AC 2008-317: STRUCTURING TEAM LEARNING TASKS TO INCREASE STUDENT ENGAGEMENT AND COLLABORATION

Steven Zemke, Gonzaga University

Steven Zemke is an Associate Professor of Mechanical Engineering at Gonzaga University. His primary responsibilities are Design courses and assessment. His research interests include effective learning environments and design teaching and learning. Prior to teaching he was a design engineer and manager for 23 years and holds five patents.

Diane Zemke, Gonzaga University

Diane Zemke is a PhD candidate at Gonzaga University in Leadership Studies. Her interests include small group dynamics, reflective practices, learning, and qualitative methods. She has co-authored papers on use of small teams in design engineering.

Structuring Team Learning Tasks
To Increase Student Engagement and Collaboration

Introduction

Design in industry is usually done in collaborative teams. So, it is only natural that design classes also use teams. Student teams, however, present a common challenge for design faculty. Every instructor is familiar with "dream" teams that excel at everything, and with "nightmare" teams that fail to complete tasks, degenerate into conflict, or both. Though the benefits of learning in teams is widely discussed,[1, 2, 3] practically understanding team-based pedagogies that reliably initiate excellent team performance is very valuable.

This study applied a well-tested team-center pedagogy, *Team Based Learning* (TBL),[4] to an intermediate design class. TBL, developed by L. K. Michaelsen, integrates pre-class reading, short individual and team assessment quizzes, and challenging in-class team tasks. The design of TBL in-class tasks is fundamental to stimulating teamwork and learning. The tasks must draw the students together collaboratively for learning. If the tasks fail to do this, teamwork and learning both suffer.

Creating in-class tasks that truly engage teams can be difficult. Some tasks that initially appear good do not initiate collaboration. Furthermore, Michaelsen's guidelines for creating good tasks do not easily transfer to engineering design. Our intent in this study was to learn how to create tasks that engage students and initiate active collaboration.

In this study, we taught an intermediate design class using TBL. Video-recordings of teams working on tasks and the class handouts that initiated the tasks were collected as data. Mixed quantitative and qualitative research methods[5] were used to assess which in-class tasks supported high student collaboration and why. The findings of this study apply directly to using TBL in design classes and generally apply to other team tasks.

Team Based Learning

TBL divides a course into 2-3 week topics, each topic taught in three phases:

1. Phase 1, Preparation: Students read the textbook chapter before class. In class, the students are given a short quiz over the material, first individually and then as a team. During the team quiz, the instructor grades a few of the individual quizzes to spot areas of weakness. The instructor then gives a short lecture to improve student understanding in weak areas. The preparation exposes students to the content while freeing class time for application.

2. Phase 2, Application: Teams are alternately given in-class exercises with end-of-class feedback and out-of-class homework. The complexity of the feedback and homework is

increased each session. Team cohesion develops during this time due to working together to complete tasks. The application trains students to use the content learned during preparation.

3. Phase 3, Assessment: Each topic concludes with either an exam or a graded team project.

Though similar to other forms of Collaborative and Cooperative Learning (Johnson, Johnson, and Smith[6], Sharan[7]), Michaelsen, Bauman Knight, and Fink[4] draw some distinctions. TBL does not use assigned roles whereas Cooperative and Collaborative Learning (C&CL) frequently do. TBL depends on group grading, prompt feedback, and peer assessment to stimulate team interdependency, C&CL may or may not. C&CL advocates specifically teaching and monitoring group processes, whereas TBL depends on difficult tasks to stimulate group processes.

Applying TBL to the Design Class

TBL was applied in the following way to the class in this study:

1. Learning phases were one week long to fit chapter length in the design text, *Engineering Design* by Eggert.[8]
2. In-class quizzes and exercises followed the TBL model.
3. A team design project spanning several weeks was the homework. Weekly assignments on the project were required.
4. Grading of the weekly assignments and a midterm formed the assessment.

The class met in two-hour blocks, twice weekly for 15 weeks. The class of 24 students, 21 men and 3 women, was pseudo-randomly divided into six teams of four by the instructor. Although teams were assigned, team members chose their roles within the team; the instructor did not assign them. These teams remained constant until mid-semester, when the instructor created new teams that balanced student abilities.

