Information Literacy and Engineering Design: Developing an Integrated Conceptual Model

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Abstract:

Engineering education is moving increasingly toward an active-learning based pedagogy. Traditionally relegated to a final-year design project, more and more engineering design projects are appearing earlier, even in the first-year of undergraduate education. With the increased frequency of these projects that are problems without a single 'right' answer, engineering librarians are finding more opportunities to work with students throughout their educational careers instead of just in a capstone course. To fully take advantage of these opportunities, librarians need to translate their own knowledge of information literacy into the language of engineering educators, and indeed inform the pedagogy of those educators. This paper attempts to create just such a bridge, focusing on the information resources and processes needed by engineers engaged in the design process and bringing together the literature of both the engineering education and library science communities.

Introduction

Engineering design is perhaps the defining technique used by professionals in the field. "Design is regarded by many as the core problem-solving process of technological development. It is as fundamental to technology as inquiry is to science and reading is to language arts" (ITEA, 2007, p.90). Using the knowledge developed by the scientific community, engineers translate, innovate, and ultimately design a solution to a problem faced by an individual, group, or society at large. Engineering is always situated in a societal context, and engineers are always solving *someone's* problems.

Engineering design problems provide a real-world context for the underlying skills and techniques that students learn during their coursework. In particular, design problems highlight the importance of 'professional skills', i.e., non-content skills, to the work of engineers. It is precisely these professional skills that the *Engineer of 2020* report highlights as key to the success of the next generation of engineers. Indeed, it embraces the concept of the 'Renaissance Engineer,' who can contribute their expertise as a part of a team to solve the increasingly complex and interdisciplinary problems facing our society, both locally and globally (National Academy of Engineering, 2004).

Mosberg et al (2005) surveyed professional engineers to determine what they felt were the most important design activities, and 'seeking information' was the fourth highest rated activity out of twenty-three options, rated above prototyping, testing, building and brainstorming. When further asked how much they agreed with several statements about design, 'information is central to design' was the third-highest rated statement out of 17 options. Ennis and Gyeszly's (1991) study of professional engineers also found information gathering to be an integral part of the design process. Bursic and Atman (1997) declared that 'expert designers should be able to gather information to adequately define the problem, generate appropriate alternative solutions, and analyze, evaluate, and select the best solution to meet customer needs.'

How Do Engineering Students Perform?

One would think that engineering educators have analyzed the information gathering habits of engineers, since that stage does in fact appear in their own problem solving models. Indeed, there is some, but not very much research into the questions of how information is integrated into the design process. Overall, engineering educators have found that beginning students typically do not spend much time in the information gathering stage of design development and especially neglect the initial stages of the process, when a foundational understanding of the problem needs to be formed so a targeted solution can be found.

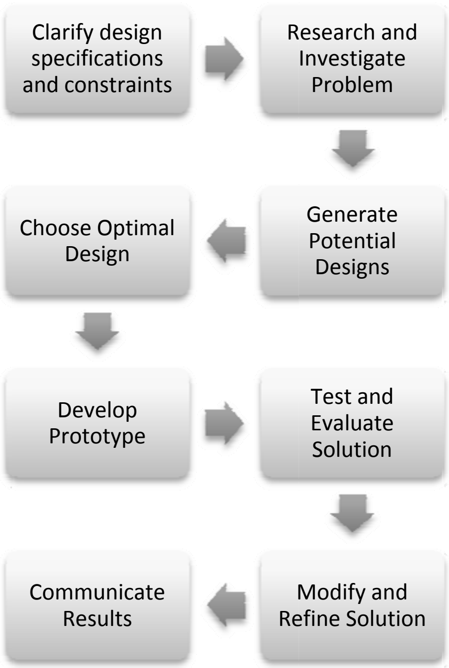
Condoor et al (1992) found that students tend to lock in on a single solution, not exploring alternatives and ending up 'satisficing,' that is, coming up with a suboptimal solution that meets the minimal requirements of the project. Atman et al (1999) found that first-year students gathered very little information compared to seniors in a design protocol study, although they did spend about 13% of their time on the information gathering stage of the initial design process. They found a positive correlation in design quality with the number and breadth of information requests made by the students they studied. Mullins, Atman, and Shuman (1999) found gains in student capacity can be seen as early as the end of the first year of education, if students are introduced to the design process in the first year. Atman et al (2007), meanwhile, found senior engineering students spent significantly more time on problem scoping and information gathering than first year students, and these results "support the argument that problem scoping and information gathering are major differences between advanced engineers and students, and important competencies for engineering students to develop."

