Team-Based Learning and Screencasts in the Undergraduate Thermal-Fluid Sciences Curriculum

Dr. Georg Pingen, Union University

Georg Pingen is an Assistant Professor in the Engineering Department at Union University in Jackson, TN. He teaches courses across the Mechanical Engineering curriculum with a focus on thermal-fluid-sciences. His research interests are in the areas of computational fluid dynamics, topology optimization, and engineering education. He received his Ph.D. from the University of Colorado in aerospace engineering sciences.
1. Introduction:

In order to actively engage students in their own learning while maximizing the breadth and depth of course content, the author utilized a Team-Based Learning\textsuperscript{1,2} approach supplemented by screencasts\textsuperscript{3} to redesign the two semester thermal-fluid-sciences course sequence in the author’s department. In response to the revised course format, student participation and student discussion of the course material increased significantly. Students’ enthusiasm and curiosity are evident in the classroom, which were not observed in previous offerings of the same course sequence. Students have taken increased ownership of the learning process, come prepared for class, and are able to apply higher-level analysis skills to complex team-application problems.

Since becoming a faculty member, it has been my goal to actively engage students in the classroom in order to enhance student participation and ultimately student learning. At the same time the breadth and depth of material cannot be sacrificed. While Thermodynamics, Fluid Dynamics, and Heat Transfer are traditionally taught in 3 or 4 distinct courses as part of most Mechanical Engineering programs, Union University offers a two semester Fluid-Thermal Science course as part of a General Engineering degree with Mechanical Engineering concentration. Teaching this course sequence – one course during the sophomore year (EGR 250) and one during the senior year (EGR 450) – I have found that the three core subjects – thermodynamics, fluid dynamics, and heat transfer – lend themselves well to being taught in an integrated fashion. However, while the integrated approach seems slightly more efficient than teaching the courses separately, it is not feasible to cover all of the material from the 3 or 4 separate courses. In addition, while great textbooks have been written for integrated Fluid-Thermal Science courses, providing good macroscopic overviews and breadth, they tend to lack the level of depth desired to develop critical higher-level analysis skills.

In 2010 I moved from a larger department at a more research-focused public university to a smaller department at a private university that primarily focuses on undergraduate education. As a result of this change, I began to reevaluate my teaching methods in light of smaller class sizes and additional time for student/faculty interaction. With this in mind, I designed EGR 250 for the Spring 2011 semester, following the course design process outlined in “Creating Significant Learning Experiences” by Dee Fink\textsuperscript{4}. This process allowed me to be very intentional in my course design, having a specific learning outcome in mind for each class period and topics covered in my course. “Creating Significant Learning Experiences”\textsuperscript{4} also provided my first exposure to team-based learning (TBL). However, while the goals and promises of TBL were very appealing, I questioned the feasibility of implementing TBL in content-heavy, quantitative engineering courses without removal of required course content. Having a strong proponent of TBL as my faculty mentor during the Spring 2011 semester, I experimented with aspects of what I considered at the time to be TBL – textbook problems as team activities, traditional quizzes as team quizzes, and an overarching team application problem inspired by the work of Gross et al.\textsuperscript{5}. 


While there were lessons learned and benefits from these attempts, this did not constitute true TBL.

In Spring 2012 I began to implement a flipped-classroom approach\(^6\) using screencasts\(^3\). I had previously recorded and uploaded my lecture notes using a tablet PC to allow students to focus on comprehension rather than having to write down every word during class. Screencasts served as an extension of these tablet-recorded notes by recording screen-captures and audio using the open source software Camstudio\(^7\) for short mini-lectures and example problems. The resulting screencasts are then uploaded to YouTube and embedded on the course website or into PDF reading guides using LaTeX. This has permitted the recording of “passive” course content as screencasts provided to students prior to class as part of their reading assignment. This ability to move essential but “passive” course content out of the classroom has served as the key enabler for the use of TBL in content-rich, quantitative engineering courses. TBL has been used to introduce meaningful teamwork and in-depth real-world application activities into the Fluid-Thermal Sciences courses, details of which will be provided in the following sections. First, a brief overview of team-based learning as applied to EGR 450 will be provided, followed by specific examples. Next, the use of TBL in EGR 450 during the Fall 2012 semester will be assessed based on student feedback, instructor observation, and a limited comparison using concept inventories.

