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Using Team Based Learning to Ensure Student Accountability and Engagement in Flipped Classrooms

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Abstract

Ensuring student accountability and engagement can be a concern for faculty wanting to utilize a flipped classroom; however, Team-Based Learning (TBL) achieves both student engagement and accountability in engineering courses as a result of its coherent framework. The Team-Based Learning Student Assessment Instrument, grades from in-class quizzes, and instructor observations were used to assess whether students came to class prepared and were engaged in the in-class activities. The results demonstrate that students are accountable for their learning and are interactively engaged in the classroom.

Introduction

In terms of student learning, active, constructive, and interactive modes are better than the passive mode[1], which promotes the use of flipped classroom pedagogies. Proper implementation of activities is important, but "there still may be obstacles to successful implementation of those activities in the classroom, and learning outcomes may not match expectations."[2]. Typical obstacles include students not engaged in the activities especially when interactive modes are used in-class, which requires that all students of a group contribute substantially to a joint intellectual effort. How can we assure student accountability and engagement in an interactive class room environment? We will present data showing how Team-Based Learning (TBL)–as a result of its coherent framework–achieves student engagement and accountability in engineering courses. In addition, most of the classroom activities in TBL are interactive–the most effective mode for student learning is the interactive mode[2]–making TBL a prime candidate when considering "flipping" a course. For an in-depth comparison between TBL, Problem-Based Learning, and Collaborative Learning practices consult Davidson et al.[3]

Team-Based Learning is currently used successfully nationally and internationally in professional schools such as medical, pharmacy, law, and business schools, and is gaining a foothold in undergraduate programs in the humanities, sciences, and engineering[4]. TBL has been shown to improve the communication, team working, problem solving, critical thinking, and lifelong learning skills of students in TBL taught courses more than in traditionally taught courses[4,5]. The nature of Team-Based Learning—such that the students solve problems in teams during class time, and then must report and defend their answers to the entire class—effectively gives students the opportunity to learn, practice and refine their communication, problem solving and critical thinking skills. The individual accountability for the pre-reading promotes lifelong learning skills. Since these skills are critical to being successful in industry, it is our job to give students ample opportunity to develop these skills in their engineering student career, and using TBL as a teaching/learning technique in engineering courses will do so.

Another benefit of TBL for the students is in-depth knowledge and understanding of topics that comes from solving complex problems interactively. In addition, students gain an appreciation for team work and learn to work as effective team mates. The effectiveness of team work can also be demonstrated to the students—Michaelsen et al.[5] has shown that in the past twenty years, over 99.95% of the teams have outperformed their best member by an average of almost 14%, and the worst team typically outperforms the best student in the class.

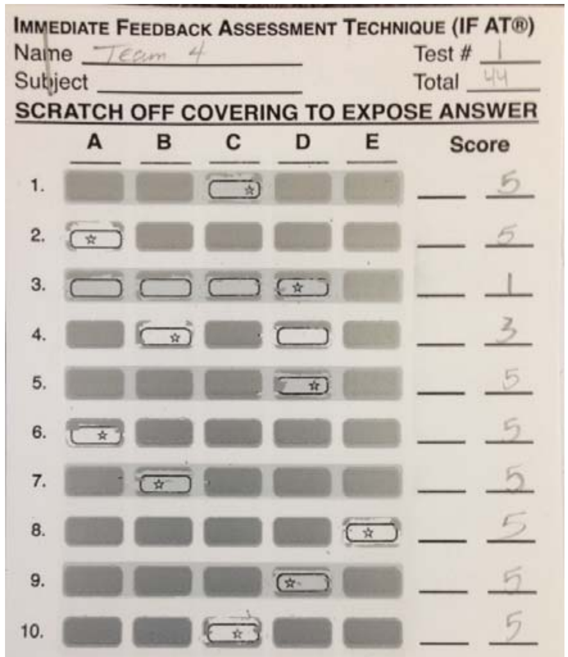
Benefits for instructors and administrators include: (1) minimal team facilitation because the groups tend to develop into self-managed learning teams. (2) TBL is cost effective since it can be used in large classes using the same instructor/TA costs as small classes. (3) There are fewer worries about students not being in class or failing to prepare for class. (4) Student-faculty interactions are more like working with colleagues when students are prepared for class and instructors have time to develop personally rewarding relationships with students[5].

