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A Virtual Company-based Integrated Learning Methodology to Produce Industry Ready Graduate

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Sam Anand is a Professor of Mechanical Engineering and also serves as the Director of Additive Manufacturing Center and Director of Center for Global Design and Manufacturing at the University of Cincinnati. Dr. Anand's areas of research expertise are CAD/CAM, Product Lifecycle Management, Inspection & Computational Metrology, Virtual Modeling, Simulation and Optimization of Additive and Subtractive Manufacturing Processes. His recent research focus is on optimizing energy consumption and predicting and correcting part errors in Additive Manufacturing. At UC, he also serves as the Director for Partners for the Advancement of Collaborative Engineering Education (PACE). Dr. Anand has published over 80 technical papers, written book chapters and made several invited and conference presentations in his areas of research. He has also successfully obtained funded grants and contracts from various industries, federal and state government agencies. At UC, Dr. Anand has graduated over 50 MS and 8 PhD students in the areas of Design and Manufacturing. He teaches undergraduate and graduate courses in Manufacturing Processes, CAD for Manufacturing, Precisions Engineering and Computational Metrology. He has previously served as Associate Editor of Journal of Manufacturing Systems and Scientific Committee member of the North American Manufacturing Research Institute (NAMRI) of SME. He is senior member of SME and a member of ASME.

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Dr. Imelda Castañeda-Emenaker, MBA, Ed.D, has a Master in Business Administration and a Doctorate in Educational Foundations. She has had primary responsibility for the design and implementation of numerous state and federally funded program evaluations addressing educational issues for pre-K through graduate studies. Dr. Castañeda-Emenaker brings in more than 15 years of program and policy evaluation experience and a strong background in educational research and evaluation methods. She has been key evaluation personnel on projects focused on curriculum development and assessments, planning and implementing professional development that involved both traditional and innovative methods, STEM-related projects, college access, and various other community projects. Dr. Castañeda-Emenaker is the program evaluator of the NSF-funded College of Engineering and Applied Science Seamless Transition from Academic to the Real-world (CEAS STAR) Project, which implemented a Virtual Company-based Integrated Learning Methodology to Produce Industry Ready Graduate.

A Virtual Company-based Integrated Learning Methodology to Produce Industry Ready Graduate

1. Introduction

Traditionally, engineering students are taught in a classroom setting with the instructor explaining various concepts and deriving the appropriate mathematical relationships. The instructor may also present some applications of these concepts. However, students may not really appreciate the true learning of these concepts unless they are tied to a real-world industrial problem that has a direct bearing on the concepts. In addition, an optimal solution to a larger industrial problem requires appropriate synthesis and adaptation of multiple concepts in a discipline or across disciplines in a comprehensive manner. Currently available curricula at most engineering institutions do not include a systematic study of real-world problems, although some organize problems disparately among different courses. Because prevailing engineering education pedagogies do not target real-world problem solving in a comprehensive manner, our graduates need to go through a substantial period of after-hire training before they can contribute to their employers.

To maintain competitive advantages in today's global market, companies are challenging higher education institutions to produce industry ready graduates. To meet this challenge, we developed the EXPLORES **(**Experiential and Problem-based Learning within Opportunities for Real-world Engineering Settings) model based on the problem-based learning (PBL) pedagogy, where students in Mechanical Engineering are exposed to real-world industrial problems that will have a direct bearing on fundamental engineering concepts taught in core mechanical engineering courses. The model is implemented in a learner-centered, knowledge-centered, assessment-centered, and community-centered student learning environment. Specifically, real-world industrial problems are identified that can be broken down into sub-problems and mapped to a selected set of key concepts taught in clusters of core courses in the Mechanical Engineering curriculum. These case problems are presented under a virtual company framework. Students post their work in the virtual company repository during different stages of the learning process. Their solutions and procedures are then viewed by the instructor, industry partners, and other students who provide periodical feedback. Industry experts then meet with students to discuss the pros and cons of the solutions from a real-world perspective.

