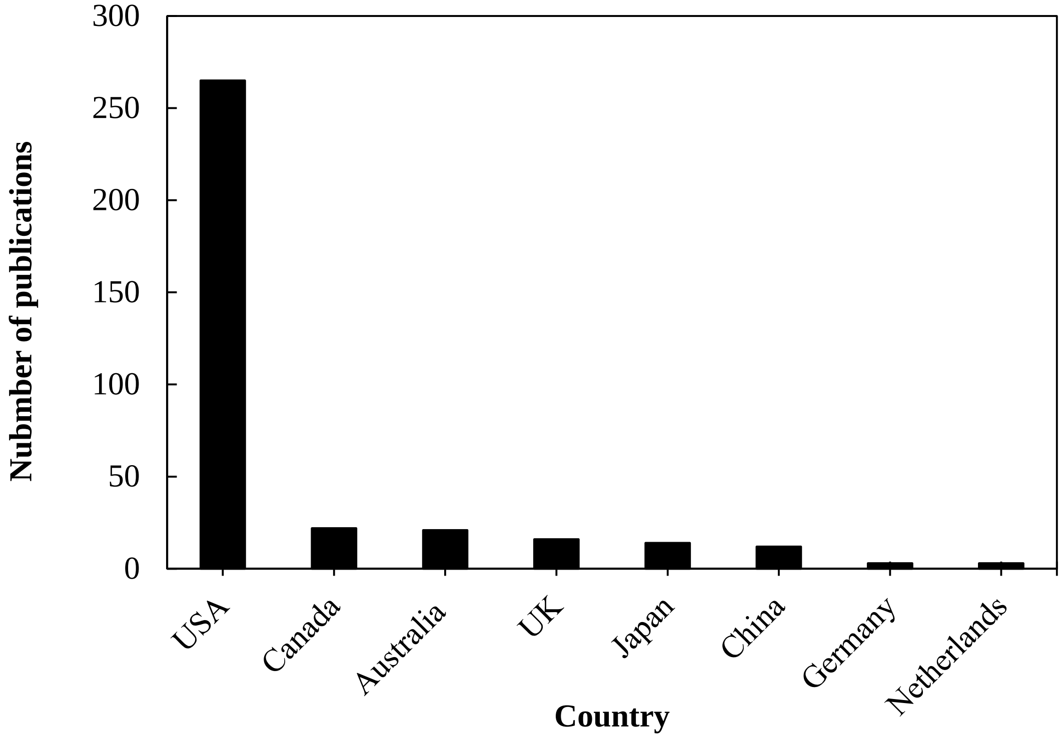

300
250
200
150
100
50
0
Nubmber of publications
USA
Canada
Australia
UK
Japan
China
Germany
Netherlands
Country