Team-Based Learning Description

Team-Based Learning (TBL) is a specific pedagogical tool that emphasizes collaborative learning and is distinct from other cooperative or collaborative pedagogies because it follows a prescribed sequence of individual work and group work, and includes immediate feedback as well as peer evaluation. TBL is similar to other flipped classroom approaches in the sense that students have to prepare, e.g. by reading a chapter of a textbook, before coming to class to be prepared for in-class discussions and activities. The uniqueness of TBL is that in class students work in permanent teams throughout the quarter, activities follow a prescribed process–first a reading assignment (or studying material from other sources), then an in-class quiz, and finally problems solved interactively in class that require students to apply facts and concepts from the pre-reading.

The framework of assuring that students come prepared to class is called the “Readiness Assurance Process" (RAP) which is unique to TBL. The RAP consists of an individual Readiness Assurance Test (iRAT) and a team Readiness Assurance Test (tRAT). Students first take the iRAT as an individual, and then take the tRAT, answering the same multiple choice questions from the iRAT as a team. During the tRAT, each team must come to a consensus for the answers to the questions, and they immediately check their answers using the Immediate Feedback Assessment Technique (IF-AT) form. The IF-AT form–shown in Figure 1–is a scratch off sheet in which a star is located under the correct answer. Teams receive points based on the number of scratches it takes to determine the correct answer. Using the IF-AT form during the tRAT is key to help students to correct misconceptions in real time, and the points-scale gives the students motivation to learn to work together effectively as a team without instructor input. After all teams have completed the tRAT, the instructor can give a short—typically 5 to 10 minutes—lecture clearing up any remaining confusion about the topic. Students are given an opportunity to submit a written appeal, as a team, of any RAT question they believe might be ambiguous. An example of a RAT is given in the appendix.

The applications–on which the most time is spent in class–are problems that the students must solve as a team. The applications follow a 4-S format: Same problem, Significant problem, Specific choice, and Simultaneous report. A class discussion accompanies each application, and mini-lectures are given throughout to clarify misconceptions and answer questions. The problems are related to the course content and are challenging and rich enough that one student alone could not solve the problem in the time given, requiring the students to work together if they want to be successful in answering the problem.


IMMEDIATE FEEDBACK ASSESSMENT TECHNIQUE (IF AT®)

Name Team 4 Test # 1

Subject Total 44

SCRATCH OFF COVERING TO EXPOSE ANSWER

	A	B	C	D	E	Score
1.						5
2.						5
3.						1
4.						3
5.						5
6.						5
7.						5
8.						5
9.						5
10.						5

Figure 1: IF-AT Form. Points are given based on the number of scratches it takes to determine the correct answer.

The final part to TBL is peer evaluation. Permanent heterogeneous teams of 5-7 students are formed at the beginning of the course. Students rate their team mates on their contributions to the team performance and the peer evaluation is part of their final grade.

In summary, the uniqueness of the TBL framework is that students are held accountable for both their individual work—iRAT, peer evaluations—and group work—tRAT, and applications. The majority of class time is used for interactive team assignments that use the course content applied to larger and more difficult problems than can normally be done by individual students. For additional details about TBL and how to implement it in the class room see Sibley[6].

Methods

Team-Based Learning has been implemented in four undergraduate mechanical engineering courses in the thermal sciences having a total of 173 students. The courses include two fundamental courses–Thermodynamics I and Heat Transfer–and two technical electives–Fundamentals of HVAC Systems, and Introduction to Refrigeration Principles.

To assess the success of using Team-Based Learning, the Team-Based Learning Student Assessment Instrument (TBL-SAI), was administered at the end of each course[7]. The TBL-SAI has 33 questions, asked on a five level agree/disagree Likert scale, and is validated to measure (1) student accountability, (2) TBL vs. lecture preference, and (3) student satisfaction[7,8]. Student comments and faculty observations are used to qualitatively evaluate the success of the TBL taught courses.