Four (4) industrial case studies have been developed and implemented in the Manufacturing Processes course. The outcome was evaluated by the University of Cincinnati's Evaluation Services Center (UCESC) through a cohort study. The evaluation produced some interesting findings that are important to guide the implementation of the EXPLORES model. The results have been used to guide the implementation of the EXPLORES model in Engineering Statistics, which is undergoing the same evaluation process in the 2014-1015 academic year.

This paper is organized as follows. Section 2 presents the background of the development of the EXPLORES model, including its theoretical and educational feasibility. Section 3 depicts the details of the EXPLORES model, including the organization of the virtual company. Section 4 describes the implementation of industrial case studies in the Manufacturing

Processes course. The result is discussed in Section 5. Finally, Section 6 summarizes the conclusions drawn.

2. Background

The methodology of incorporating real-world industrial problems in engineering curriculum under a virtual company framework is rooted in the Problem-Based Learning (PBL) pedagogy, which has gained increasing popularity in higher education. The desirable outcome of PBL, compared to traditional modes of teaching is that students develop deep learning approaches that enable them to engage in lifelong learning. Other advantages include increased retention of knowledge, development of integrated knowledge, and increased motivation[1]. The central features of PBL include the following: (1) learning is student-centered; (2) students identify, find, and use appropriate resources; (3) students learn group co-operation in all stages of work; (4) instructors are facilitators; (5) inter-disciplinary learning where solution of the problem can extend beyond traditional subject-related boundaries and methods; (6) opportunity to acquire deeper learning; (7) problems form the stimulus for learning; (8) problems are based on complex, real-world situations; and (9) problems are contextualized to promote student motivation and comprehension.

Recently, application of PBL in engineering education emerges as a response to the demand for engineers with multidisciplinary training to work with the complexity of modern industry. Several studies about PBL in engineering classes found that students favor PBL approach because it stimulates them to tackle the problem and that they can apply their prior knowledge; and students' learning ability is enhanced by learning to work in a cooperative environment[2-4]. Other studies demonstrated the usefulness of PBL in engineering education for promoting students' cognitive skills to solve problems and integrative scholarship[5-6]. However, a meta-analysis by Newman *et al*. on the effectiveness of PBL reports some evidence in favor of PBL as an approach to learning, but not in a consistent manner or in large effect size[7]. Few studies have randomized experiential design to determine the differences between PBL and traditional teaching method for students' learning outcome. One quasi-experimental design by Dennis found that PBL in both face-to-face and online format were equally supportive to students' learning but students in online PBL groups spent more time on learning and that there was a significant relationship between learning issues generated and higher exam scores[8].

A few recent studies showed that integrated approach of PBL pedagogy and online delivery model enhanced students' learning attitudes[9], better prepared students for applying the knowledge learned in the classroom[10], and provided a coherent and comprehensive learning environment[11-12]. These evidences support the presentation of real-world industrial problems using the previously developed virtual company framework. Students will have a better understanding of the industrial environment, why they are learning Mechanical Engineering, and how they can apply what they learned to solve problems that have a direct bearing on company missions.

3. Methodology

Research has shown that people construct new knowledge and understandings based what they already know and believe[13-15]. Students come to the classroom with preconceptions about the subject matter. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn for the purpose of taking tests but revert to their preconceptions outside the classroom[16]. Therefore, instructors must draw out and work with the preexisting understandings that the students bring with them. They must actively inquire into students' thinking and create conditions under which student thinking can be revealed. Formal understanding of the subject matter can then be more effectively built on the basis of student preconceptions. Therefore, a well-designed learning environment must be learner-centered.