Figure 4

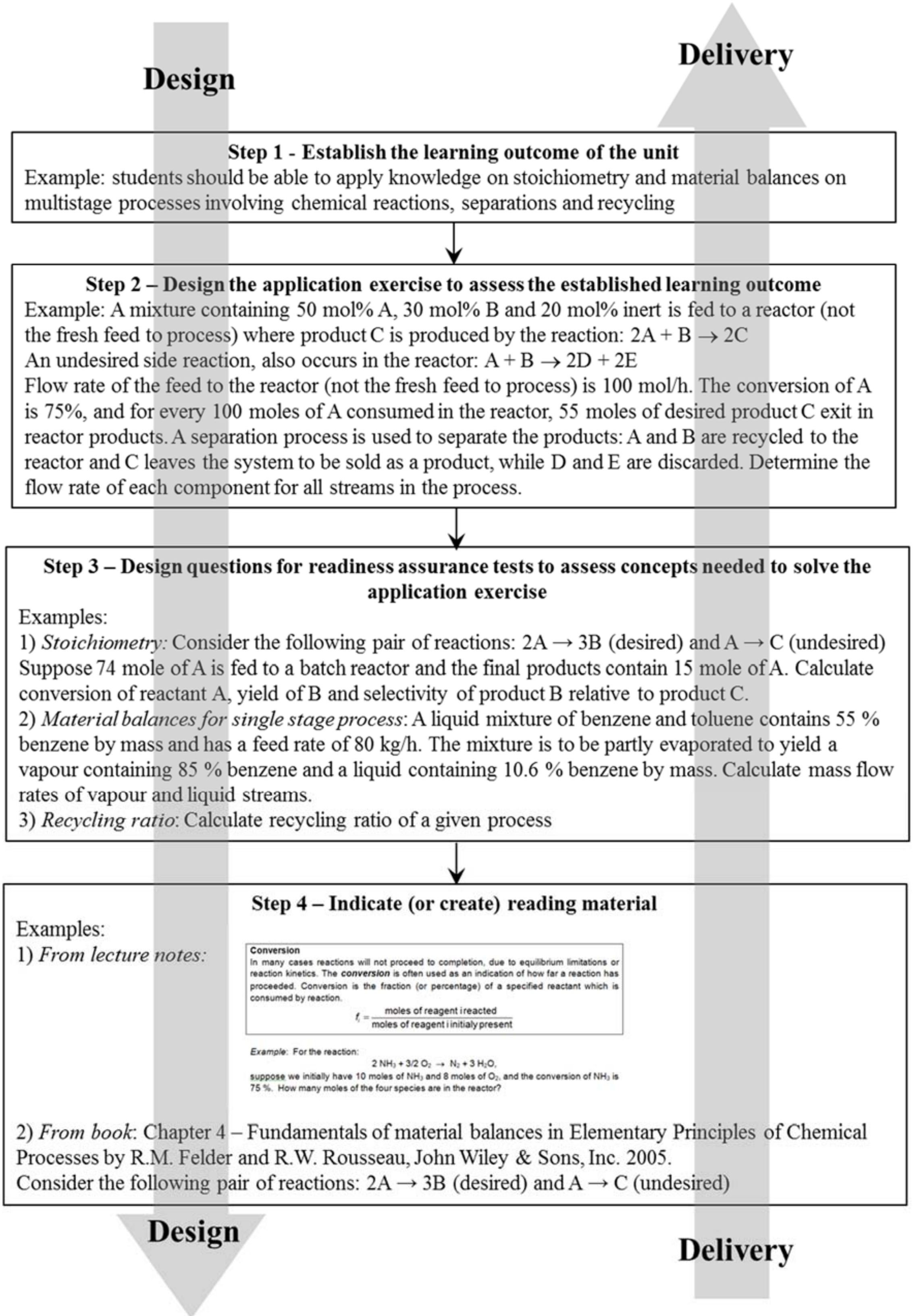
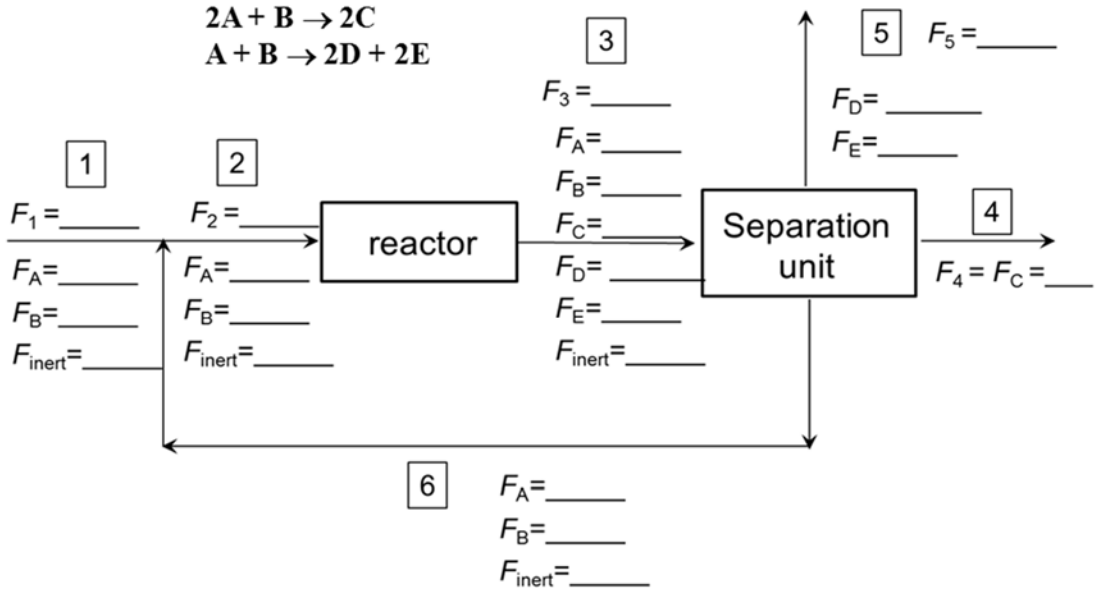