Student grades on the individual and team RATs give an indication about the level of student accountability and engagement. The RAT tests students' understanding of the assigned reading and indicates whether or not a student prepared for class. To help the students prepare for the RAT the students are given a detailed list of learning objectives–facts and concepts–on which they will be tested in addition to the reading assignment. An example of the mapping of RAT questions to learning objectives is included in the appendix for one RAT. The multiple choice questions for the RATs were written following best practices developed by medical educators[9,10] and were all single best answer (SBA) Type A test items. Item analysis of individual multiple choice questions includes the Difficulty Factor (DF) and the Discrimination Index (DI), which are measures of well written test questions. The DF is determined from the percentage of students who answered a question correctly. The goal is to have a range of questions in terms of difficulty on an exam or quiz. Difficult questions are defined as having a DF between 50% and 75% and moderate difficult questions have a DF in the range of 75-90%. Low difficulty questions have a DF between 90% and 100%.

The Discrimination Index is the percent difference in correct responses between two groups of students–typically the top and bottom students. For this study, the top students were defined as those who had nine or ten questions correct out of ten questions on the iRAT, and the bottom students were defined as those who had less than six questions correct. The DI is a ratio between -1.0 and +1.0–the closer the ratio is to +1.0 the more effective the question distinguishes between students who know the material (top group) and those who do not (bottom group). A discrimination factor greater than 0.20 for the majority of questions is desirable. The DI and DF are two measurements that were used to evaluate all the questions on the RATs from the two fundamental courses.

Results and Discussion

The results of the TBL-Student Assessment Instrument are shown in Table 1. The table includes the TBL-SAI subsets' possible ranges and the neutral point of each subset. The range, average and standard deviation are given for each subset, as well as the percentage of the student's whose score was above the neutral point. The results indicate that 93% of the students have felt accountable to not only themselves, but also to their team to participate in the learning. The majority of students (72%) showed a preference for TBL compared to lecture instruction. In addition, 87% of the students were satisfied with the course. Together, these results indicate a successful implementation of Team-Based Learning in the mechanical engineering courses.

Table 1: Results from the TBL Student Assessment Instrument for four courses.

Category	Possible Range	Minimum Score	Maximum Score	Neutral Point	Average	Standard Deviation	Percent above Neutral Point	Number of Responses
Accountability	8 to 40	17	40	24	30.5	4.25	92.7%	150
TBL vs. Lecture	15 to 75	19	74	45	51.4	10.04	71.9%	146
Satisfaction	9 to 45	15	45	27	33.9	6.27	86.7%	150
Total	33 to 165	55	148	99	115.6	16.25	84.2%	146

The individual RAT scores confirm that students are coming to class prepared. The average iRAT score was 7.92 out of 10 (0.90 standard deviation). Only four students or 2.3% had an average iRAT score of less than 6/10. In other words, the majority of the students had an average greater than 6/10 indicating that *97.7% of the students came to class prepared*, and 87% of the students had an average iRAT score of 7/10 or higher. Since the iRAT questions are designed to be answered correctly only if a student does the reading and prepares for class, the iRAT scores are the strongest measurement of student accountability and preparation for class. It is important to remember that the students take the iRAT based on the pre-assignment, i.e., no in-class lectures are given before the iRAT/tRAT.

The results of the RAT question item analysis from the fundamental courses are shown in Table 2. The average Difficulty Factor was 77% and most (70%) of the questions are classified as moderate to difficult questions. Each RAT had a range of questions in terms of difficulty that required the students to understand the pre-reading in order to know the correct answer. The average Discrimination Index was 0.44, and 73% of the questions had a DI of +0.20 or higher. Therefore, a majority of the questions were able to discriminate between the students who had prepared and knew the material from those that did not know the material. These two quantitative assessments of the RAT questions indicate that the RATs were properly written to assess whether students understand basic concepts and terminology that are critical to understanding before students are able to solve the problems presented in the application activities.

