Integrating Information into the Engineering Design Process

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Learning Objectives

So that you can guide student teams on effective strategies for extracting deep learning from their design projects, upon reading this chapter you should be able to assist them to

- Choose a disciplined framework for reflecting on their practice as a means to learn and improve
- Capture and appropriately document design information and knowledge generated during a project
- Systematically capture the lessons learned about the process of team-based design
INTRODUCTION

Frequently, students, instructors, and indeed practicing engineers view the final presentation and documentation as the end of a design experience. However, the lessons are not fully learned until students have reflected on their experiences and internalized their insights into their professional practice. Engineers tend to be results oriented. They focus on solving a problem and once it is solved, and the challenge is over, they move on to the next project. However, during the course of any design project new technical knowledge is created and the teams can learn important lessons about how to work as a team in such a project. This new knowledge and lessons on process can usefully be applied to future projects so as to avoid reinventing the wheel or suffering the same frustrations in not having a team perform well for the same reasons over and over again.

Unfortunately, experience from engineering practice in many industry sectors suggests that too often this knowledge is not adequately extracted, articulated, captured, and/or transferred to future projects. Large engineering organizations have knowledge management systems that are designed to overcome this shortcoming, but the lesson learned database is often only sparsely populated or even empty. Often it only gets sufficient attention after there is a major failure (see Boxes 14.1 and 14.2).

Whereas once such knowledge management systems were paper based, now they take the form of sophisticated computer-based systems. Just as libraries have moved toward more digital repositories, so it is with lessons learned databases. However, this change in the technology of storage and indexing has not changed the tendency of engineers to do a very basic job of documenting the outcome of a project, beyond that necessary to meet contractual requirements.

To the extent that engineering design is a learning activity, the design cycle is not fully closed (see Figure 1.3) until reflection has occurred to extract meaning, generate new ideas, or improve design processes. As discussed in Chapter 2, the How Students Learn report (National Research Council, 2005) advises that effective learning requires students to address their preconceptions (and overcome misconceptions), develop competence through a conceptual framework to organize the knowledge they have developed, and take ownership of their learning process, including developing skills to monitor their own progress and competency level.

Although reflection and knowledge management principles should be integrated throughout the design process, as indicated in the Information-Rich Engineering Design (I-RED) model, the culmination of a project

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**BOX 14.1**

**NASA Lessons Learned Database**

Following the loss of NASA’s space shuttle Challenger and crew in 1985, the NASA Lessons Learned program was formulated to assure that NASA’s key knowledge is documented and made available to everyone, both the public and NASA personnel.

Following the loss of NASA’s space shuttle Columbia and crew in 2003, the Columbia Accident Investigation Board was convened to identify underlying causes of the accident. The Board determined that NASA’s organizational structure and culture prevented it from being a learning organization. One proposed solution to this problem was the NASA Engineering Network (NEN), a suite of information retrieval and knowledge-sharing tools aimed at facilitating communication among engineers at all the NASA centers and affiliated contractors, thus taking knowledge sharing from availability to participation and collaboration.

From NASA, 2010.
provides the final opportunity to reflect on the entire process, allowing students to extract more global learnings about the project and their and their teammates’ participation in it, as well as aggregate the reflections and learnings they gathered throughout the process.

COMMON CHALLENGES FOR STUDENTS

Perhaps not surprisingly, engineering students anticipate the behavior of engineers in practice in that they tend not to take the time to reflect in a disciplined way on projects they undertake in order to extract lessons and learning that can be transferred to future work. This natural disposition is reinforced when grades are assigned predominately on the basis of the technical deliverables in student design projects.

An increasing number of universities and colleges include critical thinking as one of a set of core learning outcomes (or competencies upon graduation) for engineering (and other) students. Unfortunately, the operational reality is that many of these schools do not integrate intentional learning activities into courses and curricula designed to develop and explicitly reward practices such as disciplined reflection.

BOX 14.2
Lessons Learned: Information Systems Must Be User Friendly

Following the failures of the Mars Climate Orbiter and Mars Polar Lander in the late 1990s, the Office of the Chief Engineer was tasked with developing a plan for implementing the resulting mishap investigation boards’ recommendations. The Office’s report, released in 2000, made the following observations relating to lessons learned.

The continuous capture and application of project knowledge and lessons learned must become a core business process within the Agency’s program and project management environment. Regular input into NASA’s knowledge bases, such as the lessons learned database, should be emphasized. Programs and projects should implement a “document-as-you-go” philosophy, promoting continuous knowledge capture for the benefit of current and future missions. More importantly, program and project managers must regularly utilize the knowledge management tools to apply previous lessons learned to their own projects. The Agency can provide help for individuals to understand, learn from, and apply the lessons of others to their own work as part of a daily routine.