Design
Delivery
Step 1 - Establish the learning outcome of the unit
Example: students should be able to apply knowledge on stoichiometry and material balances on multistage processes involving chemical reactions, separations and recycling
Step 2 – Design the application exercise to assess the established learning outcome
Example: A mixture containing 50 mol% A, 30 mol% B and 20 mol% inert is fed to a reactor (not the fresh feed to process) where product C is produced by the reaction: 2A + B → 2C
An undesired side reaction, also occurs in the reactor: A + B → 2D + 2E
Flow rate of the feed to the reactor (not the fresh feed to process) is 100 mol/h. The conversion of A is 75%, and for every 100 moles of A consumed in the reactor, 55 moles of desired product C exit in reactor products. A separation process is used to separate the products: A and B are recycled to the reactor and C leaves the system to be sold as a product, while D and E are discarded. Determine the flow rate of each component for all streams in the process.
Step 3 – Design questions for readiness assurance tests to assess concepts needed to solve the application exercise
Examples:
1) Stoichiometry: Consider the following pair of reactions: 2A → 3B (desired) and A → C (undesired) Suppose 74 mole of A is fed to a batch reactor and the final products contain 15 mole of A. Calculate conversion of reactant A, yield of B and selectivity of product B relative to product C.
2) Material balances for single stage process: A liquid mixture of benzene and toluene contains 55 % benzene by mass and has a feed rate of 80 kg/h. The mixture is to be partly evaporated to yield a vapour containing 85 % benzene and a liquid containing 10.6 % benzene by mass. Calculate mass flow rates of vapour and liquid streams.
3) Recycling ratio: Calculate recycling ratio of a given process
Step 4 – Indicate (or create) reading material
Examples:
1) From lecture notes:
Conversion
In many cases reactions will not proceed to completion, due to equilibrium limitations or reaction kinetics. The conversion is often used as an indication of how far a reaction has proceeded. Conversion is the fraction (or percentage) of a specified reactant which is consumed by reaction.
f_i = moles of reagent i reacted / moles of reagent i initialy present
Example: For the reaction:
2 NH3 + 3/2 O2 → N2 + 3 H2O,
suppose we initially have 10 moles of NH3 and 8 moles of O2, and the conversion of NH3 is 75 %. How many moles of the four species are in the reactor?
2) From book: Chapter 4 – Fundamentals of material balances in Elementary Principles of Chemical Processes by R.M. Felder and R.W. Rousseau, John Wiley & Sons, Inc. 2005.
Consider the following pair of reactions: 2A → 3B (desired) and A → C (undesired)
Design
Delivery