Table 2: Results of RAT Question Item Analysis

	Average	Standard Deviation
Difficulty Factor	77%	21
Discrimination Index	0.44	0.27

To quantitatively measure the engagement of students during the tRAT, the team tRAT score is compared to the team's average iRAT score and the range of the individual iRAT scores in Figure 2. Immediately evident from the plot is that the team's average iRAT scores do not correlate to the team tRAT score. All teams, except one, had an average tRAT score of 90% or higher, regardless of the iRAT score. The average difference between the iRAT and tRAT scores is an increase of 1.7 points—almost 2 grade points—which is significant ($p = 0.0001$, $t = 16.4$). The average difference between the top student in a team and the team score is 0.82 and is also significant ($p = 0.0001$, $t = 7.21$). The conclusion from Figure 2 is that the students *must work together and be engaged* in order to achieve the high tRAT scores.

When the students do the tRAT, they do not know the correct answers until they scratch the IF-AT card. If everyone in the team has a different answer, they do not know *who* is correct and must debate to determine the correct answer. During the tRAT, typical conversations overheard by the instructors include students saying "Why did you choose A?", "I chose A because of X, which means that Y must be true" and "I remember reading X, Y, Z, so the answer cannot be B". This sort of back and forth debate–which is more than just "majority rules"–indicates that the students are engaged in an interactive mode of learning, the highest level of learning[2]. Because the team immediately sees if they are correct once they scratch an answer, when they are wrong they go back and reason again through the remaining options.

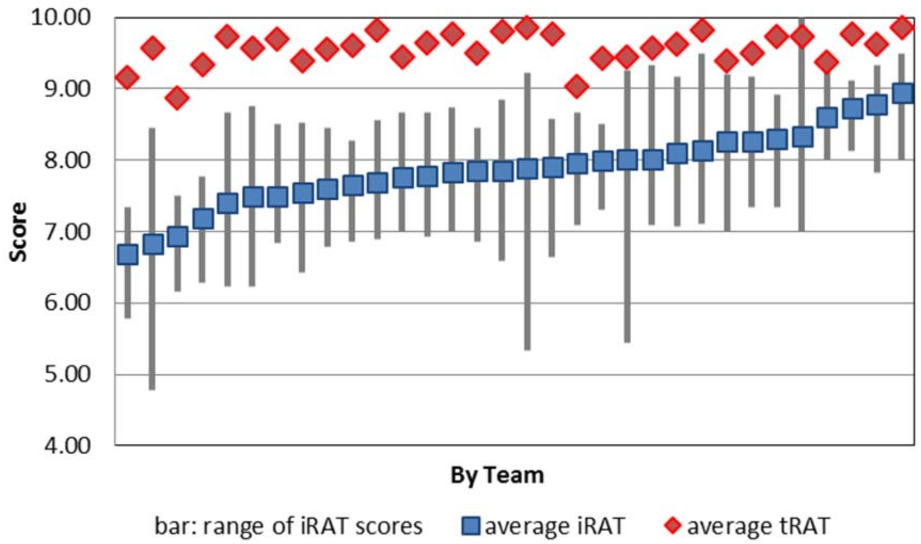
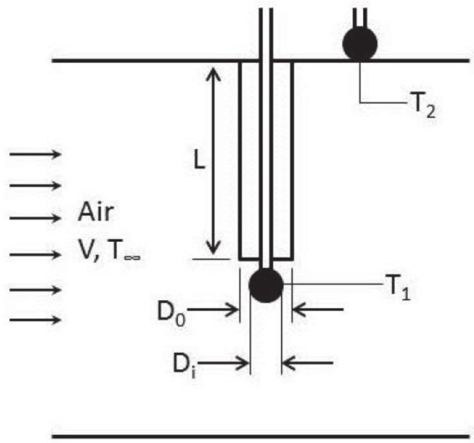


Figure 2: The average iRAT scores do not correlate to the team tRAT scores. The team typically does better than its individuals members. Note: The exception was a graduate student who had 10/10 on all iRATs.