Each team activity fit in a 50-minute period. A short lecture was given before each activity to orient the teams to the activity and to answer questions. The students were given a handout defining the task and other necessary information. The teams then completed the task and posted their results on the board. A whole-class discussion followed to give the students feedback on their work. Table 1 summarizes the assigned tasks and artifacts to deliver for the discussion. An example of the classroom handout for Session 1 is included in Appendix A.

Overview of In-Class Sessions		
Session	**Tasks**	**Artifacts**
1. Analyzing Design Alternatives	Arrange production equipment to optimize material/part flow on a factory floor	• Layout guidelines • Optimized layout • Presentation of results
2. Product Decomposition	Decompose a product into subassemblies to fit assembly cell constraints	• Product decomposition diagram

Overview of In-Class Sessions		
Session	**Tasks**	**Artifacts**
3. Customer Requirements & Engineering Characteristics	Identify top three customer requirements from a set of customer surveys, convert requirements into measurable design goals	• Table relating customer requirements to engineering design characteristics
4. House of Quality (HoQ), part 1	Create a HoQ with <10 customer requirements, <10 engineering characteristics and determine relationship between the two	• HoQ diagram for customer requirements and engineering characteristics
5. House of Quality (HoQ), part 2	Set the performance targets for the new product by building on part 1 and homework internet searches of benchmark data	• Remaining HoQ room from part 1
6. Concept Design, part 1	Create a use analysis for a glass-cutting machine, generate a concept design by combining alternative sub-functions constrained by the use-analysis	• Use analysis • Sketch of best three concepts
7. Concept Design, part 2	Create 3 machine concept alternatives by combining competing sub-function concepts, evaluate alternatives using Pugh's method	• Sketch of best concept
8. Configuration Design	Optimize a gearbox configuration for volume and efficiency given a reduction ratio and gear pair efficiencies	• Sketches of optimized gearbox configurations
9. Design improvement	Apply DFM and DFA guidelines to improve part design and assembly on student project	• Sketch showing each instance of a DFM or DFA improvement
10. Performance Evaluation	Assess self and teammates abilities using teamwork rubric, review assessments, and create team rules to improve performance within team	• List of team rules to improve team performance
11. Parametric Design	Determine the lightest standard structural beam to meet load and deflection requirements	• Identity of the lightest beam to meet requirements
12. Summary of Design process	Create a flow diagram that explains the design process	• Process diagram
13. Work breakdown and schedule	Create a work breakdown block diagram and a Gantt type schedule	• WBS diagram • Gantt chart

Methods

Collecting data

During thirteen separate class sessions, one team was selected at random and video recorded. The recordings were typically 30 minutes in length. Teams quickly forgot they were being recorded and engaged in authentic behavior while being recorded. The recording process yielded 13 high quality DVDs of team interaction, 11 of which were intact teams from the beginning of the semester.

Reviewing the videos

We reviewed all videos, as a set, two times, and some videos a third time. During the first viewing, the students' actions were recorded. It quickly became obvious that some student discussions were intense and others were distracted. During the second viewing, four questions were developed to focus data gathering. These questions were:

1. What was the level of student engagement? Each session was rated on a four-point scale for engagement.
2. How well were ideas and concepts being developed? The source of ideas, how they were assessed, and how they built into concepts were rated on a four-point scale.
3. Was a visual, verbal, or numerical medium used for collaboration? What purpose did the medium serve? Qualitative descriptions of each session were recorded.
4. What were the most notable aspects of the interactions? Again, a qualitative description was recorded.

The third viewing of the videos rechecked the coding.

The reviewing process was orderly, though not as step-by-step as the description above implies. During review, videos were frequently paused for note taking and discussion between the reviewers. Scenes were replayed for better understanding. Many sessions were partially reviewed and replayed before the final coding scales were settled upon.

Coding scales and underlying premises

Two basic premises underlie coding questions one and two above. First, the amount students learn depends on how actively they apply themselves during learning. The deeper a student engages, the greater that student's learning will be. Further, we assumed that student engagement was observable by their interactions, facial expressions, and body language. Our engagement coding scale is shown in the following table. Student engagement varied during each activity, so use of this scale reflects average engagement.