Figure 5



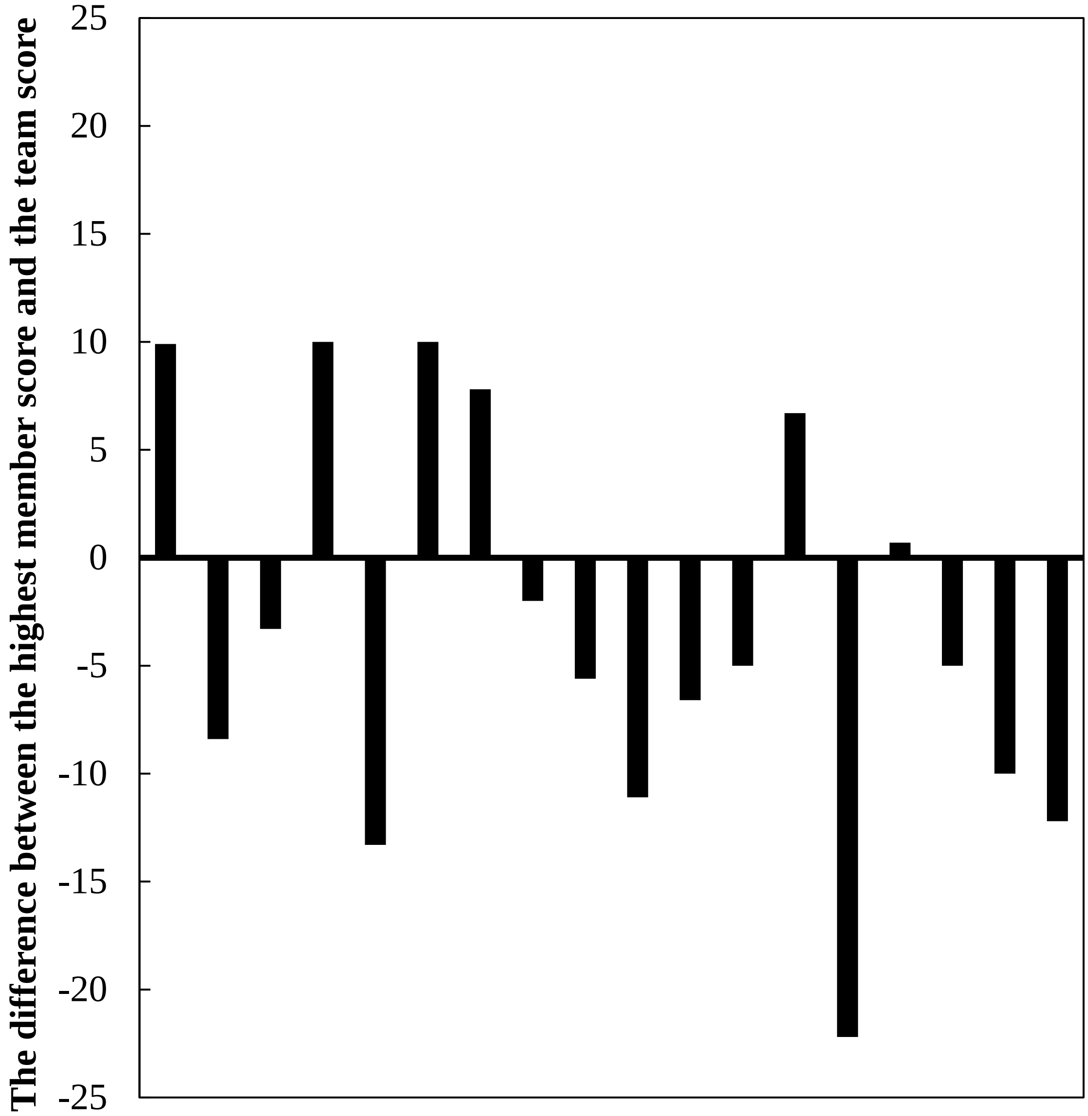
The flow rate of component A (mol/h) in the stream 3 is:
A. 75.0
B. 60.0
C. 28.6
D. 12.5
E. 2.8

The flow rate of component C (mol/h) in the stream 3 is:
A. 41.3
B. 33.0
C. 20.6
D. 6.9
E. 1.5

The flow rate of component B (mol/h) in the stream 3 is:
A. 55.3
B. 65.0
C. 28.6
D. 37.5
E. 2.8

The overall flow rate (mol/h) of the stream 3 (F_1) is:
A. 64.7
B. 20.0
C. 0
D. 33.8
E. 3.9

Figure 6



The difference between the highest member score and the team score
25
20
15
10
5
0
-5
-10
-15
-20
-25