Team-based learning has received increased interest within the engineering community in recent years. For example, Olsen\(^8\) and Brewer\(^9\) have used TBL to teach heat transfer courses, O’Connell\(^10\) has used TBL in an electric circuits course, and several courses at the University of British Columbia are taught using TBL (e.g. Construction Management and Mechanical Design\(^11\)). The present work demonstrates an example of TBL for heavily quantitative engineering courses that retains and even increases content coverage through the use of screencasts, while improving student learning and student/faculty satisfaction. It is believed that this use of TBL and screencasts fits well into the changing academic landscape where an increasing amount of excellent content is made freely available online. For example, at learncheme.com\(^12\) faculty at the University of Colorado at Boulder provide hundreds of online screencasts for Chemical Engineering courses. Khan Academy\(^13\) provides an extensive set of screencasts and online problems to teach primarily math and science to K-12 students. At a more comprehensive level, Udacity\(^14\) utilizes screencast-like mini-lectures to provide college level courses taught by prominent experts in the field free of charge, and edX\(^15\) and Coursera\(^16\) provide free online courses in massive online open course (MOOC) format from leading universities. In a recent essay on “The Future of Higher Education,” Baker\(^17\) suggests that to be successful universities must provide students with greater value at lower cost and ponders if ultimately university faculties will change to consist of a small number of expert professors who create educational content and a majority of educational facilitators. Within this context faculty must continue to update teaching methods in order to maintain relevancy and provide added value to
students. Transitioning to a role of in-class learning facilitator, using screencasts – increasingly
provided by leading experts in the field – in combination with TBL can be a powerful method to
create a learning environment that fosters maximum student learning through the practical
application of course content.

2. Team-Based-Learning for Fluid-Thermal-Sciences:

Team-Based-Learning is defined by Michael Sweet in “Team-Based Learning in the Social
Sciences and Humanities”18 as “a special form of collaborative learning using a specific
sequence of individual work, group work, and immediate feedback to create a motivational
framework in which students increasingly hold each other accountable for coming to class
prepared and contributing to discussion.” (For a condensed summary of TBL the reader is
referred to the document “What is TBL?” by Sibley and Spiridonoff.19) The goal of team-based
learning is to shift the in-class focus of a course from obtaining knowledge to learning how to
apply that knowledge. Considerable focus is placed on harder course concepts, providing
students with the opportunity to apply course concepts at higher levels of Bloom’s taxonomy
(applying, analyzing, evaluating, creating) rather than placing the focus of the majority of class
time on lower level knowledge skills (remembering and understanding).

Following the team-based learning (TBL) approach, students are assigned to learning teams
during the first day of classes and remain in those teams throughout the semester. While the
traditional TBL approach consists of Pre-Class Preparation (no in-class time), Readiness
Assurance (1-2 class periods), and Team-Application of Course Concepts (1-4 class periods), the
approach was adjusted to provide students with more guidance during the Preparation Phase (3-4
50 minute class periods), which in this work will also be referred to as the Basic Knowledge
Acquisition Phase due to its extended nature. Here the objective was to shift basic textbook
material (covered during in-class lectures in previous years) outside of the classroom, in the
spirit of the flipped-classroom approach. During the Basic Knowledge Acquisition Phase of the
TBL cycle, students read textbook material, watch brief screencasts prepared by the instructor to
highlight, explain, and/or illustrate difficult concepts, and answer a few conceptual reading
questions for each class period. In-class time is then spent discussing the assigned reading and
having students actively involved in problem solving. The main homework assignment for the
module is due at the end of the Preparation/Basic Knowledge Acquisition Phase. Following this
phase, students are given a multiple choice Readiness Assurance Test (RAT) focused on
conceptual questions and very brief problems to ensure a foundational understanding of the
course material. The RAT is completed first individually (IRAT) and then by each team (TRAT)
utilizing “IF AT” forms20 for immediate feedback. Using this approach, I have been positively
surprised by the success of team-learning and the active student-led discussion during the TRAT
phase. Finally, during the Application phase, student teams are given complex problems that
model real-world applications of the course material.
For Thermal-Fluid Sciences II (EGR 450), the following course topics are covered using "Fundamentals of Thermal-Fluid Sciences" by Cengel et al. as the primary textbook: 2nd Law, Entropy, Power Cycles, Potential Flow, External Flow, Internal Flow, Forced Convection, Natural Convection, Heat Exchangers, and Radiation Heat Transfer. In the past, this course was taught as a 6 module course with 5 quizzes and one final exam. Each module consisted of roughly 6-8 50 minute class periods of lecture and problem solving, followed by a quiz on the material. For Fall 2012, this course was redesigned using 6 team-based learning modules, one Midterm, and one Final Exam. Details for each learning module are shown in Table 1. Subsequent sections will provide specific examples of team formation and assessment, the basic knowledge acquisition phase, the readiness assurance tests, team-application problems, labs, and grading. All examples will be taken from Module III: Aerodynamic Design, so that the reader can see one complete learning module.

Figure 1: Comparison of Instructional Activity Sequences. For each instructional method, the top row shows in-class activities and the bottom shows out-of-class activities.
2.1 Team Formation and Assessment

One of the essential elements for the success of team-based learning is team formation. Michaelsen et al.\(^1\) note that two variables are key for successful teams – group cohesiveness and equal talent pool – which can be achieved by having sufficiently large teams, evenly distributing student talents between the teams, and preventing subgroup formation that hinders overall team cohesion. To accomplish this, the instructor should form teams in a way that is transparent to students\(^1\). Differing from other group-based learning approaches, teams in team-based learning are permanent for the duration of the semester in order to maximize team development and synergy. For my course of 11 students, two teams were formed. Students were lined up around the perimeter of the classroom by asking several questions that identified student talents relevant to the course material, especially experience related to the planned application problems. Teams “1” and “2” were then formed by counting off 1-2-2-1-2… to evenly distribute student talents between the teams. The specific questions asked were:

1. Who has participated in undergraduate research in the past?
2. Who enjoys and has experience with computational fluid dynamics?