During the tRAT, once the correct answer for a question is determined after one or more false attempts, typical student comments include, “Now why is the answer C?” “Where in the reading is that stated?”. Simply finding the correct answer is not good enough for the students–they want to understand why the correct answer is correct. These questions are usually answered through a mini-lecture by the instructor, during which the students are engaged and asking more questions because they want to understand why the correct answer is correct (and why the wrong answers are wrong). During the entire tRAT and mini-lecture, the students are fully engaged in the activities and learning. At the end of class, they walk out not only knowing their grades on the iRAT and tRAT, and the correct answers to the RAT questions, but also why the answers are correct.

During the applications, the instructors observed that the students are engaged in solving the problems, asking each other questions and working together to determine the answer. An example of an application question from heat transfer–involving external convection–is shown in Figure 3. The application follows the 4S format–it is Significant in that it engages the whole team to solve the problem in 40 minutes, all teams worked on the Same problem at the same time, the students must make a Specific choice for the final answer and the teams reported their answer Simultaneously by holding up colored coded flags corresponding to their choice. Additional examples of applications from all the courses are given in the appendix. The key to having full student engagement during applications is to follow the 4S format as closely as possible, especially focusing on having significant problems.

You need to determine the temperature of a gas flowing through a duct. A thermocouple is inserted into the duct—as shown in the figure—inside a steel thermocouple well to protect it. A second thermocouple is used to measure the duct temperature. Your measurements indicate that $T_1 = 450\ K$ and $T_2 = 375\ K$.



1. For the given dimensions and conditions below, determine the error associated with simply using T_1 as the gas temperature compared to correcting for the duct temperature and steel encasing. What do you recommend to do to report the gas temperature, T_∞? Neglect radiation.

   (a) Use the temperature measurement in the middle of the duct T_1

   (b) Use the wall temperature measurement, T_2.

   (c) Use the corrected temperature measurement.

Figure 3: Example of an application in the 4S format from heat transfer.

To ensure student individual accountability and encourage engagement in the classroom, the syllabus outlines that in order to pass the course, the student must pass the individually graded portion of the course, i.e., the iRAT, midterm and final exams. This policy not only ensures student accountability, but also informs the students that they will not be able to “slide by” on the team grade, but must take ownership of learning the material. If students were not accountable and engaged in class during the RAT and applications, we would expect the failure rate to increase compared to a lecture only course, however, the failure rate is not significantly different. As Table 3 shows, students are not failing fundamental courses in the thermal sciences at a higher rate when using Team-Based Learning.

Table 3: Comparison of the failure rate in TBL taught courses and lecture taught courses.

Course	TBL	Lecture
Heat Transfer	1.7% (n=58)	2.7%(n=36)
Thermodynamics 1	4.7% (n=63)	5.7%(n=70)

Student comments about the courses ranged, but in general students commented on the uniqueness of the course format and that they remembered the course material better compared to their lecture based courses. Selected students comments are listed below.

> I was initially very skeptical about TBL, but the system made the class much more conducive to learning the material.
>
> Great teaching format and learned more in this class than many of my others.
>
> I want to say that when I entered the class at the beginning of the quarter, I was very distraught and skeptical of the TBL and the course as a whole. However, as the quarter progressed and I got to know my group and the material better, I began to change my mind. I believe that I learned and retained the information and concepts very well (better than a lecture-based course) and I want to thank you for that. I actually enjoyed thermo[dynamics].
>
> At first I hated the idea of team learning but now I prefer it.
>
> I really have enjoyed working with my team this quarter. We have grown more cohesive over the quarter, and I enjoy working in team-based learning. It is much less stressful than normal lecture. Thank you.
>
> Style of learning works extremely well once we are used to it!
>
> Throughout the quarter I think our group has really worked well together. I feel as though each member has made positive contributions from time to time. Some members seem to think quicker which enables them to figure out the problem faster, but by the end of the question each member takes the time to make sure all members have caught up and understand what is going on.
>
> I liked the team based learning and this class taught me how to effectively read a textbook.
>
> Love the team based learning. I have never seen a teaching style I like this much.