Figure 7

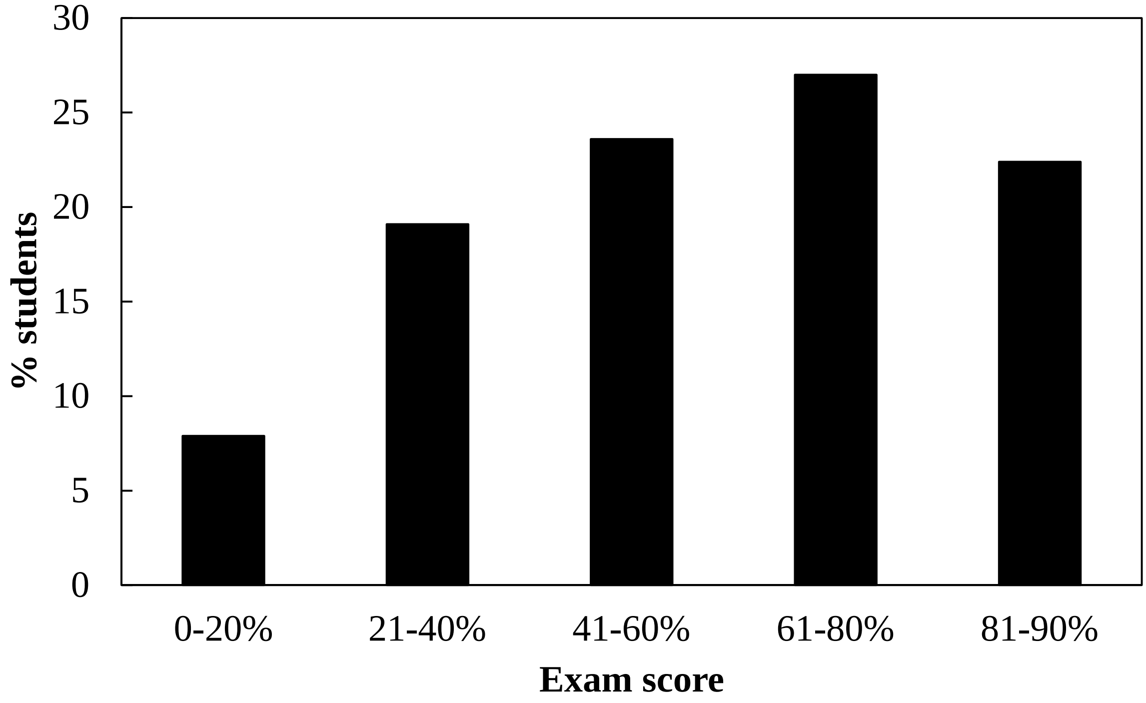
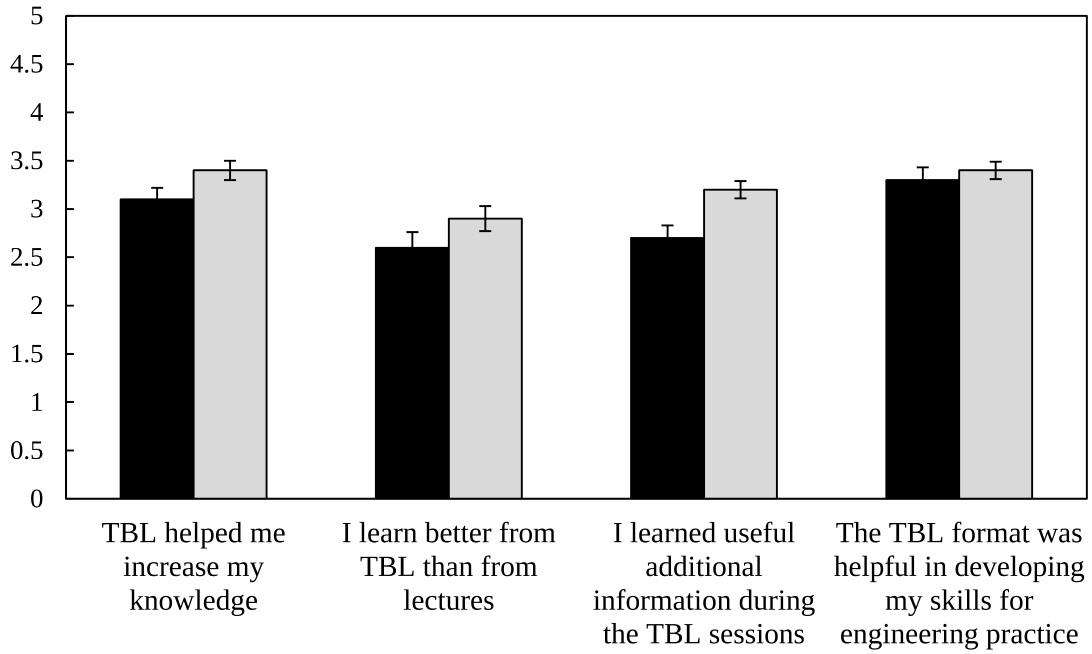
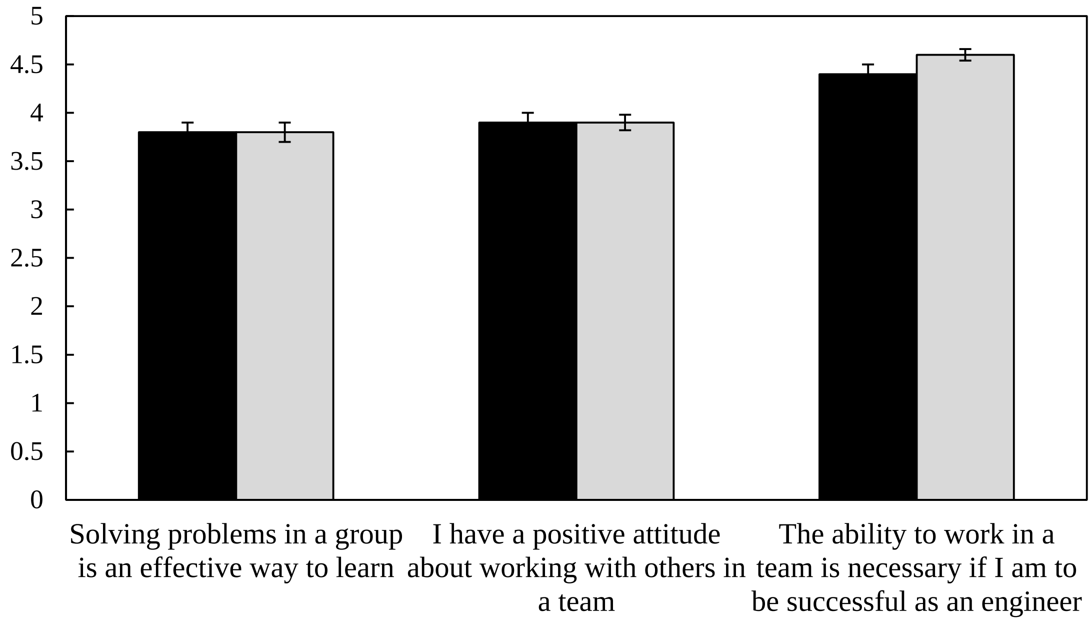