The following mechanism is used to draw out students' preconception of a subject matter. Real-world industrial problems will be presented under an on-line virtual company framework. At the beginning of each course, related problems will be presented to the students and the students will be asked to solve these problems as if they are employees of the company who are assigned to work on the projects. Presenting the problems on-line will allow students to conduct in-depth investigation outside the classroom during their convenient time at their own pace. Students will then be required to post their proposed solutions in the virtual company repository. These initial solutions will be used as the basis for group discussions facilitated by the instructor. This process will reveal students' preconception and allow the instructor to employ "diagnostic teaching" to better present key concepts related to the problems. Specifically, the instructor will be able to discover what students think in relation to the real-world problems they are attempting to solve. If there are any misconceptions, the instructor can discuss these misconceptions and provide examples to stimulate the students' thought process to enable them to readjust their ideas[17]. This process will allow students to more effectively build formal understanding of the subject matter.

To help students achieve expertise in the subject matter, the learning environment must be knowledge-centered. Instructors must take seriously the need to help students become knowledgeable by learning in ways that lead to understanding and subsequent transfer[18]. Bransford *et al*. pointed out that many curricula fail to support learning with understanding because they present too many disconnected facts in too short a time, i.e., the "mile wide, inch deep" problem[16]. Therefore, superficial coverage of all topics in a subject area must be replaced with in-depth coverage of fewer topics that allows key concepts to be understood. Gick and Holyoak showed that when key concepts are taught in multiple contexts with examples demonstrating their applications, students are more likely to abstract the relevant features of these concepts and to develop a flexible representation of knowledge[19]. In addition, Brown *et al*. suggested that in terms of organizing their knowledge, students could benefit from the strategies experts used to approach problem solving[20]. Therefore, when selecting real-world industrial problems we will use those that can be broken down into a number of sub-problems that can be mapped into different courses. The solution of each sub-problem will require the knowledge of a few key concepts. Note that we are not abandoning broad coverage of the subject area (which will be delivered via traditional lectures). Rather, we focus on a few key concepts in course projects. Students will work on at least two different projects (originated from different industrial partners in different application domains) so they can develop a flexible representation of knowledge to facilitate knowledge transfer to other applications. After students complete these projects, industry experts would meet with students to discuss the problems and provide solutions based on industry's best practice. Students will then get a better idea of what expertise looks like and gain a more thorough understanding of the subject matter from an industrial perspective.

In addition to being learner-centered and knowledge-centered, an effectively designed learning environment must also be assessment centered. What is assessed must be congruent with students' learning goals and the assessments should provide opportunities for feedback and revision. A traditional learning environment usually relies heavily on summative assessment; namely, measuring what students have learned at the end of some set of learning activities (e.g., mid-term and final tests). In an assessment-centered environment, formative assessments (designed to make students' thinking visible to both teachers and students) are essential to monitor learning progress. These assessments allow the instructor to grasp the students' preconceptions, understand where the students are in the "development corridor" from informal to formal thinking, and conduct instruction accordingly[16]. To facilitate formative assessment, students are required to post their project work in the virtual company repository during different stages of solutions. By analyzing these students' works and engaging students in discussions, the instructor can learn about the students' thinking and understanding. This will allow the instructor to continuously incorporate feedbacks in classroom instruction in a nonintrusive manner. In addition, industrial partners will be invited periodically to evaluate students' work-in-progress and provide feedbacks from an industrial perspective. Through these activities, students can learn to assess their own work as well as the work of other students. As a result, everyone can learn more effectively[21].

Developments in the science of learning suggest that the degree to which a learning environment is community-centered is also important. There are several aspects of a community, including the classroom, the school, and the connection to the larger community of homes, businesses, states, the nation, and even the world[16]. Here we will focus on the classroom environment and the connection to local industry. In the classroom, we will develop a norm that value the search for understanding and allow students the freedom to make mistakes in order to learn. Brown and Campione[22] and Cobb *et al.*[23] have shown that such a norm can enhance learning. Students will also be encouraged to learn from one another and to continually attempt to improve their project works. Presenting real-world problems under the virtual company framework and engaging local industrial partners throughout the learning process will allow students to establish a clear connection to the real-world. Students will feel that their project works are making a real contribution to the local industry, which is an important motivation factor to engage in lifelong learning[24]. Figure 1 illustrates the EXPLORES learning environment.