Table 1: EGR 450 Fall 2012 Learning Modules

<table>
<thead>
<tr>
<th>Module</th>
<th>Topics</th>
<th>Application Problems</th>
</tr>
</thead>
</table>
| I: 2\textsuperscript{nd} Law and Engines | 2\textsuperscript{nd} Law  
Carnot Cycles  
Intro to Entropy  
Otto & Diesel Engines  
Chemical Reactions (Handout) | Design of a Gasoline Engine |
| II: 2\textsuperscript{nd} Law and Gas/Vapor Cycles | Entropy: Liquids, Solids, Gases  
Entropy: Steady-Flow Devices  
Entropy Balance  
Rankine and Brayton Cycles  
Combined Cycle PP (Handout) | Biogas Power Plant Efficiency Improvement  
a) Regenerator  
b) Combined Cycle |
| III: Aerodynamic Design | Conservation Equations (Handout)  
Aerodynamic Design  
Boundary Layer Flow (Handout)  
Potential Flow (Handout)  
Flow over a Flat Plate  
Bicycle Aerodynamics (Handout) | 1. Lift on a Quonset Hut  
2. Drag effect on Shotgun BB shot  
3. Final Project: Bicycle Aerohelmet Design/Construction |
| IV: External Convection | Forced Convection: Flat Plate  
Natural Convection | Design of a Heat Sink |
| V: Internal Flow and Heat Transfer | Laminar/Turbulent Pipe Flow  
Pipe Networks and Pumps  
Thermal Pipe Flow  
Heat Exchangers | 1. Drain Cleaning Robot Flow Analysis  
2. Heat Recovery Steam Generator Design |
| VI: Radiation | Radiation Properties  
Radiation Exchange: Black Bodies  
Radiation Exchange: Gray/Diffuse Bodies | Greenhouse Effect: Solar Oven Analysis |
3. Who enjoys working in the department workshop? (relevant for term project)
4. Who has taken Energy Conversion?
5. Who is a Senior?

This formation process led to two evenly distributed teams that performed well throughout the semester. Immediately following the team formation, the remainder of the first class period was used to give students an individual and team readiness assurance test that reviewed relevant material from previous courses and provided a first exposure to the use of TBL.

Due to the use of permanent teams in team-based learning, it is usually not necessary to formally teach group processes. Assignment quality and immediate feedback serve to promote functioning teams\(^1\). However, in order to provide students with limited formative feedback and to differentiate between individual team-member performances, students completed two peer evaluations during the semester. The peer evaluation form used was a combination of two example forms provided by Michaelsen et al.\(^1\) with some slight modifications and is included in Appendix 1 for the reader’s reference. One formative assessment was performed midway through the semester in order to provide students with constructive positive and negative feedback on their team performance. Each student was provided with an aggregate peer evaluation score and specific comments made by teammates were shared (names withheld) to allow each student to address concerns voiced by their team. The peer evaluation was repeated at the end of the semester and each student’s aggregate score was used as a weighted multiplier to all team-work based course grades. This served to reward strong team contributors and to discourage “social loafing.” Using this approach, I was positively impressed by the constructive feedback provided by students and the careful considerations that students made in determining their peers’ contribution to the team.

At this point I would like to point out that in the past – both as a student and as a professor – I have generally disliked group-work and avoided group assignments, with the exception of labs and end-of-semester projects. My aversion to group-work stemmed mainly from the frequently encountered uneven contributions by team members. While minor tensions arose in this TBL-based course in both teams (involving athletes and/or international students), those where resolved without instructor intervention as teams worked through the various team activities. Even though Michaelsen et al.\(^1\) claim that the TBL format by itself promotes functioning teams, the small sample size and short duration during which I have employed TBL in my courses is insufficient to support or dispute this claim. However, the fact that almost all team-activities took place during class time ensured that team members were present and promoted collaboration on all problem solving aspects. Furthermore, the instructor’s presence during those team activities likely further increased student motivation, given that non-contributing team members would be immediately noticed and given feedback. Thus, this TBL approach to team-work compared favorably to my past experience with team assignments, where teams frequently divided the work into individual tasks to be completed by each team member – a process that often leads to
conflict and poor performance. Finally, it should be pointed out that the small class size at a university with a fairly homogeneous student body likely further reduced the potential for team conflicts.

### 2.2 Preparation/Basic Knowledge Acquisition

Each course module begins with the Basic Knowledge Acquisition Phase, which focuses on broad content coverage. As stated previously and shown in Fig. 1, this phase was expanded in comparison to the traditional TBL Preparation Phase in order to account for the heavy quantitative nature of this course. Students are given reading assignments supplemented with screencast mini-lectures and example problems, and the material is further reinforced with conceptual reading homework assignments. Several class periods are then used to discuss the reading material and solve in-class example problems. The Basic Knowledge Acquisition Phase culminates with a homework assignment. The following paragraphs provide specific examples from the four class periods devoted to this phase in Module III: Aerodynamic Design.