As the comments also indicate, buy-in by the students to any new teaching method is critical and some students will push back against the idea of Team-Based Learning as a valuable learning experience. However, as the iRAT/tRAT analysis demonstrates, learning is occurring even for students who might not like TBL at the onset. Instructors observed–and reviewing the students' comments–indicates that introducing TBL at the beginning of the term to the students reduces the anxiety of students. The key is to explain why TBL is being used and how it affects student learning in a positive way. As with any instructional method, 100% of satisfaction is typically not achievable, however, the TBL-SAI results showed that 87% of the students are satisfied with TBL by the end of the term. For more information about how to introduce TBL to students see Sibley[6].

Conclusions

Team-Based Learning has been implemented in four undergraduate mechanical engineering courses and assessment was conducted using the TBL-Student Assessment Instrument and analyzing student RAT performances. Student comments and instructor observations qualitatively supplement the quantitative analysis.

The results show that students are accountable for their learning in a TBL flipped classroom. The analysis of the iRAT scores–the strongest measurement of student accountability–shows that 97.7% of the students prepared for class. The TBL-Student Assessment Instrument showed that 93% of the students felt accountable to not only themselves, but also to their team to participate in the learning.

The RAT analysis shows that all teams, except one, had an average tRAT score of 90% or higher, regardless of the iRAT score. The average difference between the iRAT and tRAT scores was significant ($p=0.0001$, $t=16.4$) as well as the average difference between the top student in a team and the team score ($p=0.0001$, $t=7.21$). The conclusion from the iRAT/tRAT comparison is that the students must work together and be engaged in order to achieve the high tRAT scores. In class observations by the instructors confirm the high level of student engagement during tRAT and application exercises. No significant change in terms of failing rate was observed between the TBL taught courses compared to traditional lecture taught courses.

The TBL framework ensures student taking ownership of learning the material, both outside and inside the class room, and promotes a high level of engagement. In addition, 87% of students reported they were satisfied with TBL. The instructors also enjoyed the interactions with the students and–because of the preparedness of the students–the in class discussions focused on applying engineering concepts and facts instead of lecturing about them.

References

1. Chi, M. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. Topics in Cognitive Science, 1(1), 73-105.

2. Menekse, M., Stump, G., Krause, S. , & Chi, M. (2013). Differentiated overt learning activities for effective instruction in engineering classrooms. Journal of Engineering Education, 102(3), 346-374

3. Davidson, N., Major, C., & Michaelson, L. (2014). Team-Based Learning Practices and Principles in Comparison with Cooperative Learning and Problem Based Learning. Journal on Excellence in College Teaching, 25(4)

4. Sibley, J., & Parmelee, D. (2008). Knowledge is no longer enough: Enhancing professional education with team-based learning. New Directions for Teaching and Learning, 2008(116), 41-53.

5. Michaelsen, L., & Sweet, M. (2008). The essential elements of team-based learning. New Directions for Teaching and Learning, 2008(116), 7-27.

6. Sibley, J. (2014). Getting Started with Team-Based Learning. Sterling, Virginia: Stylus Publishing.

7. Mennenga, H. (2012). Development and psychometric testing of the team-based learning student assessment instrument. Nurse Educator, 37(4), 168-172.

8. Mennenga, H. (2010). Team-based Learning: Engagement and Accountability with Psychometric Analysis of a New Instrument. n.p.: ProQuest, UMI Dissertations Publishing

9. Collins, J. (2006). Writing multiple-choice questions for continuing medical education activities and self-assessment modules. Radiographics, 26(2), 543-551.

10. Case, S., & Swanson, D. (2001). Constructing Written Test Questions for the Basic and Clinical Sciences. Philadelphia: National Board of Medical Examiners.

Appendix

Example Learning Objectives for RAT

The following table is a list of the Facts and Concepts Learning Objectives given to students before the RAT. The topic of the module is "Introduction to Convection and External Flow Convection". The objectives are mapped to the RAT questions shown on the next page.