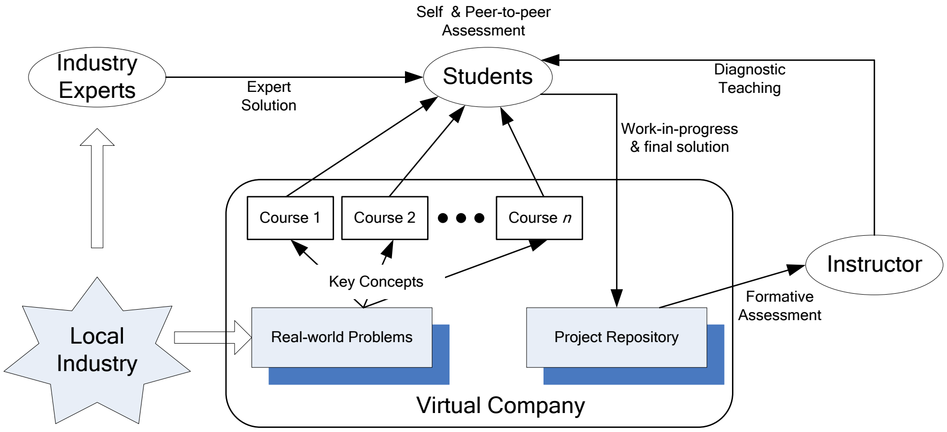


Figure 1: The EXPLORES learning environment.

The purpose of using a virtual company is to give students a more realistic feeling of the practicality of their projects. The company was named STAR Corp. Technical Center. It has two departments; namely, Manufacturing (corresponding to the Manufacturing Processes course) and Quality Assurance (corresponding to the Engineering Statistical Methods course). There are three types of users, summarized as follows:

- *Engineers*. They are students who will be working on projects pertinent to the courses that they are taking.
- *Directors*. They are course instructors who will assign projects to the engineers, monitor project progress, and assess the performance of the engineers.
- *Consultants*. They are industrial experts who will provide feedback to the engineers.

The virtual company framework is shown in Figure 2. A snapshot is shown in Figure 3.