In preparation for the first day, students were given a handout from Chapter 5.7 of “Heat Transfer” by Mills\(^{22}\) supplemented with a screencast overview of the conservation equations (see Fig. 2). Here, it should be reiterated that the use of screencasts is the main enabler for team-based learning in this content rich course with a heavy quantitative nature, permitting the shift of lecture content out of the classroom and allowing in-class time to be used for more student centered active learning approaches. (Currently I have prepared more than 100 screencast mini-lectures and example problems for EGR 250 and EGR 450.) Day 1 of the module was then spent on actively guiding students through the solution of the conservation equations for Poiseuille flow between two infinite parallel plates. The reading assignment for Day 2 included sections from the course textbook\(^{21}\) on external flow, as well as the paper “Ludwig Prandtl’s Boundary Layer” by Anderson\(^{24}\). Day 2 was then spent discussing aerodynamic design and watching the “Clean Car vs Dirty Car” Mythbusters episode\(^{25}\). Preparation for Day 3 consisted of a handout of chapters 6.4-6.6 from Munson et al.\(^{26}\) on potential flows followed by an in-class discussion of examples and insights gained from and limitations of potential flow solutions. Finally, preparation for Day 4 consisted of additional reading from the course textbook, as well as a handout on bicycle aerodynamics from “Bicycling Science” by Wilson\(^{27}\). While this is a considerable amount of material to cover in four class
periods, the goal at this point is a broad coverage of concepts and simple applications, not mastery of the material. Specific in-depth applications of the material are the focus of the team-application activities to be discussed later.

2.3 Readiness Assurance Process

The Readiness Assurance Process follows the Basic Knowledge Acquisition Phase of each module in order to ensure that students have a basic conceptual understanding of the course material and can solve a few simple problems. For the present course, this stage consists of Individual Readiness Assurance Tests (IRAT), Team Readiness Assurance Tests (TRAT), and a discussion phase. Here, the IRAT and TRAT tests are the same multiple-choice test, given first individually and then to each team. While I was initially skeptical of multiple-choice tests, it was this aspect of team-based learning that first impressed me with the ability of TBL to get students to actively discuss/debate course topics and learn from each other. The excitement, information sharing, and learning that happens during this phase of TBL, if the RAT questions are well-designed, is surprising. The challenge in designing a good readiness assurance test is to ensure that questions cover foundational concepts and are sufficiently difficult to promote group discussion during the TRAT phase. Thus, the conceptual questions are purposefully difficult, leading to relatively low IRAT average test scores (between 52% and 72% for the 6 tests in this course) and promoting engaged team reasoning rather than trivial agreement on the obvious answers during the TRAT phase. While this requires a considerable up-front time investment by the instructor, students benefit from immediate feedback and instructors from instant grading. The immediate feedback during the TRAT phase is further enhanced through the use of multiple-choice “IF-AT” forms. Using these forms, each team scratches-off the intended multiple choice answer and receives immediate feedback on its correctness as shown on the example “IF-AT” form shown in Figure 3. If an answer is incorrect, the team is encouraged to discuss the question further in order to...
arrive at the correct answer, which is rewarded with partial credit (½ credit for arriving at the correct answer with the 2\textsuperscript{nd} attempt and ¼ credit for the 3\textsuperscript{rd} attempt). Following the IRAT and TRAT tests, questions regarding the RAT are clarified and remaining misunderstandings are explained and discussed.

A sample Readiness Assurance Test for Module III: Aerodynamic Design is included in Appendix 2. While this particular RAT turned out to be too difficult and slightly unclear with an individual average score of only 5.2/10, it highlights the basic components of the RATs used in this course. The team average was 9.38/10 and serves as an example of the value of team collaboration. While one team had a team member with a perfect individual score and also obtained a team score of 10/10, the second team had a TRAT score of 8.75/10, much better than the best individual score of 7/10. Averaged over the whole semester, both teams had a TRAT score of 96\%, average individual IRAT scores of 63.5\% and 64.5\%, and average best team member scores of 93\% and 87\%. These averages illustrate that often all teams in a class outperform the best individuals\textsuperscript{1} and that the team formation process led to an evenly distributed talent pool. A sample “IF-AT” form for the Readiness Assurance Test in Appendix 2 is shown in Fig. 3.