Figure 8

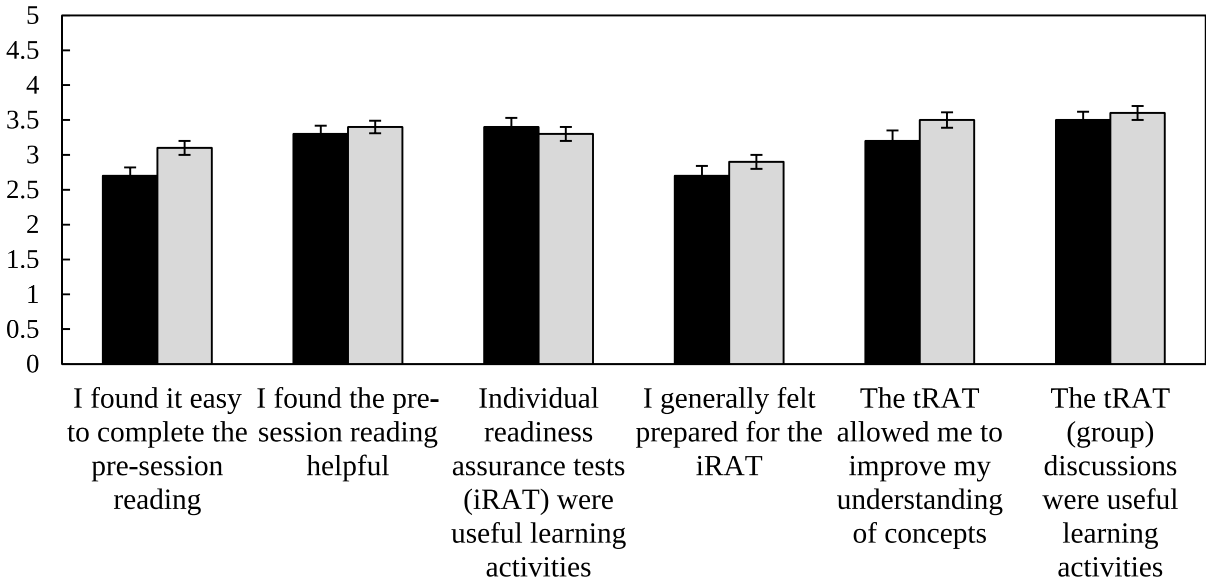
(A)