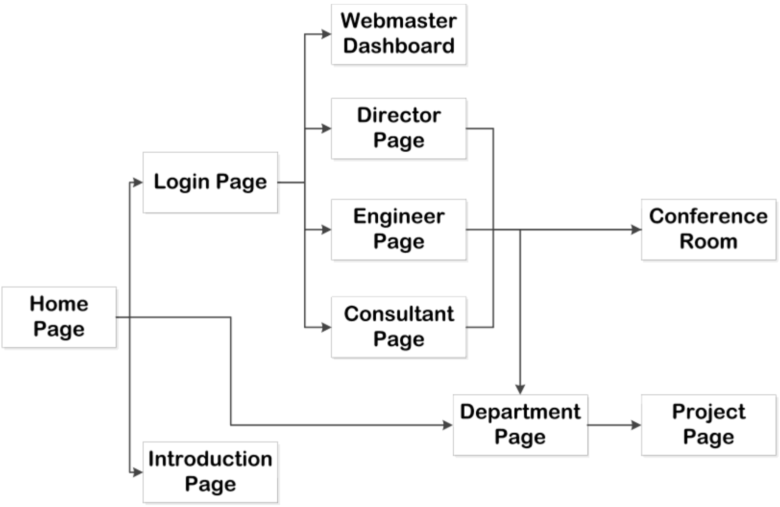
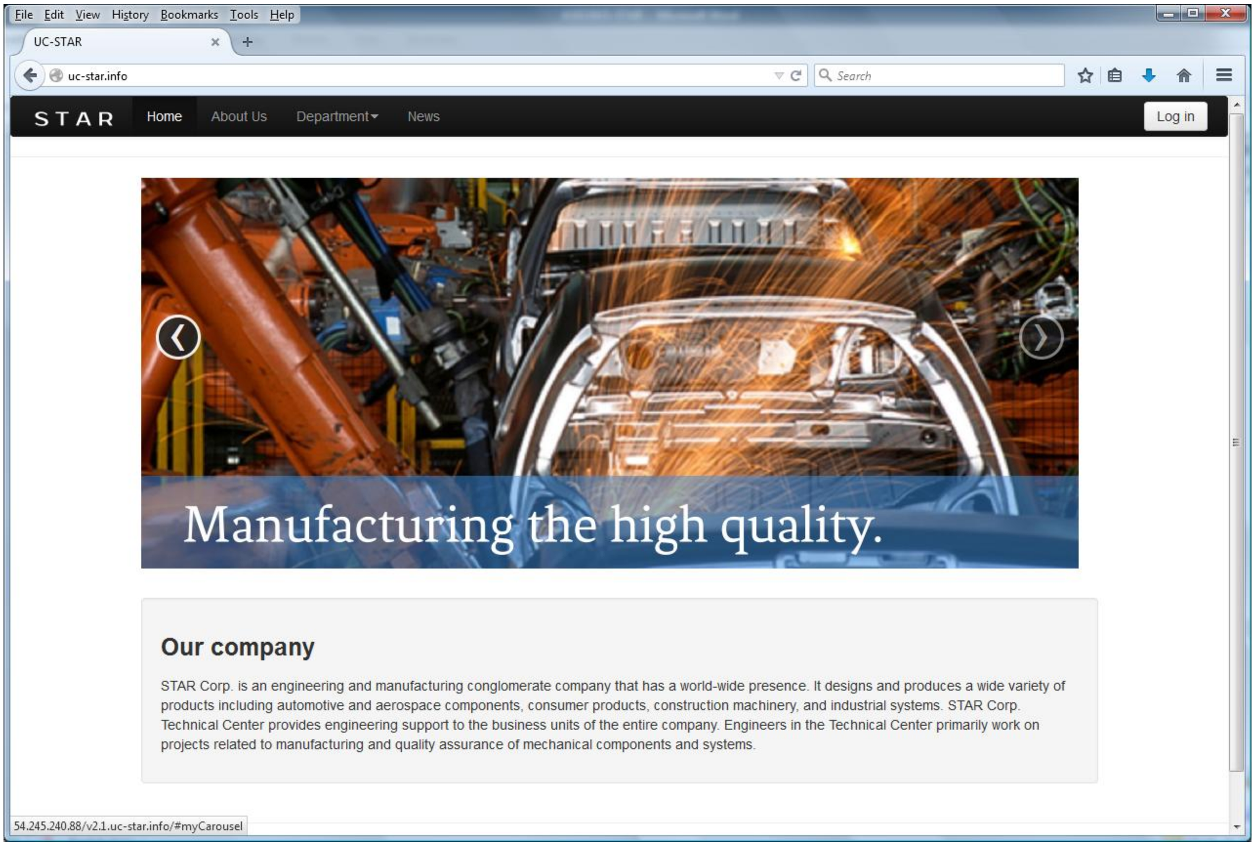


Figure 2: Virtual company framework.



Our company

STAR Corp. is an engineering and manufacturing conglomerate company that has a world-wide presence. It designs and produces a wide variety of products including automotive and aerospace components, consumer products, construction machinery, and industrial systems. STAR Corp. Technical Center provides engineering support to the business units of the entire company. Engineers in the Technical Center primarily work on projects related to manufacturing and quality assurance of mechanical components and systems.

Figure 3: Snapshot of the virtual company.

4. Implementation in Manufacturing Processes

During Fall'13 semester, the EXPLORES model was implemented in the Manufacturing Processes course. Two experts from GE Aviation provided a total of 4 industrial case studies (see Appendix). The experts from GE Aviation and the instructor had a series of meeting prior to the start of the semester to facilitate the integration of industry problems with the course material. Course material was realigned to best suit the needs of the industry problems. For each of the industry problems, students focused on key concepts based on selection of manufacturing processes, process capability, variability (tolerances) and design for manufacturability.