The second premise underlying the coding is that team learning depends on a source of good ideas that are mutually built and assessed. Without joint processing of a rich pool of ideas, the students could learn just as well individually. The flow of ideas and how they are processed is observable in the videos. We label the ideas and processing the *collaboration space* and roughly quantify them with the following scale.

Student Engagement Coding Scale	
Full (3)	Full concentration, physically leaned into task, discussing ideas relevant to *correctly* completing the task.
Moderate (2)	Concentrating but interruptible, physically in the conversation but relaxed, no apparent concern that the completed task will be correct, joking off-task.
Low (1)	Sporadic concentration, physically moving in and out of the conversation, not aware of flow of task conversation.
None (0)	Little or no activity on the task, physically turned away from the group, joking that distracts from the task.

	Collaboration Space Coding Scale			
	High (3)	**Moderate (2)**	**Low (1)**	**None (0)**
Idea Source	Team synthesizes, combines, and/or applies new ideas	Team sifts ideas out of a pool of ideas or experiences	Team lifts intact ideas from a source, no filtering or sifting required	Team is using very few to no ideas
Idea Assessing	Explicit defensible criteria applied and stated	Mix of explicit criteria and unstated opinion, simple error checking	Stated or unstated opinion used	Little to no assessing of ideas
Idea Building	Final solution is synthesis of multiple ideas	Final solution is synthesis of two ideas	First solution is never expanded or improved	Solution is from one person and is inadequate

Question three classifies what *medium* the students used to collaborate. Since every collaboration involved discussion, the classification system considers the inclusion or exclusion of non-verbal expression of ideas. The classification system is shown in the following table.

Collaboration Medium Classification	
Verbal	Tasks without visual or quantitative elements, ideas expressed solely with oral or written words.
Visual	Tasks where sketches, hand gestures, or physical objects are used to convey concepts. Also includes diagrams where position of words adds significant meaning.
Quantitative	Tasks with calculated values or estimates of size.

Creating inferences

The sessions were sorted based on the quantitative coding of engagement and collaboration space. Once sorted, commonalities between high engagement tasks were compared with commonalities between low engagement tasks, to identify features that affected engagement and collaboration. Observations of how the students completed the tasks were then used to understand why these task features were significant.

Results

The table below is an overview of the student engagement and collaboration space rating for each session. The sessions are listed in order of highest student engagement. Brief qualitative descriptions of how the students worked each task are also included.

Observations of Videos Listed by Highest Engagement

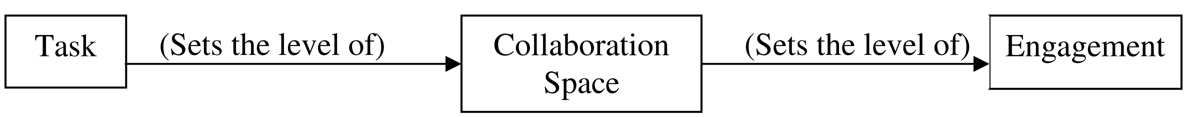
Session	Engagement	Collaboration Space Coding			
		Source	Assessing	Building	Medium
1. Factory floor layout	3,3,3,3 → **12**	3	3	3	Visual
Discussion was intense with all contributing. Floor layout, hand gestures to convey possibilities, and appeal to physical reasoning dominated discussion. Team excelled at layout task at the expense of creating a clear list of layout guidelines.					
2. Product Decomposition	3,3,3,3 → **12**	3	3	3	Visual
Students spent significant time studying the exploded view of a remote control which formed the problem. Discussion was intense with appeal to physical reasoning and hand gestures to convey assembly steps. Scribe created diagram while rest of team continued to work and assess it.					
8. Optimize gearbox	3,3,3,3 → **12**	3	3	3	Visual and numeric
Students spent significant time determining how gear ratios are compounded and how to correctly calculate combined ratios. Once oriented, they created the variations quickly and check the results for ratio and efficiency. Toward end of session, students divided work between sketching and calculating.					
11. Optimize beam	3,3,3,* → 12	2.5	3	2.5	Numeric
(* One team member missing, so total score is adjusted) Team of 3 members fully engaged on finding the optimum beam size. Initial discussion of how to quickly find the answer leads to calculations, calculations fail to yield a solution due to inadequate unit analysis. Team alternates between strategy discussions and calculations. Students analyze variables within equations to assess how to proceed.					