5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
TBL helped me increase my knowledge
I learn better from TBL than from lectures
I learned useful additional information during the TBL sessions
The TBL format was helpful in developing my skills for engineering practice

(B)


5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Solving problems in a group is an effective way to learn
I have a positive attitude about working with others in a team
The ability to work in a team is necessary if I am to be successful as an engineer

(C)


5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
I found it easy to complete the pre-session reading
I found the pre-session reading helpful
Individual readiness assurance tests (iRAT) were useful learning activities
I generally felt prepared for the iRAT
The tRAT allowed me to improve my understanding of concepts
The tRAT (group) discussions were useful learning activities

(D)

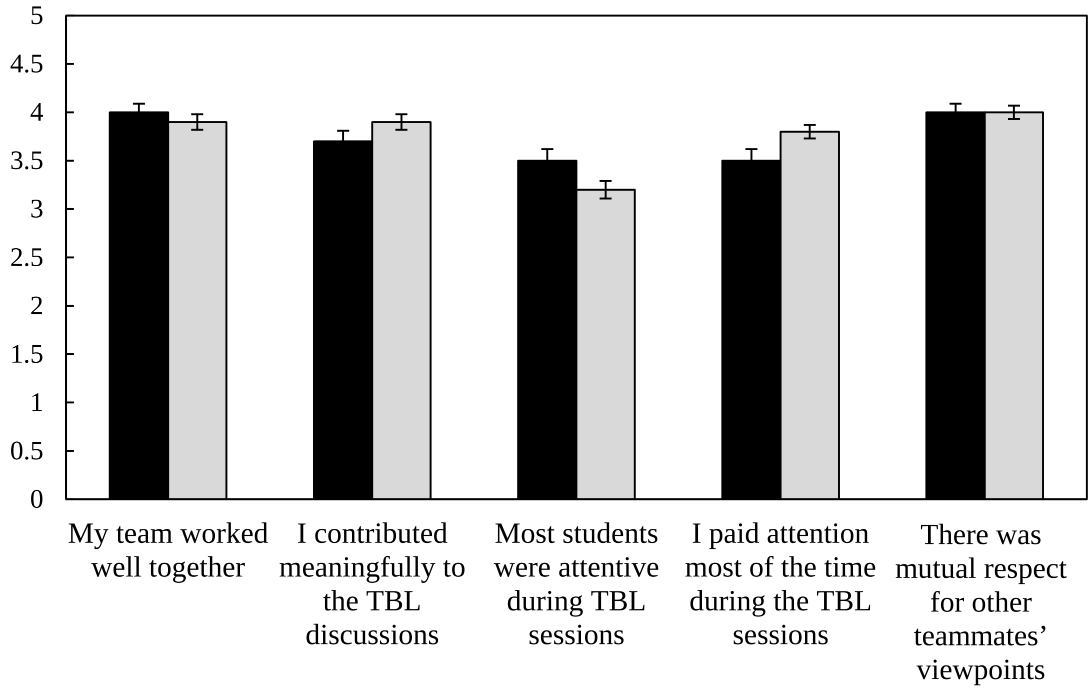

5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
My team worked well together
I contributed meaningfully to the TBL discussions
Most students were attentive during TBL sessions
I paid attention most of the time during the TBL sessions
There was mutual respect for other teammates' viewpoints

Table 1. Assessment scheme.