After the start of the Fall semester, the experts briefed the students about the case studies they were supposed to work on in groups. The following teaching pattern was executed throughout the semester:

- The instructor covered the relevant key concepts required for the case study to be worked on by students in a group.
- Experts from GE Aviation visited the UC campus during the designated class hours to brief students about the case study.
- Students interacted with the experts directly during the class with any doubts or questions they came across.
- The case study assignment was posted on the Virtual Website specifically designed for the EXPLORES model with all the relevant material

- Students groups (max. 3 or 4 students per group) were given at least 2 weeks to turn in the solution for the case study.
- The case studies were graded via the virtual company by the instructor and experts from GE Aviation either at GE Learning Center, Cincinnati or at UC Campus.
- Experts from GE Aviation again visited the UC campus during the class hours to distribute the graded case studies and also provide feedback to students. After the interactive session with students, experts from GE Aviation provided brief summary about the next case study which was due in 2 weeks from that day.

5. Result

- All students' motivation and learning strategies had significant moderate correlation with their course grades (r (87) = .367, p =.046). It is possible that the EXPLORES students had to go through major adjustments in their approach to learning, since this may have been the first time they were subjected to the PBL approach.
- The EXPLORES students leaned toward moderate visual and moderate sensing learning styles. The pictures, diagrams, and schematics that accompanied the problems catered to this visual learning style. As sensing learners, the need for details and hands-on work of the project worked well for them. However, the sensing learning style of these students could have played a role in the significant decreases in their learning strategies post survey results particularly in self-regulation [t (31) = 2.16, p =.04], effort regulation [t (31) =2.55, p=.02], and study management [t (32) = 2.74, p=.01] as they became frustrated with complications and surprises in the problems presented. There was one positive significant difference: peer learning [t (31) =-2.56, p=.02] seemed to improve. This could be a result of the group structure in the case studies. Other than these, there were no significant differences in any other aspects of motivation and learning strategies of these students.
- The use of PBL in the EXPLORES class provided opportunities for students to exercise their critical thinking and higher order learning skills. The fact that the problems given were actual manufacturing scenarios meant students had opportunities to learn applied engineering knowledge and skills needed by the industry. These were opportunities not provided in the traditional class.
- The EXPLORES students' products through their case study reports, provided them better opportunities for applying their critical thinking skills compared with those who attended the traditional class since they did not have this exposure. The EXPLORES students dealt with actual manufacturing problems and they had the chance to interact with industry champions. Thus, there were greater opportunities for these students to learn applied engineering knowledge and skills needed by the industry compared with similar students who were trained with the same courses but were in traditional classrooms.

6. Summary

The evaluation result produced some interesting findings that are important to guide the implementation of the EXPLORES model. Specifically, peer learning for the experimental group (EXPLORES) has improved compared to the control group (traditional). However, the experimental group's learning strategy has somewhat deteriorated with respect to self-regulation, effect regulation, and study management. The likely cause is that the case studies are too complicated (the students are Sophomores). The evaluators also commented that the implementation of the EXPLORES model did not strictly follow the model design. The EXPLORES classroom observations indicated almost the same instructional mode as the traditional class except for the presence of the industry partners presenting the manufacturing case studies and the inclusion of the case studies as part of the course work. As such, no significant differences in any other aspects of motivation and learning strategies of these students were detected.

Based on these findings, we have redesign the implementation of the EXPLORES model. The presentation of key course concepts is now done via small textbook problems rather than through traditional lecture. Students are encouraged to ask questions regarding these problems before course concepts are introduced. The purpose is to understand if the students have any preconception that may not be correct. The number of case problems is reduced from 4 to 2. The problems are separated into two phases. The first phase aims to allow the students to develop a deep understanding of the nature of the problem. The students are also required to develop a plan for solving the problem before they proceed to solve the problem in the second phase. This strategy is currently being implemented in the Engineering Statistic Methods course. For the first two tests in the course, the experimental group has significantly higher average scores than the control group (Test I: $e(45) = 19.2$, $c(43) = 17.5$, $p = 2.14\times10^{-5}$; Test II: $e(45) = 19.3$, $c(43) = 18.2$, $p = 7.69\times10^{-6}$. The full evaluation result is expected at the end of April, 2015.