<table>
<tr><th colspan="7">Observations of Videos Listed by Highest Engagement</th></tr>
<tr><th rowspan="2">Session</th><th rowspan="2">Engagement</th><th colspan="4">Collaboration Space Coding</th></tr>
<tr><th>Source</th><th>Assessing</th><th>Building</th><th>Medium</th></tr>
<tr><td>9. Apply DFA & DFM</td><td>3,3,3,2 → 11</td><td>3</td><td>3</td><td>3</td><td>Visual</td></tr>
<tr><td colspan="6">Engagement is full, but discussion is not intense. Students are modifying their part concepts by assessing with DFM rules and creating assembly sequence by applying DFA rules. Much physical reasoning and hand gestures to describe assembly steps. Cell phone used to physically represent design.</td></tr>
<tr><td>7. Combine concepts</td><td>3,2.5,2,1→8.5</td><td>2</td><td>2</td><td>2</td><td>Verbal and visual</td></tr>
<tr><td colspan="6">Student engagement and handling of ideas was dependent on the portion of the exercise. In the first portion, the students worked verbally and visually to synthesize and rate concepts. In the second portion one team member sketched the resulting idea and the others disengaged.</td></tr>
<tr><td>3. Requirements into Design Specifications</td><td>2,2,2,2 → 8</td><td>1.5</td><td>1</td><td>1</td><td>Verbal</td></tr>
<tr><td colspan="6">Discussion was primarily round-robin sharing. Team did not correctly separate customer requirements from engineering design characteristics. No mention of, “Is it right?” or any assessment criteria.</td></tr>
<tr><td>6. Analyze product use to constrain concepts</td><td>2,2,1,2 → 7</td><td>2.5</td><td>2</td><td>2</td><td>Verbal</td></tr>
<tr><td colspan="6">Ideas were shared and recorded with a written list. When combining ideas, verbal descriptions with some hand gestures were used even though sketches would work better. Assessment of ideas was intentionally suppressed during brainstorming.</td></tr>
<tr><td>13. WBS & schedule</td><td>2.5,2.5,1.5,.5 → 7</td><td>.5</td><td>.5</td><td>1</td><td>Verbal and Visual</td></tr>
<tr><td colspan="6">Two students concentrated on the task and other two primarily watched. Though engagement was not terrible, the source of ideas was minimal which rippled to assessing and building of ideas.</td></tr>
<tr><td>4. HoQ, part 1</td><td>2,2,1.5,.5 → 6</td><td>1</td><td>1</td><td>1</td><td>Verbal</td></tr>
<tr><td colspan="6">Discussion was relaxed and meandering. Students did not apply any unstated or stated rules to create the House of Quality. Low effort was given to extracting and assessing problem information to translate customer market into new product target. Time pressure at end temporarily increased engagement.</td></tr>
<tr><td>12. Summarize design process</td><td>2,2,0,1 → 5</td><td>1</td><td>.5</td><td>1</td><td>Visual</td></tr>
<tr><td colspan="6">Students merely lifted information from charts in book to draw their diagram. There was little discussion concerning the best way to present the information. Diagrams in book were considered “the right answer.”</td></tr>
</table>

Observations of Videos Listed by Highest Engagement					
Session	**Engagement**	**Collaboration Space Coding**			
		Source	**Assessing**	**Building**	**Medium**
5. HoQ, part 2	1,1,1,1 → **4**	1	0	1	Verbal
The team completed this exercise by doing tasks by rote. The 1st task was transcribing data from vendor web site information into cells in the HoQ. The 2nd and 3rd tasks required weighing competing values. However, the team had little discussion and applied no opinions or criteria to assess the weighting values.					
10. Performance Eval.	1,1,1,1 → **4**	1	0	0	Verbal
Students seemed engaged in individually assessing performance, but avoided stating any socially uncomfortable comments of teammate's performance. Students entirely dismissed task of creating team rules to improve performance.					

Discussion

The student engagement ratings and the collaboration space ratings roughly track each other. The higher the engagement, the more likely the discussion involved a rich source of ideas being assessed and built. The lower the engagement, the fewer ideas being considered and the simpler the thinking about them. We conjecture that the engagement level depends on the collaboration space level and not the other way around. We also conjecture that the collaboration space depends on the task. These conjectures are diagrammed below.