As of January 2012, the Agency has not met those goals. In fact, NASA’s Aerospace Safety Advisory Panel recently stated in its 2011 Annual Report that in spite of excellent examples of individual and specific programmatic efforts to facilitate knowledge sharing, these efforts do not ensure the identification and capture of critical knowledge or provide for an Agency-wide single process or tool for locating and accessing all information resources.

Specifically, we found that LLIS is underutilized and has been marginalized in favor of other knowledge management tools such as Ask Magazine and the annual Project Management Challenge seminar. Users told us they found LLIS outdated, not user friendly, and generally unhelpful, and the Chief Engineer acknowledged that the system is not operating as originally designed. Although we believe that capturing and making available lessons learned is an important component of any knowledge management system, we found that, as currently structured, LLIS is not an effective tool for doing so. Consequently, we question whether the three quarters of a million dollars NASA spends annually on LLIS activities constitutes a prudent investment.

that will foster such critical thinking in the context of engineering. Ideally, students need to be introduced as early as their first year to metacognitive language and activities that allow for self-realization of their effective learning styles, so that when they are faced with a capstone design project, they will be able to practice skills rather than having to learn and apply at once.

Engineering students also frequently struggle with developing professional skills, and particularly with appreciating the value of those skills, which they might classify as touchy-feely or soft skills, compared to the more technical competencies that have traditionally been associated with engineering (Shuman, Besterfield-Sacre, & McGourty, 2005). Engineering students often self-select based on their technical skills, not their interpersonal skills, and thus instilling in them the value of nontechnical skills requires reinforcement throughout the curriculum.

**FRAMEWORKS FOR DISCIPLINED REFLECTION BY STUDENTS**

Christine Hogan (1995) proposed a structured journal writing activity based on the acronym SAID (Situation, Affect, Interpretation, Decision). It is a step-wise approach whereby the students document the following:

**Situation:** What actually happened?
- What images/scenes do you recall?
- Which people/words/comments struck you?
- What sounds/smells/sensations do you recall?
- Were there any other elements?

**Affect:** Incorporating your feelings and intuitions is important.

- What was the high/low spot?
- What was your mood/feeling?
- What was your gut reaction?

**Interpretation:** What did you learn?
- What can you conclude from this experience?
- What was your learning?
- How does this relate to appropriate concepts, theories, skills?

**Decision:** What will you do as a result?
- What do you need to do before this sort of thing happens again?
- What should you do differently next time?
- What would you say to people who weren’t there?
- What was the significance of this experience in your life?

The SAID framework has been demonstrated to be an effective tool to guide engineering students in disciplined reflection in order to extract the lessons learned from projects and other practice-based learning experiences. (Jolly & Radcliffe, 2000; Walther et al., 2009).

Another approach to guiding students toward a disciplined approach to reflecting and thereby capturing transferable lessons learned from one design project and applying these to the next one is the SII method (Wasserman & Beyerlein, 2004). SII stands for Strengths, areas for Improvement, and Insights.

**(S) Strengths:** Identify the ways in which a performance was of high quality and commendable. Each strength statement should address what was valuable in the performance, why this attribute is important, and how to reproduce this aspect of the performance.
**(I) Areas for Improvement:** Identify the changes that can be made in the future, between this assessment and the next assessment, that are likely to improve performance. Improvements should recognize the issues that caused any problems and mention how changes could be implemented to resolve these difficulties.

**(I) Insights:** Identify new and significant discoveries/understandings that were gained concerning the performance area—for example, what did the assessor learn that others might benefit from hearing or knowing? Insights include why a discovery or new understanding is important or significant and how it can be applied to other situations.

There are numerous other frameworks in the literature that provide a structured basis for disciplined reflection. One advantage of methods like SAID over that of SII is that the former method pivots on getting at the emotions (affect), how it felt for the students. Often the best reflections and the deepest learning comes from critical incidents or aha moments that are impactful to the individual because of the visceral impact of the event.

**APPLICATION OF DISCIPLINED REFLECTION IN A DESIGN CLASS**

It is widely recognized that assessment drives learning, or at the very least it focuses the attention of the student. Thus, asking students to reflect on and even self-evaluate their work at these times of assessment, summative or formative, has the emotional hook necessary. Each type of assessable task in a typical student design project affords unique opportunities for students to be asked to reflect and learn. This can be in relation to the technical work they have done or to their teaming or other process skills in conducting a project.

**Peer Reflection on Presentations**

Immediately following a series of in-class presentations, it is helpful to ask each team to consider two questions:

1. What did you like or especially admire about the presentations of the other teams?
2. How might you adopt (and adapt) this to your next presentation?