\subsection*{2.4 Application Problems}

Following the Readiness Assurance Process, students spent several class periods solving complex, real-world, team-based application problems. As indicated by Sibley and Spiridoff\textsuperscript{19}, the application problems should be (a) relevant and significant, (b) the same for each team, (c) require specific choices to be made, and (d) allow teams to report results simultaneously. As such, the application problems chosen for this course were more difficult and more application focused than problems covered in the previous offering of the course. A list of application problems for all modules is provided in Table 1. For Module III in particular, three application problems were given. First, the analysis of a Quonset Hut was used to reinforce the coverage of potential and viscous flows (2 class periods). Second, the effect of aerodynamic drag on the velocity of shotgun BB pellets was determined (1 class period). (This problem was given as an exam question during the previous year with no student obtaining a correct answer but was solved successfully by both teams in the TBL setting.) Third, students were asked to analyze, design, and construct a time-trial aerodynamic bike helmet as an overall, semester-long course project. Details of both Application Problems 1 and 2 are provided in Appendix 3. While the application problems for this course were well received by students, the majority of problems were somewhat open-ended, not providing students with specific choices as suggested by Sibley and Spiridoff\textsuperscript{19}, making simultaneous reporting and direct comparison between teams difficult at times. As I see benefits to both problem types (open-ended and specific-choice), I am considering to add specific choices to some application problems while maintaining a mixture of both problem types.
2.5 Labs

Traditionally EGR 450 consisted of three 50 minute class periods and one separate 160 minute lab period each week. Transitioning to TBL, I maintained some of the traditional lab experiments but integrated lab and class much more closely, modifying many lab experiments to specifically complement and support application activities. Labs related to Module III included Potential Flow and Turbulent Flow analysis using COMSOL Multiphysics, Windtunnel visualization of flow separation, and construction of fiber-glass composite airfoils in preparation for the final project aero helmet construction.

2.6 Grading

Compared to the previous traditional offering of EGR 450, a considerable portion of the grade for the redesigned TBL course is based on teamwork (40%) to emphasize the value and importance placed on teamwork. Of those 40%, TRAT grades constituted 10%, lab and application activities 15%, and the final team project 15% of the overall grade. As mentioned previously, peer evaluation scores were used as a weighted multiplier to all team-work based course grades rewarding strong team contributors and discouraging “social loafing.” The individual grades were 20% for the midterm exam, 20% for the final exam, 10% for homework, 5% for IRAT grades, and 5% for completing the Concept Inventories for Thermodynamics, Fluid Mechanics, and Heat Transfer. The primary purpose for the use of outside concept inventories was the comparison between the TBL and non-TBL version of EGR 450. Grades were given for taking the concept inventories (not for particular scores) in order to discourage academic dishonesty and to obtain a more accurate comparison between courses. Both midterm and final exam consisted of traditional, individually graded problem solving, similar to previous years but with different problems and less partial credit awarded. The homework assignments were submitted and graded individually; however, students were encouraged to study for and work those problems with their peers.

3 Assessment

Due to the small program size at Union University (11 students in the current class) it is not feasible to offer 2 versions of EGR 450, one using TBL and one as a control group. Further comparing 2 courses from consecutive years would not provide statistically significant results. Thus, the assessment of the success of teaching EGR 450 using TBL is based primarily on student feedback and instructor perception. As a quantitative measure of comparison, both the Fall 2011 and Fall 2012 offering of the course completed concept inventories. While the available concept inventories are limited in their applicability to compare the two courses due to a) an ambiguous formulation of some questions, b) coverage of material beyond the current course or during the first course, and c) an insufficient student number for statistically significant
results, they provide the only direct comparison between the TBL and non-TBL courses. Students during Fall 2011 took concept inventories for Fluid Mechanics$^{30}$ and Heat Transfer$^{31}$ with averaged scores of 45.8% and 56.2% respectively, while students during Fall 2012 took concept inventories for Thermodynamics$^{29}$, Fluid Mechanics$^{30}$ and Heat Transfer$^{31}$ with averaged scores of 60.0%, 52.1%, and 62.6%, respectively. These results indicate a slight improvement in overall scores for the TBL course which seems plausible due to the increased focus on conceptual reading questions and conceptual questions on the RAT; however, the results from the comparison are statistically insignificant, given the small sample size. (The Thermodynamics inventory was added in 2012 for completeness sake. During Fall 2011 I was not aware of the inventories at the beginning of the course when the relevant Thermodynamics material was covered.)

In addition to Union University’s standard course review questionnaire, I provided students with two additional opportunities to provide specific feedback on the course’s TBL format, one midway through the semester and one at the end. Results from these questionnaires are summarized in Table 2. Overall, the student responses to TBL are very positive. Based on the first portion of Table 2, students feel that the TRAT contributes particularly to their learning. When asked to compare the effectiveness of traditional quizzes with the Readiness Assurance Tests, 8 out of 11 students favor the TBL approach. Students particularly liked justifying and discussing their answers with their peers and receiving immediate feedback. The main concerns expressed were that the RAT was closed book and that traditional quizzes serve as better preparation for the midterm and final exams as they follow the same format.