Reference

1. Greening T, 1998, “Scaffolding for Success in PBL,” Med Education Online, Vol. 3, retrieved from http://www.med-ed-online.net/coaction/index.php/meo/article/view/4297
2. Hung IW, Choi ACK, and Chan JSF, 2003, “An Integrated PBL Model for Engineering Education,” International Journal of Engineering Education, Vol. 19, pp. 734-737.
3. Jih HJ, 2001, “Promoting Interactive Learning Through Contextual Interfaces on a Web-based Guided Discovery CAL,” The Journal of Computers in Mathematics and Science Teaching, Vol. 20, pp. 367-376.
4. Tse WL, and Chan WL, 2003, “Application of Problem-Based Learning in an Engineering Course,” International Journal of Engineering Education, Vol. 19, pp. 747-753.
5. Ramos F, and Espinosa E, 2003, “A Self-learning Environment Based on the PBL Approach: An Application to the Learning Process in the Field of Robotics and Manufacturing Systems,” International Journal of Engineering Education, Vol. 19, pp. 754-758.
6. Smith TL, and Janna W, 2003, “Reflection on Scholarship of Integration as a Model for PBL in Undergraduate Engineering Education,” International Journal of Engineering Education, Vol. 19, pp. 730-733.
7. Newman M, *et al.*, 2003, “A Systematic Review of the Effectiveness of PBL – Results of a Pilot Study,” American Educational Research Association Annual Conference, Chicago, IL, April 2003.
8. Dennis JK, 2003, “Problem-Based Learning in Online vs. Face-to-Face Environments,” Education for Health: Change in Learning & Practice. Vol. 16, No. 2 pp. 198-209.
9. Tseng K, Chiang FK, and Hsu W, 2008, “Interactive Processes and Learning Attitudes in a Web-based Problem-Based Learning (PBL) Platform,” Computers in Human Behavior, Vol. 24, No. 3, pp. 940-955.
10. Audy J, 2007, “Enhancing Technology Education at Surf Science: A Collaborative, Problem-oriented Approach to Learning Design, Materials and Manufacturing of Surfboards,” Eurasia Journal of Mathematics, Science & Technology Education. Vol. 3, No. 2 pp. 133-140.
11. Donnelly R, 2010, “Harmonizing Technology with Interaction in Blended Problem-based Learning,” Computers & Education, Vol. 54, No. 2 pp. 350-359.