This is best undertaken as a think-pair-share activity. Each team member takes a few minutes to write down as many ideas as they can to answer the questions. Then the team members share their ideas in pairs or as a whole team (depending upon the team size). Finally, there is a full-class discussion about the answers that each team decided upon. This helps affirm good ideas from other teams; peer recognition is a powerful incentive.

**Reflection on Interim Team Reports**

When projects are turned in to be graded there is a tendency for students to wait a week to get their grades back and then react. They can easily get upset when their visually stunning report, which they had spent an all-nighter to prepare, has lots of red ink on it with numerous comments and corrections. To avoid this type of reaction, and to foster self-assessment, one strategy is to hand back an unmarked copy of the report to each team member (on paper or electronically). Then, after reprising the lecture(s) given earlier in the course or the program on report writing, or the notes on report writing that they are meant to follow, the students are asked to spend 20 minutes individually...
reading and correcting their team report, especially the parts they wrote. Suddenly the errors and omissions will become all too obvious. Then, students are asked to share with their team what each found in the way of typos and spelling or grammar errors, as well as technical errors, poor word choice, inconsistencies, and so forth. The class is then asked to suggest a grade for the work based on the rubric that was made available before the submission was due and which was used to grade the report.

Now that students have calibrated on what was expected and have looked at their work through a fresh set of eyes, a week or so removed from the frantic rush to complete the report, the corrected and graded reports can be distributed. Now they are prepared to see the feedback, and it is not so easy for them to think that the instructor or grader was being harsh. Many lessons are driven home as a result. If this is done for an interim or preliminary (mid-semester) report, then the final reports are often significantly improved. A flexible grading system can also be used to measure the improvement, and thereby reward this learning.

**Reflection on Design Processes**

One method to encourage reflection on the design process as well as the technical outcome is to assign a substantial proportion of the report grade to be based on a critical reflection on team processes. There are a number of facets of this with relevant trigger questions. In each case the team is required to address the question and in making their case to draw upon evidence gathered during the course of the project. The sources of this evidence might include such things as team meeting minutes, document trails that illustrate the stages of the work, notes from meetings with stakeholders, and changes in documents including task description, scope, requirements, and so forth.

In an interim or preliminary report, the sorts of process topics to be reported might include the following:

_A critical analysis of team processes:_ What team tools were used, when, why, and what happened. Arguments are to be supported with evidence.

_Lessons learned:_ The major lessons the team has learned through the process thus far. This might be related to organization, interactions, team interdependence, communication, performance, or other critical aspects of how the team got the work done. Arguments are to be supported with evidence.

_Process improvements:_ What the team is planning to do differently in the next phase of this project and why. What actions the team is going to take to improve performance, what they expect to result, and why they expect this.

_Project management plan:_ How the team plans to manage the remainder of the project, including a detailed Gantt chart of the major tasks to be completed and any dependencies between these. The team is to justify these tasks, estimate how many person-hours each requires, and identify who is going to be assigned to each task.

A corresponding assessment rubric is shown in Table 14.1.

The quality of the documentation in an interim report provides an opportunity to give feedback on aspects of the information and knowledge management process that commenced when the project was set up (see Chapter 6). Some of the main criteria are logical structure; easy to read layout; effective use of diagrams; absence of errors; consistency; referencing of sources; effective use of appendices in
relation to body of report for including details, info sources, and so forth. A possible assessment rubric is shown in Table 14.2.

In a final design report the sorts of process topics to be reported might include the following:

Stakeholder interactions/information gathering: Students critically analyze issues around gathering and analyzing information and/or working with stakeholders. Based on this analysis, they propose strategies they will use in future design projects and explain why these strategies will overcome issues.

Evolution of scope: Students critically analyze the evolution of the project scope. Based on this analysis, they propose what strategies they will employ to manage the scope of future design projects and explain why these will work.

Effective team processes: Students critically analyze one or more team processes, tools, or techniques that were particularly effective. They explain why it worked and propose ways to improve upon it in future projects.

Ineffective team processes: Students critically analyze one or more of the processes that did not work well in their team. They describe what attempts the team made to overcome the problem and what resulted. Based on this analysis, students propose what they will do differently in the future to avoid this problem.