By the end of the module you should know and be able to recall the following:	RAT Question
1. Definitions and units: free stream, boundary layer thickness, heat transfer convection coefficient, free stream temperature, film temperature,	5
2. Velocity vs. thermal boundary layer over objects	7,8
3. Average vs. local heat transfer coefficient	
4. Reynolds, Nusselt, and Prandtl numbers	4
5. Laminar vs. turbulent flow for external flow	9
6. The "problem of convection"	1
7. Equations for solving convection problems-flow over a flat plate, cylinders in cross flow, sphere-having different conditions	10
8. Validity and limitations of different convection equations	10
9. Methodology to solve convection problems	2,3
10. Nu Correlation assumptions and how the correlations are derived	5,6

Example RAT from Heat Transfer

1. What is the problem of convection?
   (a) fluid condition determination
   (b) surface geometry determination
   (c) convection coefficient determination
   (d) heat transfer rate determination

2. You are solving a convection heat transfer problem. You have determined that it involves flow over a cylinder and you have found the fluid properties at the film temperature. What is your next step?
   (a) Determine whether local or average coefficient is required.
   (b) Select the appropriate correlation.
   (c) Determine whether flow is laminar or turbulent.
   (d) Calculate the Nusselt number.

3. According to the methodology for solving convection problems, which of the following is the *most* important to determine before deciding which correlation to use to determine Nu and h?
   (a) flow regime
   (b) Pr number
   (c) surface geometry
   (d) reference temperature

4. For every convection heat transfer problem, the Reynolds and Nusselt numbers are calculated. The Reynolds number is used to determine the whether the flow is laminar or turbulent. What is the primary purpose of the Nusselt number with respect to the convection coefficient?
   (a) To determine which correlation to use to find the convection coefficient.
   (b) To relate the convection coefficient to the flow regime and surface geometry.
   (c) To relate the convection coefficient to the surface geometry.
   (d) To relate the convection coefficient to the flow regime.

5. The Nu correlations implicitly assume constant properties when in fact they are not constant. Two methods were described for how to deal with the non-constant fluid properties. Which method do most of the Nu correlations for flat plates and cylinders use?
   (a) Evaluate properties at either temperature
   (b) Evaluate properties at the surface temperature
   (c) Evaluate properties at the free stream temperature
   (d) Evaluate properties at the mean boundary layer temperature

6. Most of the Nu correlations were determined using the empirical method. Which of the following statements is not a characteristic of the empirical correlations for the Nusselt number?

   (a) Coefficients and constants depend on the nature of the fluid.
   (b) Measurements were made under controlled conditions.
   (c) Data was correlated to dimensionless parameters.
   (d) Coefficients and constants depend on the surface geometry.

7. When does a thermal boundary layer develop?

   (a) When there is a temperature difference between the free stream and the surface.
   (b) When there is a temperature difference between the free stream and boundary layer.
   (c) When there is a flowing fluid across a surface.
   (d) When there is a velocity boundary layer present.

8. Why is the thermal boundary layer important?

   (a) It determines the velocity boundary importance.
   (b) It determines the type of heat transfer.
   (c) It determines the rate of heat transfer.
   (d) It determines the type of flow.

9. For flow over a cylinder or sphere, the type of flow influences the separation point and therefore the drag. What is the effect of large Re ($> 2 \times 10^5$), and therefore turbulent flow, on the drag?

   (a) Drag is increased at high Reynolds numbers.
   (b) Drag is reduced at high Reynolds numbers.
   (c) Drag is approximately constant.
   (d) Drag is exactly constant.

10. For flow over a cylinder, which of the following does *not* influence the Nu and therefore the heat transfer?

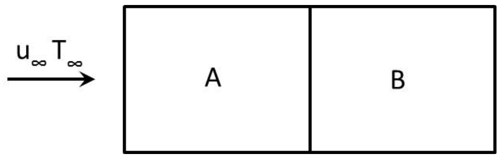
    (a) shape of the cylinder
    (b) Reynold's number
    (c) boundary layer development
    (d) cylinder material

Solution: 1C 2C 3C 4B 5D 6A 7A 8C 9B 10D

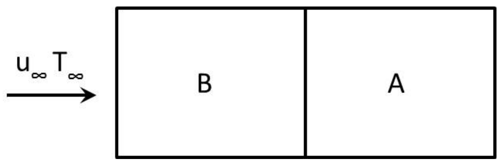
Example Application from Heat Transfer

The 3 options for how the top surface of a heated compartment is oriented are shown below. Section A is smooth and section B is highly roughened. The surface is placed in an atmospheric airstream.