Assignment	1st Step - Average	2nd Step – Peer evaluation contribution	Contribution to final mark
Exam	-		60%
$iRAT_1$	$\langle iRAT \rangle = \frac{iRAT_1 + iRAT_2 + iRAT_3}{3}$	-	20%
$iRAT_2$			
$iRAT_3$			
$tRAT_1$	$\langle tRAT \rangle_{team} = \frac{tRAT_1 + tRAT_2 + tRAT_3}{3}$	$\langle tRAT \rangle_{individual} = \langle tRAT \rangle_{team} \times (\text{Peer evaluation factor})$	10%
$tRAT_2$			
$tRAT_3$			
APP	$\langle APP \rangle_{team} = \frac{\sum_{i=1}^{n} APP_i}{n}$	$\langle APP \rangle_{individual} = \langle APP \rangle_{team} \times (\text{Peer evaluation factor})$	10%

iRAT – individual readiness assurance test
$\langle iRAT \rangle$ - average of three individual readiness assurance tests
iRAT – team readiness assurance test
$\langle tRAT \rangle_{team}$ - average of three team readiness assurance tests
$\langle tRAT \rangle_{individual}$ - average mark of team readiness assurance tests for each individual member
APP – application exercise
$\langle APP \rangle_{team}$ - average mark of application exercises for team
$\langle APP \rangle_{individual}$ - average mark of application exercises for each individual member

Table 2. Example of the peer-to-peer assessment results within a team according to Fink method

	Student 1	Student 2	Student 3	Student 4	Student 5	Student 6	Student 7	Student 8	Peer Assessment Factor
Student 1	X	10	5	10	11	0	9	10	0.55
Student 2	14.29	X	20	20	20	20	17	16	1.27
Student 3	14.29	15	X	20	20	10	17	16	1.12
Student 4	14.29	15	15	X	13	20	12	16	1.05
Student 5	14.29	15	10	10	X	10	11	10	0.8
Student 6	14.29	15	15	12.5	10	X	17	16	1
Student 7	14.29	15	15	12.5	14	20	X	16	1.07
Student 8	14.29	15	20	15	12	20	17	X	1.13
total	100	100	100	100	100	100	100	100	

Table 3. Statements on the questionnaire completed by students anonymously on two occasions: two weeks after the module has begun and at the end of module. Options: 1-Strongly disagree; 2-Disagree; 3-Neutral; 4-Agree; 5-Strongly agree.

Aspect	Nº	Statement
Perception on the TBL	Q1	TBL helped me increase my knowledge
	Q8	I learn better from TBL than from lectures
	Q10	I learned useful additional information during the TBL sessions
	Q17	The TBL format was helpful in developing my skills for engineering practice
Significance of group work	Q9	Solving problems in a group is an effective way to learn
	Q11	I have a positive attitude about working with others in a team
	Q12	The ability to work in a team is necessary if I am to be successful as an engineer
Readiness Assurance Process	Q2	I found it easy to complete the pre-session reading
	Q3	I found the pre-session reading helpful
	Q4	Individual readiness assurance tests (iRAT) were useful learning activities
	Q5	I generally felt prepared for the iRAT
	Q6	The tRAT allowed me to improve my understanding of concepts
	Q7	The tRAT (group) discussions were useful learning activities
Engagement	Q13	My team worked well together
	Q14	I contributed meaningfully to the TBL discussions
	Q15	Most students were attentive during TBL sessions
	Q16	I paid attention most of the time during the TBL sessions
	Q18	There was mutual respect for other teammates' viewpoints

Table 4. Average scores of iRATs and tRATs

	Average score ± standard deviation
Individual performance (iRATs)	(74 ± 27)%
Team performance (tRATs)	(86 ± 20)%