12. Gossman P, Stewart T, Jaspers M, and Chapman B, 2007, “Integrating Web-delivered Problem-based Learning Scenarios to the Curriculum,” Active Learning in Higher Education, Vol. 8, No. 2 pp. 139-153.
13. Cobb P, 1994, “Theories of Mathematical Learning and Constructivism: A Personal View,” Symposium on Trends and Perspectives in Mathematics Education, Institute for Mathematics, University of Klagenfurt, Austria.
14. Piaget J, 1978, Success and Understanding, Cambridge, MA: Harvard University Press.
15. Vygotsky LS, 1978, Mind in Society: The Development of the Higher Psychological Processes, Cambridge, MA: The Harvard University Press.
16. Bransford JD, Brown AL, and Cocking RR (eds.), 1999, How People Learn: Brain Mind, Experience, and School, Washington, DC: National Academy Press.
17. Bell AW, 1982, “Diagnosing Students’ Misconceptions,” The Australian Mathematics Teacher Vol. 1, pp. 6-10.
18. Bruner J, 1981, “The Organization of Action and the Nature of Adult-infant Transaction: Festschrift for J. R. Nuttin,” in *Cognition in Human Motivation and Learning*, D. d'Ydewalle and W. Lens (eds.), pp. 1-13, Hillsdale, NJ: Erlbaum.
19. Gick ML, and Holyoak KJ, 1983, “Schema induction and analogical transfer,” Cognitive Psychology, Vol. 15, pp.1-38.
20. Brown JS, Collins A, and Durgid P, 1989, “Situated Cognition and the Culture of Learning,” Educational Researcher, Vol. 18, pp.32-41.
21. Vye NJ, Schwartz DL, Bransford JD, Barron BJ, Zech L, and Cognition and Technology Group at Vanderbilt, 1998, “SMART Environments that Support Monitoring, Reflection, and Revision,” In Metacognition in Educational Theory and Practice, D. Hacker, J. Dunlosky, and A. Graesser, eds. Mahwah, NJ: Erlbaum.
22. Brown AL, and Campione JC, 1994, “Guided Discovery in a Community of Learners,” in Classroom Lessons: Integrating Cognitive Theory and Classroom Practice, pp. 229-270, K. McGilly, (ed.) Cambridge, MA: MIT Press.
23. Cobb P, Yackel E, and Wood T, 1992, “A Constructivist Alternative to the Representational View of Mind in Mathematics Education,” Journal for Research in Mathematics Education, Vol. 19, pp.99–114.
24. Schwartz DL, and Bransford JD, 1998, “A Time for Telling,” Cognition and Instruction, Vol. 16, No. 4, pp. 475-522.

Appendix

Four case studies were provided to the students. Each of the case studies related to manufacturing of an aircraft part. In each of the case studies, the students were required to complete the following tasks:

- provide a complete manufacturing process map
- choose material with explanation (Temp ~ 1000 deg F)
- provide primary datum's (axial, radial and circumferential) for assembly
- provide estimated total cost for the assembly
- provide abstract for the manufacturing processes

The students were instructed to consider the following processes:

- full machining / milling of the product
- casting the part
- forming the component
- fabricating (e.g., welding/brazing) the part
- additive manufacturing (e.g., laser sintering)

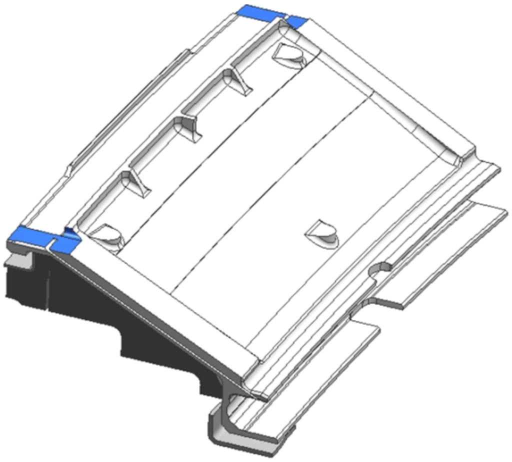
Additionally, the students were required to consider the following while coming up with the solution:

- material utilization
- equipment investment
- tooling replacement
- runtime, i.e., start to finish time
- additional processing needed (i.e., heat treat)
- design for manufacturability

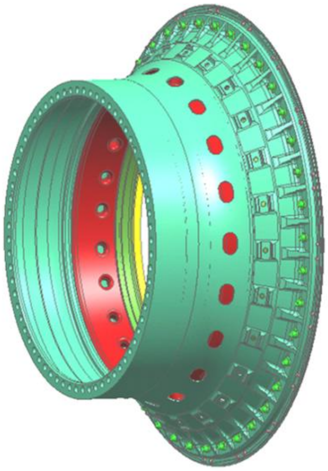
Parts for the four case studies are shown as follows.

Case Study 1: High Temperature Bracket

Case Study 2: Low Pressure Turbine (LPT) Shroud



Case Study 3: Forward Inner Nozzle Support



Case Study 4: Airfoil