To complete a simple task, only base level ideas and thinking are needed, hence the students employ little effort and little engagement on the task. To complete a difficult task, richer ideas and higher-level thinking are needed, hence the student employs greater mental effort and hence higher engagement.

A direct application of this model implies that making tasks challenging is sufficient to generate good thinking and high engagement. However, making tasks *appropriately* challenging is not necessarily easy. We observed many well-planned tasks that did not create the desired level of thinking. A task that is too difficult becomes impossible. A complex task can also be misinterpreted as a simple task by the novice. Our quantitative and qualitative review of the videos highlighted four insights that help explain why the engaging tasks were engaging.

Explicit versus implicit instructions

Many times the students did not follow the instructions *as written*. Rather, the students seemed to choose their own method to solve the problem or complete the artifact to be presented or turned in. This was true for both engaging and un-engaging tasks. For example, in Session 1, Factory Floor Layout, the students immediately began laying out the factory floor and skipped the instruction to pre-determine "rules of thumb" to guide the layout. The students later created their "rules of thumb" when preparing their final presentation, long after completing the layout. On an interesting side note, the students were stating "rules of thumb" throughout the layout process, but were unaware of it.

In Session 2, Product Decomposition, the instruction was, "Prepare a product component diagram that breaks down the final assembly…." The students studied the exploded assembly view and then began decomposing the product. Before they had fully decomposed the product, one student began creating the decomposition diagram. As he worked on the diagram, the other three students continued decomposing the product and occasionally passed more information to him. The instruction in this session, as strictly written, was to create the decomposition diagram. However, the students applied themselves to solving the problem and creating the artifact.

Throughout the videos, the students generally followed the written instructions, but chose their own methods to do tasks that completed the problem and created the artifact. At times these choices were different from the written instructions. These student-chosen approaches we label the *implicit instructions.*

Each problem or required artifact inherently embeds many possible implicit instructions. On any given problem, the students can choose several ways to complete it. Thus, it is difficult to predict what implicit instructions will be chosen by the students. However, some problems and/or artifacts bound the implicit instructions. For example, when Session 11 asked the students to find the minimum beam size to meet requirements, the students had to find a way to check all alternatives. Thus Session 11 embedded an implicit instruction of assessing alternatives.

One natural instructor response would be to provide very detailed written instructions and to hold the students to them. Though clear directions are important, students following them do not always bring about the desired learning. For example, the students followed the instructions *as written* on Session 4, House of Quality part 1:

1. Define the customer requirements (no more than 10).
2. Assign importance weightings.
3. Define the engineering design characteristics (no more than 10).
4. Prepare rooms 1 through 4 of a HoQ.

The instructions were intended to initiate a thoughtful discussion. For example, defining design characteristics (step 3) to meet the customer requirements (step 1), requires comparing many ideas to complete well. However, the students defined an inadequate list of engineering characteristics in a perfunctory way. Assigning importance weights (step 2), which involves balancing competing "goods," initiated enough discussion to establish weightings, but not enough to defend the weightings selected. What should be noted here is that the students did complete the tasks and artifact per the instructions. However, given their apparent attention to the instructions, it seemed that more detailed instructions may have increased compliance, but not learning.

From a different perspective, highly detailed instructions bear similarity to very specific equations or algorithms. Just as students are prone to plugging numbers into equations by rote, teams may be prone to plug "activities" into detailed instructions. A team tightly focused on small sequential work could impede higher-level thinking and concepts.

It seems more fruitful to create problems and required artifacts that embed high-level implicit instructions. This perspective seems necessary, but not sufficient to fully guiding the design of problems and artifacts. The following three subsections provide three insights that build on the concept of implicit tasks.

"Solving tasks" versus "Doing tasks"

Five sessions scored 10 or above on engagement. One similarity among these high sessions was that each could only be completed by "solving a puzzle." The puzzle elements in the top five sessions are listed below. Note that each puzzle involves an intrinsic performance measurement to optimize.

Session 1: Arrange floor layout to minimize material and part congestion
Session 2: Decompose product so that like assembly processes are grouped
Session 9: Modify a design so that both DFA and DFM criteria are fully satisfied
Session 8: Choose gear types and ratios to optimize a gearbox for efficiency, volume, and fewest gears
Session 11: Select the smallest structural beam that satisfies all requirements

In contrast to the high-engagement sessions, four sessions scored below 6 on engagement. The corresponding similarity among the low sessions was that each session could be completed by "doing" sequential steps.