Considering the team application problems, students enjoyed the collaborative and practical nature of the problems but asked for a more comprehensive discussion of the final results. The main negative comment by 3 students in the course was that their teams moved very fast, leaving them lost in the process. The author suspects that this is at least in part due to the open-ended nature of the team assessment problems used and hopes to address this issue by adding more specific choices to the team activities in order to promote increased team discussion and decision making.
When asked to directly compare TBL to the traditional approach used in the previous course taught by the same instructor, 8 out of 9 students responded that they prefer TBL and that TBL promoted the best learning. 7.5 out of 9 students (1 student gave comments that were both positive and negative) considered the team format to be fair with one student taking particular issue with the fact that their grade depended in part on peer evaluations. There was also expressed concern regarding the fact that not all group members could be assigned a 10/10 on the peer evaluations (see Appendix 1). Finally, while not asked as part of the EGR 450 questionnaire, the same student group indicated unanimous support for the online screencasts in the EGR 250 course questionnaire during the previous semester. The primary student request was the addition of extra screencasts with example problems. The student support for the TBL format is further reflected in the results from the standard university course evaluation. While no

<table>
<thead>
<tr>
<th>Table 2: Course Questionnaire Student Feedback Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fall 2012 EGR 450 Midterm Questionnaire: (11 responses)</strong></td>
</tr>
<tr>
<td><strong>How well do the following contribute to your learning in this course? Rate on a scale from 1= “no contribution” to 5 = “significant contribution”.</strong></td>
</tr>
<tr>
<td>Textbook</td>
</tr>
<tr>
<td>Lecture Notes</td>
</tr>
<tr>
<td>In class example problems</td>
</tr>
<tr>
<td>Homework Problems</td>
</tr>
<tr>
<td>Readiness Assurance Test (IRAT)</td>
</tr>
<tr>
<td>Readiness Assurance Test (TRAT)</td>
</tr>
<tr>
<td>Lab</td>
</tr>
<tr>
<td>Team Application Problems</td>
</tr>
</tbody>
</table>

Additional Midterm Questions: (11 responses)

<table>
<thead>
<tr>
<th><strong>Question:</strong></th>
<th><strong>Positive</strong></th>
<th><strong>Negative</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Compared to traditional quizzes, does the use of the Readiness Assurance Process including individual and team tests help you learn? Why? Why not?</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Do the Team Application problems enhance your learning? Why? Why not?</td>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

| **Fall 2012 EGR 450 Final Course Questionnaire: (9 responses)** |
| **This course was taught using a team-based learning approach. Comparing this format to the more “traditional format” used in EGR 250, please provide some brief comments:** |
| **Which format do you prefer? Why?** | **TBL** | **Traditional** |
| | 8 | 1 |
| Which format promotes the best learning? Why? | 8 | 1 |
| Was the team format fair? (grading, work-sharing, etc.) | 7.5* | 1.5* |

| **Spring 2012 EGR 250 Final Course Questionnaire: (9 responses)** |
| **Question:** | **Positive** | **Negative** |
| Did the online screencasts help you learn the course material? | 9 | 0 |

* One student provided both positive and negative responses and was therefore credited as half to TBL and half to Traditional format.
university wide course evaluation was performed for Fall 2011, the author’s EGR 450 course received an average score of 3.96/5 during Fall 2010 and an average score of 4.69/5 during Fall 2012, indicating great overall satisfaction of the TBL course by students.

The author’s perception of the effectiveness of TBL for the current course agrees with the student responses, and the use of TBL in EGR 450 seems to be a great success. The active engagement by students with course content observed during this semester surpasses the author’s previous experience and expectations for this course. Modifying the course to TBL format consisted of a considerable initial time investment, however, it is considered time well spent. While there is much room for improvement with respect to the addition of screencasts, refinement of readiness assurance tests, and further development of real-world application activities, the author will continue to transition and teach this course sequence using TBL.

4 Conclusions:

Combined with screencasts, team-based learning has been successfully implemented in a content-heavy, quantitative senior level Thermal-Fluid Science course, leading to increased student learning and overall course satisfaction for both students and instructor. Initial concerns regarding the necessity to reduce course content to implement TBL were alleviated through the use of screencasts, which are considered as a key enabling technology for TBL implementation in this course. To the contrary, the use of real-world application activities led to increased student motivation and interest and actually led to an increase in content coverage for the course, agreeing with observations made by Michaelsen et al. Further, the application activities supplement the textbook by providing missing depth and relevancy. While developing meaningful TBL activities for an existing course requires a considerable up-front time investment, overall positive student feedback and increased student engagement and learning make it worth the effort. While TBL works for all class sizes, including the 11 student, two-team EGR 450 course discussed here, I believe that more teams can provide added benefit through increased team competitiveness and comparison, further enhancing the positive learning effects of TBL. It seems that 5-10 teams might constitute an ideal environment, while even larger class sizes are certainly possible but would most likely require more planning in order to manage team interactions efficiently. Finally, the combination of TBL and screencasts provides a flexible and engaging instructional model that fits well into the changing landscape of higher education.