### TABLE 14.1 Interim Report Assessment Rubric for Process

<table>
<thead>
<tr>
<th>Standard</th>
<th>Unacceptable</th>
<th>Marginal</th>
<th>Acceptable</th>
<th>Superior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical analysis of the team processes</td>
<td>No ability to work together productively/professionally</td>
<td>Significant team problems in leadership, cooperation, and interaction</td>
<td>Leadership, cooperation, and interaction are all evident and acceptable</td>
<td>Utilized strengths of each team member fully</td>
</tr>
<tr>
<td>Lessons learned</td>
<td>Not done or done incorrectly</td>
<td>Incomplete or partially incorrect evaluation</td>
<td>Sound evaluation of processes with supporting evidence</td>
<td>Insightful/correct evaluation with strong supporting evidence</td>
</tr>
<tr>
<td>Process improvements</td>
<td>No ability to work together productively/professionally</td>
<td>Significant team problems in leadership, cooperation, and interaction</td>
<td>Leadership, cooperation, and interaction are all evident and acceptable</td>
<td>Utilized strengths of each team member fully</td>
</tr>
<tr>
<td>PM plan for delivering the project</td>
<td>Not organized; did not meet deadlines</td>
<td>Difficulty converting goals into tasks; routinely missed deadlines</td>
<td>Identified tasks, but struggled with priorities and planning; missed few deadlines</td>
<td>Effectively organized, prioritized, and met deadlines</td>
</tr>
</tbody>
</table>
An associated rubric is illustrated in Table 14.3.

**Assessment of Forward Communication of Information and Knowledge**

The amount of knowledge accumulated during the course of a design project is often very significant, even for a one-semester student project. The vast majority of this knowledge is lost when the team disperses after the project is over. A similar phenomenon happens in engineering projects in industry. While a widely recognized best practice is to maintain a lessons learned database with each project in engineering practice, this is honored more in the breach rather than in the observance. The operational reality is that the daily pressures of getting a project completed on time and on budget becomes an excuse for not capturing and recording lessons as they arise during the course of the project. Then there is a rush at the end of the project to populate the lessons learned database, but by then much has been forgotten and many personnel are focused on the next project.

Further, in engineering practice it is common for a project to last several years and for there to be many changes of personnel during
the course of the project. Each time a new team member joins, that person has to come up to speed and ideally acquire the knowledge already accumulated in the team. Most engineers have experienced the frustration of picking up a project partway through it and trying to fill in the missing pieces of information and surmise the tacit knowledge needed to understand the incomplete documentation that they inherit from the earlier phase of a project.

So, the educational challenge is to have students prepare their final reports and the accompanying collection of data, calculations, and sundry other material in such a way that it would make sense to another team who is handed their report two years later and expected to take the project to the next stage. With this in mind there are two criteria that should form the basis of assessing how robust and future-proof the final student team report is: completeness and quality.

Completeness includes such items as a comprehensive collection of information used and sources (e.g., prior art including literature); all

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**TABLE 14.3  Final Report Assessment Rubric for Knowledge Management and Team Processes**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unacceptable</td>
</tr>
<tr>
<td>Stakeholder interactions/</td>
<td>Not done or done incorrectly</td>
</tr>
<tr>
<td>information gathering</td>
<td></td>
</tr>
<tr>
<td>Evaluation of scope</td>
<td>Not organized; did not meet deadlines</td>
</tr>
<tr>
<td>Effective team processes</td>
<td>No ability to identify instances of how to work together productively/professionally</td>
</tr>
<tr>
<td>Ineffective team processes</td>
<td>No ability to identify instances of a team not working together productively/professionally</td>
</tr>
</tbody>
</table>
the people contacted (details so others can follow up); the critical information, analysis, and engineering calculations and assumption that support the main technical report (this might include photocopies from workbooks or indexing of workbooks). The quality relates to how easy it is to navigate the document and thus the ability to pick the project up where it left off. This is influenced by the report structure; layout; effective use of figures, illustrations, tables, and charts; use of appropriate technical communication style; absence of spelling and grammar errors; consistency; thoroughness in referencing of sources; overall impression; effective use of appendices in relation to body of report for including details, information sources, and so forth.

A relevant assessment rubric is shown in Table 14.4.

<table>
<thead>
<tr>
<th>TABLE 14.4</th>
<th>Final Report Assessment Rubric for Communication of Information/Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criterion</strong></td>
<td><strong>Unacceptable</strong></td>
</tr>
<tr>
<td>Completeness</td>
<td>No grasp of information; not interpreted or errors in interpretation</td>
</tr>
<tr>
<td>Quality</td>
<td>Purpose unclear; no clear structure</td>
</tr>
<tr>
<td></td>
<td>Numerous errors; not proofread</td>
</tr>
</tbody>
</table>

**SUMMARY**

Engineering design is a learning process that not only consumes existing knowledge but which also generates new knowledge. This new knowledge can be technical or process oriented in nature. Failure to adequately identify, capture, and reuse this new knowledge can lead to reinventing of the wheel each time a new project is undertaken and possibly the repeating of past mistakes. Studies of engineering practice suggest that design teams are neither particularly diligent nor effective in acquiring or using this new knowledge. In order to develop these necessary and essential skills of reflecting on practice and thereby learning, we propose strategies that encourage and reward reflective behaviors in engineering students. These strat-
Strategies are based on structured approaches that foster disciplined reflection, preferably based on the emotional impact of critical incidents in projects.

REFERENCES