The tasks in the lowest four sessions are listed below. Each of these tasks allowed, or perhaps suggested, that the students complete them by merely stepping through a sequence of low-level tasks. Note that these tasks contain no internal measurement of whether each task is done well or not.

Session 4: Complete rooms 1-4 in a HoQ given customer data
Session 5: Complete rooms 5-8 in a HoQ with competitor information found on web
Session 10: Conduct peer assessments and create team rules to increase performance
Session 12: Diagram the design process

It seems reasonable that tasks with an innate puzzle stimulate better learning than tasks that are merely "doing." However, many desired learning outcomes appear to be "doing" tasks. In the class in this study, learning to "do" a House of Quality, "step through" a Design Process, or "run" a Pugh's comparison are reasonable learning outcomes. How can these be converted to puzzle tasks? We suggest the following approach to convert some "doing" tasks into puzzle tasks.

Many "doing" tasks are a sequence of sub-tasks. Some of the sub-tasks are simply "doing," but other sub-tasks are puzzles to solve. When combined into a lengthy sequence, the puzzle elements get diluted. So, we propose finding the puzzle sub-tasks within the "doing" tasks and creating sessions around them and dispense with the "doing" tasks. For example, one step in completing a House of Quality is to prioritize the customer requirements. This can be a puzzle task if given as, "Prioritize the customer requirements to *maximize* potential customers across two adjoining markets." Customer information, with conflicting needs, for the adjoining markets would be provided with the problem.

Accessible assessment criteria

In each of the high-engagement sessions, the students had readily accessible assessment criteria. The students used these criteria to continuously assess their solutions as they created them. We observed four primary assessment criteria:

1. <u>Physical reasoning</u> (Sessions 1, 2, 8, and 9): Students frequently compared whether an activity was physically possible or not. For example, when decomposing the product in Session 2, the students kept track of which part had to be assembled before another so that the whole product could be put together.
2. <u>Problem constraints</u> (Sessions 1, 2, and 11): Limits on acceptable solutions formed another assessment criterion. For example, limits on available floor space in Session 1 provided a criterion the students used to test various layouts.
3. <u>Numerical value</u> (Sessions 8 and 11): Calculated values are one way for students to compare one design to another. In Sessions 8 and 11 the students used finding a highest or lowest value to optimize a design.
4. <u>Optimization rules</u> (Session 9): In Session 9 the students applied a set of DFA and DFM rules to optimize their designs. In contrast to Session 8 and 11 where optimization meant finding "the best" solution by a numeric value, the rules allowed the students to find a "better" design out of a field of competing good designs.

Assessment criteria are a natural part of problem solving. Not only do they allow students to identify a good solution, but they also provide a means for the students to explain why the solution is good. This basic level of understanding is necessary for learning that is more than superficial.

The *accessibility* of the assessment criteria is also important. The students must be able to apply the criteria to shape their solution. In each of the high-engagement sessions the criteria were easily mastered by the teams. This does not however mean that the criteria were necessarily trivial or black and white. For example, each DFA rule is trivial, however taken as a set the rules represent competing goods to balance in a design.

In contrast to the high-engagement sessions, the low-engagement sessions had no meaningful assessment criteria. These sessions specified no assessment criteria, trivial criteria, or impossible criteria. The House of Quality sessions had several tasks and would require a mix of either trivial or difficult criteria to assess. The peer assessment and teamwork session required criteria that crossed a difficult social boundary. Diagramming the design process was trivial to assess since the students chose to present the design process identically to the figures in the text.

Proper use of the collaboration medium

A previous study reported that providing a visual collaboration space improved students' learning together.[9] Similarly, use of a visual collaboration medium dominated the high-engagement sessions in this study. In contrast, in the low-engagement sessions only verbal collaboration was used. A simple application would be to include visual elements in all sessions. However, though visual elements dominated high-engagement sessions, visual elements were also present in very low collaborations as well.