During the ongoing Spring 2013 semester, I am implementing TBL in Union University’s sophomore level fluid-thermal science course (EGR 250) with mixed preliminary results. As students enter this course with less prior background knowledge, students were initially overwhelmed by the “Basic Knowledge Acquisition” phase of learning. As a result, I devoted more class time than planned to knowledge acquisition, in-turn allowing less time for TBL application problems. I am currently experimenting with placing “Udacity\textsuperscript{14}-like” lessons on the
course management website that guide the students through the “Basic Knowledge Acquisition” process by providing multiple short (average of 2 minutes each), detailed but focused, screencasts interspersed with brief quiz questions in preparation for each class period in this phase of the TBL process. This approach seems to be well received by students and provides more in-class time for active discussion of the course material. Based on this experience, I believe that TBL has the potential to improve student learning in this lower level course as well. However, it seems that for lower level courses, shorter and more frequent team application problems might be advantageous, while students in upper level courses can be tasked with more comprehensive application problems spanning multiple class periods.

For future courses in the Thermal-Fluid Science sequence, I consider to further revise the “Basic Knowledge Acquisition” phase by creating additional screencast based lessons and supplementing them with screencasts from the extensive library provided on www.learncheme.com. I further plan to revise the primarily open-ended application activities to provide more specific choices for students. Finally, while the use of a TBL-based approach has led to improved student engagement and perceived learning in the discussed senior level Thermal-Fluid Science course, I would like to mention that I see TBL as only one of many options to more actively engage students in the learning process and do not plan to use it in all of my courses.

References:
8. Olson, B. W. A Practical Application of Team Based Learning to Undergraduate Engineering Coursework. Proceedings of the 2005 Midwest Section Conference of ASEE.
10. O’Connell, R. M. *Adapting Team-Based Learning to Early Engineering Courses*. Proceedings of the 2011 Midwest Section Conference of ASEE.


Appendix 1: Peer Assessment (slight augmentation from Michaelsen et al.1)

EGR 450 – Mid-Term Group Member Assessment

Peer Evaluation

Name: _____________  Team #: ___________

Please assign scores that reflect how you really feel about the extent to which the other team members of your team contributed to your learning and/or your team’s performance. The present assessment is for the benefit of each team member and will not be factored into your course grade. At the end of the semester, this evaluation will be repeated and will contribute to the team component of the course grade. (Note: If you give everyone pretty much the same score, you will be hurting those who did the most and helping those who did the least.)

In your evaluation of everyone’s contribution you should consider such things as:

- Preparation – Were they prepared when they came to class? Did they come to class?
- Contribution – Did they contribute productively to group discussion and work?
- Respect for others’ ideas – Did they encourage others to contribute their ideas?
- Flexibility – Were they flexible when disagreements occurred?

Instructions: In the space below please rate each of the other members of your team. Each member’s peer evaluation score will be the average of the points they receive from the other members of the team. To complete the evaluation you should:

1) List the name of each member of your team.
2) Assign an average of 10 points to the other members of your team. (Thus, for example, you should assign a total of 50 points if your team has 6 members, including yourself).
3) Differentiate some in your ratings. E.g. you must give at least one score of 11 or higher and one score of 9 or lower
4) Provide brief reasons for your evaluation. These comments – but not information of who provided them – will be used to provide feedback to students who would like to receive it.

1. Name: ______________________________  Points Awarded: ______________ 
   Reasons for your evaluation:

2. Name: ______________________________  Points Awarded: ______________ 
   Reasons for your evaluation:

3. Name: ______________________________  Points Awarded: ______________ 
   Reasons for your evaluation:

4. Name: ______________________________  Points Awarded: ______________ 
   Reasons for your evaluation:
1. The main aerodynamic advantage of an aerodynamic bike helmet when compared to a traditional road-racing helmet comes from:
   a) A reduction in helmet weight
   b) A decrease in the bicyclist’s frontal area
   c) A reduction in friction drag due to the helmet’s smoothness
   d) A reduction in pressure drag by minimizing flow separation

2. Considering a constant drag coefficient, the power required to overcome aerodynamic drag increases as a function of:
   a) V^4
   b) V^3
   c) V^2
   d) V

3. The figure below shows the velocity magnitude for flow over a golf ball (left to right). Potential flow models the fluid with reasonable accuracy in which of the following regions:
   a) I
   b) I & II
   c) I, II, & III
   d) I, II, III, & IV

4. A spherical 5-m-diameter hot air balloon that has a total mass of 230 kg is standing still in air on a windless day. The balloon is suddenly subjected to 40 km/h winds. The density, viscosity and Coefficient of drag for the balloon are given as: \( \rho = 1.204 \text{ kg/m}^3 \), \( \mu = 1.825 \times 10^{-5} \text{Ns/m}^2 \), and \( \text{Cd} = 0.5 \) (if Laminar – RE<200000) or \( \text{Cd} = 0.2 \) (if Turbulent – RE>200000). The initial acceleration of the balloon is most accurately given by.
   a) 1.27 m/s^2
   b) 3.17 m/s^2
   c) 4.23 m/s^2
   d) 10.57 m/s^2
5. The conservation of mass and conservation of momentum equations for 3D Cartesian coordinates are shown below. For the steady-state flow scenario shown on the right, where fluid is located between 2 infinite plates, separated in the y-direction. To what equation does the system of equations simplify if the top plate is pulled in the x-direction with a velocity of $U$ and we can neglect gravity ($f_x=f_y=f_z=0$) – no pressure gradient exist in the fluid?