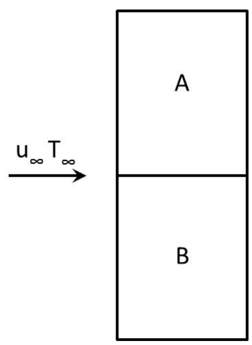
1. Which orientation is preferred to minimize total convection heat transfer from the surface?



(a)



(b)



(c)

2. For orientation A, which correlation should you use to calculate the convective heat transfer coefficient?

   (a)
$$\overline{Nu}_L = (0.037 Re_L^{(4/5)} - 871) Pr^{(1/3)}$$

   (b)
$$\overline{Nu}_L = 0.037 Re_L^{(4/5)} Pr^{(1/3)}$$

   (c)
$$\overline{Nu}_x = 0.664 Re_x^{(1/2)} Pr^{(1/3)}$$

   (d)
$$Nu_x = 0.0296 Re_x^{(4/5)} Pr^{(1/3)}$$

3. For orientation B, which correlation should you use to calculate the convective heat transfer coefficient?

   (a)
   $$\overline{Nu}_L = 0.037 Re_L^{(4/5)} Pr^{(1/3)}$$

   (b)
   $$\overline{Nu}_L = (0.037 Re_L^{(4/5)} - 871) Pr^{(1/3)}$$

   (c)
   $$\overline{Nu}_x = 0.664 Re_x^{(1/2)} Pr^{(1/3)}$$

   (d)
   $$Nu_x = 0.0296 Re_x^{(4/5)} Pr^{(1/3)}$$

Example Application from Thermodynamics

Steam enters a turbine at steady state. Key data are given in the table below. At point 2, 22% of the entering mass flow is extracted at 1103 kPa. The rest of the steam exits as a two-phase liquid-vapor mixture. The turbine develops a power output of $2.6 \times 10^5\ kW$. Neglect potential energy effects and heat transfer between the turbine and its surroundings.

State 1	State 2	State 3
$p_1 = 11032\ kPa$	$p_2 = 1103\ kPa$	$p_3 = 7\ kPa$
$T_1 = 538°C$	$T_2 = 232°C$	$x_3 = 0.85$
$V_1 = 0.6\ m/s$	$V_2 = 3\ m/s$	$V_3 = 45\ m/s$

1. How significant is the kinetic energy for this turbine system?

   (a) Significant, it needs to be included in the calculations for each state point.

   (b) Only the kinetic energy at state 3 is significant and needs to be included.

   (c) Not significant and can be neglected in the calculations.

2. What happens to the efficiency of the turbine when the steam is extracted at state 2 compared to a system in which no steam is extracted, assuming all state points remain the same?

   (a) The efficiency stays the same

   (b) The efficiency goes up

   (c) The efficiency goes down

Example Application from Fundamentals of HVAC Systems

A new building complex is being designed. The complex contains a bank, several office spaces, a gym with a swimming pool and a large retail store. Usually several HVAC systems would be installed to serve the different requirements, for example the gym needs humidity control, the retail store is open 24/7 whereas the bank and office spaces are occupied during regular work hours and closed on the weekend. The owner decides to install only one central HVAC system. Given the information about the building and how the spaces will be used, which HVAC system would be best for this situation?

a) Single-duct, zoned reheat, constant volume system

b) Single-duct, variable air volume system

c) Dual-duct system

d) Dual-duct, variable air volume system

e) Three-deck multizone system

Example Application from Introduction to Refrigeration Principles

In a grocery store a display case holds refrigerated food at a temperature of 34°F.

Assuming the store temperature is held at 68°F, what maximum relative humidity would you recommend to be kept inside the store?

a) 5%
b) 20%
c) 25%
d) 30%
e) 45%