In the high-engagement sessions, sketches, physical objects, and hand motions were used extensively to share, assess, and build ideas. These appeared to be more than simply the means to communicate; they appeared to be the means to think. For example, in laying out the factory floor, hand gestures were used to represent the flow of materials. Bumping hands into each other represented materials colliding. Students would build on each other's ideas by moving their hands in the same physical space around the same imagined objects. Similar effects happened nearly every session when students discussed physical designs.

In contrast, visual elements were used differently in low-engagement sessions. In these cases visual elements, typically sketches, were drawn simply for reporting. The thinking had all been completed and the scribe was recording the ideas. During these times the rest of the team usually watched, corrected spelling, or joked. This phenomenon of the team watching the scribe work was also common in tasks with a verbal collaboration medium. On occasion, a student was able to both record information and participate. However, this was rare.

The basic key to the collaboration medium is that it must support the group thinking quickly. If the medium slows down the ideas, then the thinking is impeded or the medium is simply abandoned. If 3-second hand gestures convey an idea nearly as well as a 20-second sketch, the hand gesture will typically be used. If the quick sketch takes more than a minute, the rest of the team usually moves on.

The practical implication is to structure tasks so that a team's *working* collaboration medium is the artifact to present. When the teams' working sketch is to be presented, it becomes the center of the collaboration and scribing is eliminated.

Effect of team ability on engagement

One concern about interpreting the videos is whether a team's collective ability influences their engagement. For example, would a high performing team typically engage more than a low performing team? If so, coding engagement could mislead inferences about the tasks. However, comparison of three teams, that were each recorded more than once, indicate that the task can be correctly evaluated based on the present methods.

The first team, which performed lowest, was recorded in Sessions, 4, 5, and 11. The team inadequately completed all three tasks. However, the engagement of this team was low on tasks 4 and 5, but quite high on task 11. Furthermore, this team's source, assessment, and building of ideas on task 11 was high. They failed to produce the solution on task 11 due to mistakes with units in calculations, rather than poor thinking relative to the task.

Second, a moderately performing team was recorded in Sessions 1, 6, and 12. This team adequately completed both tasks. In Session 1 the team was highly engaged and the collaborative thinking was high. However, in Session 12 the engagement and collaborative thinking were both low. Session 6 rated half between them.

A third team, which always performed high, was recorded in Sessions 3, 7, 9, and 10. This team completed all tasks well. Similar to the other teams, this team was highly engaged and thinking well on some tasks, and disengaged on other tasks.

A team's engagement seemed to be a much stronger function of the nature of the task than of the team's collective ability. The qualitative observations of the teams also agree with this inference. The students always seemed to be "answering" the "call" of the task. If the task was challenging, they responded with high engagement. If the task was trivial, they responded with an appropriate level of effort.

The primary difference between the high and low teams seemed to be their capacity for overcoming obstacles. The lower performing team seemed to employ less clear strategies, make more errors, and take longer to notice and correct them. The high performing teams had clear strategies, kept track of what they knew and did not know, and caught errors quickly.

Conclusions

Recommendations

This study tested in-class team-learning activities in a junior level design class. We video-recorded student teams at work on 13 different sessions. These recordings were reviewed several times to determine what activities created high student engagement and collaborative thinking. The qualitative and quantitative analyses of our data support the following four recommendations.

1. Structure each task so that the implicit instructions align with the desired learning outcome. Whereas explicit instructions are written, the implicit instructions are unwritten and are embedded in the completion criteria of the task. For example, a task of "finding a minimum beam size" embeds the implicit instruction of comparing several alternative beam sizes. Though the students generally followed the explicit instructions, they seemed more focused on completing the tasks. Hence, the implicit instructions can be more important than the explicit instructions.

2. Structure each task so that it can be completed only by solving an embedded puzzle, rather than by executing a series of simple sequential steps. Tasks with an embedded puzzle generated high student engagement and collaborative thinking. Tasks which could be completed by sequential steps generated low engagement and collaborative thinking.

3. Include accessible assessment criteria in each task. The criteria are accessible if the students can easily employ them to assess the quality of their solution as they create it. Students were observed using four different sources of assessment criteria:
    a. Physical reasoning to determine if an activity was physically possible or not.

b. Constraints within the stated problem.
c. Calculated values to compare one design to another.
d. Optimization rules to compare a design to an ideal.