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0
\]

\[
\rho \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = -\frac{\partial p}{\partial x} + \mu \nabla^2 u + \rho f_x
\]

\[
\rho \left( \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right) = -\frac{\partial p}{\partial y} + \mu \nabla^2 v + \rho f_y
\]

\[
\rho \left( \frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} \right) = -\frac{\partial p}{\partial z} + \mu \nabla^2 w + \rho f_z
\]

a) $\frac{\partial P}{\partial x} = \mu \left( \frac{\partial^2 u}{\partial y^2} \right)$
b) $\mu \left( \frac{\partial^2 u}{\partial y^2} \right) = 0$
c) $\rho u \left( \frac{\partial u}{\partial x} \right) = -\frac{\partial P}{\partial x} + \mu \left( \frac{\partial^2 u}{\partial y^2} \right)$
d) None of the above is the correct simplification of the system of equations.

6. The Potential Flow equation discussed and used in class is based on which assumptions about the flow field?

a) Irrotational, inviscid, steady flow
b) Irrotational, frictionless, incompressible flow
c) Inviscid, incompressible, steady flow
d) All of the above

7. The Momentum Equations (Navier-Stokes equations) are derived by summing the following effects over a control volume

a) Gravity as a body force and pressure and shear stresses as surface forces
b) Gravity as a body force and pressure, normal, and shear stresses as surface forces
c) Work of gravity, work of surface forces, and convection
d) Energy Inflow, Conduction, Work of body forces, Work of surface forces, heat generation

8. At a low velocity (Reynolds number close to 1), which of the following shapes, drawn to scale, would have the lowest drag if the fluid moves across the object from left to right (all objects have the same height)?

a) [Shape A]
   b) [Shape B]
   c) [Shape C]
   d) [Shape D]
9. In class we showed that the pressure distribution around a circular cylinder as predicted by the potential flow theory is given by \( P_x = P_\infty + 0.5 \rho U^2 (1 - 4 \sin^2 \theta) \) and that the drag on the cylinder can be computed as

\[
F_x = F_d = -\int_0^{2\pi} P_x (\cos \theta) ad \theta.
\]

The lift on the upper half of this cylinder as illustrated below - if the internal pressure is \( P_\infty \) - is best expressed as:

a) \[ F_L = -\int_0^{\pi} \left[ 0.5 \rho U^2 (1 - 4 \sin^2 \theta) \right] (\cos \theta) ad \theta \]

b) \[ F_L = -\int_0^{\pi} \left[ P_\infty + 0.5 \rho U^2 (1 - 4 \sin^2 \theta) \right] (\cos \theta) ad \theta \]

c) \[ F_L = -\int_0^{\pi} \left[ P_\infty + 0.5 \rho U^2 (1 - 4 \sin^2 \theta) \right] (\sin \theta) ad \theta \]

d) \[ F_L = -\int_0^{\pi} \left[ 0.5 \rho U^2 (1 - 4 \sin^2 \theta) \right] (\sin \theta) ad \theta \]

10. For laminar flow over a flat plate the coefficient of drag is given as: \( C_d = \frac{1.33}{Re^{1/2}} \). Assuming the flow to remain laminar. By what factor will the drag force change if the velocity is doubled?

a) 2.83 fold increase

b) 1.41 fold increase

c) 0.71 fold increase

d) 5.64 fold increase
Appendix 3: Application Activities for Module III

Application Problem: Quonset Hut - EGR 450

Your team is working for Barns INC, the nation’s leading supplier of metal sheds. Tornado season has identified a key flaw in recently installed barns, as they do not seem to be anchored sufficiently and lift off the ground during storms.

Your team is tasked with determining the lifting forces on your company’s standard shed, which has a diameter of 6m and a length of 18m. Maximum winds of 100 km/h are expected for outside temperatures of 5°C and a barometric pressure reading of 720 mm of Mercury both inside the shed and at $P_{\text{inf}}$.

1. Use potential flow theory to determine the Lift on the barn.

2. To check if your previous results are reasonably accurate, your boss requests a more detailed analysis based on experimental results for the wall shear stress and pressure coefficient over the barn. Taking the wall shear stress profile from Example 9.8 and the pressure distribution from Example 9.9 in Munson et al. determine the net force tending to lift the hut off its foundation and compare the results to those obtained from the potential flow solution.

Application Problem: Shotgun - EGR 450

You team is working for Remington to determine the effectiveness of its BB-shotgun shells for duck hunting. The shot has a diameter of 4.57mm and a mass of 0.57g. If it leaves the muzzle of a shotgun at 1550 ft/s (473.6 m/s), as accurately as possible, approximate its velocity after 40 meters if the pellet has a smooth surface and state your assumptions/simplifications clearly. Also determine the time it takes for the bullet to travel that distance. Remember the basic equations: $a = \frac{dv}{dt}$; $v = \frac{dx}{dt}$.

\[ a = \frac{dv}{dt}; v = \frac{dx}{dt}. \]