4. Structure each task so that the artifacts (sketches, charts, etc.) used to solve the task are the artifacts to be presented or turned-in at the end. Visual artifacts seem especially useful in this way.

Participate in a Community of Practice

Creating and testing in-class activities, such as the ones in this study, represents a large investment of time. On the other hand, they can generate excellent learning outcomes. By the time of publication, each of these activities will have been improved and tested again in class. We would like to create a community of instructors using activities of this type. To that end, we freely offer all of our activities for use. We also welcome others to join us in creating and testing more activities. If you are interested, please contact the first author via email.

The first author is also particularly interested in creating activities that specifically teach collaboration skills such as active listening, giving peer feedback, or assigning tasks on teams. These skills are especially relevant to engineers today but represent a significant challenge to teach well. If you are interested in developing an effective and tested curriculum in this area, please also contact the author.

Finally, we wish to thank Brent Fales for his effort in creating half of these activities. Brent taught a parallel section to the one in this study. Without his help, this study would not have been possible.

References

1. Smith, K. A., Sheppard, S. D., Johnson, D. W., & Johnson, R. T. (2005). "Pedagogies of Engagement: Classroom-Based Practices," *Journal of Engineering Education,* 94(1), 87-100.

2. Prince, M., (2004). "Does Active Learning Work? A Review of the Research," *Journal of Engineering Education*, 93(3), 223-231.

3. Wankat, P., and Oreovicz, F., (2006). "A Push for Participation," *ASEE Prism,* 15(5), 39.

4. Michaelsen, L. K., Knight, A. B., & Fink, L. D., eds. (2004). Team-Based Learning: A Transformative Use of Small Groups in College Teaching. Sterling VA: Stylus Publishing.

5. Crewsell, J. W. (2003). Research Design: Qualitative, Quantitative, and Mixed Methods Approached (2nd ed.). Thousand Oaks, CA: Sage Publications.

6. Johnson, D. W., Johnson, R. T., & Smith, K. A. (1991). Active Learning: Cooperation in the College Classroom. Edina: Interaction Book Company.

7. Sharan, S., ed. (1999). Handbook of Cooperative Learning Methods. Westport, CT: Praeger Publishers.

8. Eggert, R. J (2005). Engineering Design. Upper Saddle River, NJ: Pearson Education, Inc.

9. Zemke, S., Elger, D., & Beller, J., "Tailoring Cooperative Learning Events for Engineering Classes," *Proceedings of the American Society for Engineering Education, annual conference*, ASEE, Salt Lake City, UT, June 2004.

Appendix A: Example classroom handout for Session 1

Case: You work for a company that manufactures small parts by molding and machining. The company is profitable, but one of the bigger problems is moving parts around the factory. Some parts are first made on one type of machine, but are completed on a second type of machine. Carts are used to move parts from machine to machine. Many times the carts create a traffic jam in the middle of the factory. The factory floor is only big enough for the machinery, room for one cart next to each machine, and aisles.

The company is shutting down for a week to rearrange the machinery. You are designing the machinery layout so that moving raw material and parts causes fewer problems. The floor is rectangular and is twice as long as it is wide. There are two shipping doors on one of the narrow ends of the building. Raw material comes in one door throughout the day, is moved to the machines, made into parts, brought to the other door, and shipped out. The machinery in the factory includes:

1. 8 mold presses (injection molded parts)
2. 4 numerically controlled (NC) machining centers (like milling machines)
3. 2 numerically controlled (NC) lathes

You have catalogued the parts the factory makes and the sequence of machines that are used to make them. They are:

Number of parts per week	**1st machine used to make part**	**2nd machine used to make part**	**3rd machine used to make part**
100,000	Mold Press	-------------------	-------------------
2000	Machining Center	-------------------	-------------------
50,000	Mold Press	Machining Center	-------------------
50,000	Machining Center	Mold Press	-------------------
500	Mold Press	Machining Center	NC Lathe

You will present the new layout to your boss's, boss's, boss in one month. This boss is a stickler for attention to detail and clear reasoning.

Tasks:
1. Create a few "rules of thumb" to guide the layout. These rules should allow you to compare one layout with another.
2. Create a layout and analyze it using the above rules.
3. Iterate the layout to optimize the flow of materials and parts.
4. Prepare your rules and layout to present in a company meeting to the boss.