Recently, Ekwaro-Osire, Afuh, and Orono's (2008) in-depth analysis of two student teams found only .1% of the time spent on a design project was doing 'library research'. Of the 7% overall amount of time gathering information, half of which was 'planning to gather information.' Denick et al (2010) found students engaged in a design task underutilized handbooks and other formal information sources in favor of lower quality web resources, a finding echoed by Wertz et al (2011). Wertz et al also identified student weaknesses in appropriately applying information from resources to a design project (i.e., mis-use of information they located). In a general, large-scale survey of undergraduate students, Head and Eisenberg (2010) reported that less than one-third of respondents reported having a 'research strategy' when working on projects, less than one half had a system for organizing information found, three-quarters of students reported difficulty getting started on a project, and over half had difficulty choosing a topic and sifting through irrelevant results.

Engineering Design Models

It is easy to equate information literacy (IL) with the 'lifelong learning' ABET student learning outcome (ABET, 2010). This tends to marginalize IL in the discussion with engineering faculty. It limits the impact of IL skills on student education and the work of engineers. Rather than being relegated to a 'professional development' role, IL needs to be integrated into the fundamental problem solving process for engineers. Riley et al (2009) were the first to map the ACRL IL standards to the ABET accreditation criteria for undergraduate engineering programs. However, even they did not explicitly tie information activities to the design process for engineering.

Several models of engineering design exist. Some popular models include Engineering is Elementary, a 6-step process appropriate for students under 12 years of age (Boston Museum of Science, 2011), the Informed Design model (Figure 1, Hacker and Burghardt, 2004), appropriate for ages 12-20, and Mosborg et al's (2005) iterative block-diagram "One Model" condensed from a selection of college-level textbook examples (Figure 2).



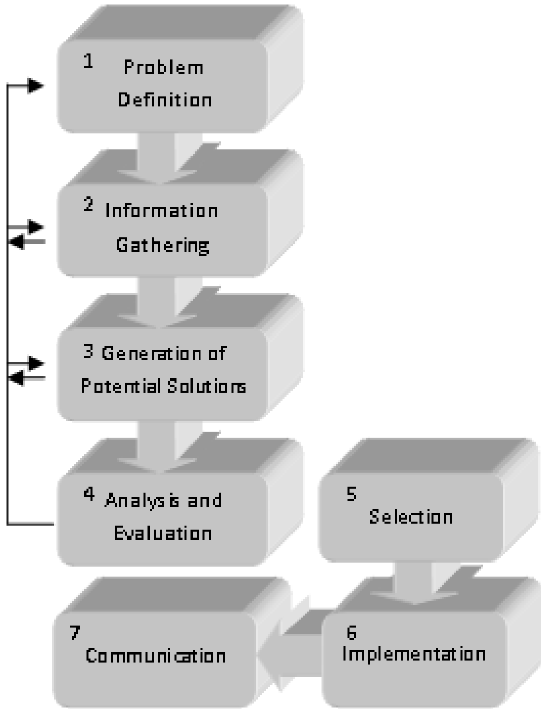


Figure 1: *Informed Design Model (from Burghardt and Hacker, 2004)*

Figure 2: *"One Model" (from Mosborg, 2005)*

These design models anticipate the process steps to be iterative, even if not explicitly included in their model diagrams. Several studies have found that the more iterative the process used, the better the final results of the project (Guindon, 1990; Radcliffe and Lee, 1989). Although an information gathering stage is explicitly present in each of these models, IL principles are present in many of the other stages as well.

Information Search Process Model

The ACRL IL competency standards (ACRL, 2000) articulates a list of skills, abilities, and behaviors that information literate individuals demonstrate. Unlike the Informed Design Model, they do not describe a process, i.e., a sequence of steps information literate students go through in order to complete a task. Kuhlthau's Information Search Process (ISP) (2004, see Figure 3) provides such a process model that can be valuable to compare with the engineering design model. While the ISP has not been verified specifically in an engineering context, it has been shown to be robust in describing the activities of researchers in many fields. This paper, argues that the stages of the ISP align with stages in the engineering design process and the design process incorporates several of the ACRL IL competency standards.

According to the ISP model, there are six stages that students go through when solving a problem, as follows:

- *Initiation*, when a person first becomes aware of a lack of knowledge or understanding and feelings of uncertainty and apprehension are common.

- *Selection,* when a general area, topic, or problem is identified and initial uncertainty often gives way to a brief sense of optimism and a readiness to begin the search.
- *Exploration,* when inconsistent, incompatible information is encountered and uncertainty, confusion, and doubt frequently increase and people find themselves "in the dip" of confidence.
- *Formulation,* when a focused perspective is formed and uncertainty diminishes as confidence begins to increase.
- *Collection,* when information pertinent to the focused perspective is gathered and uncertainty subsides as interest and involvement deepens.
- *Presentation,* when the search is completed with a new understanding enabling the person to explain his or her learning to others or in some way put the learning to use. (Kuhlthau, 2011)

In general, the first three stages of the ISP relate to the search for 'relevant information,' - trying to figure out what information is relevant to the task at hand, either the information that is searched for or that which accompanies the problem itself. Once a focus has been found in stage 4 and a formal, specific question has been articulated, then the search strategy changes from one of exploration to one of documentation. In the documentation stage, one primarily looks for information to fill in specific gaps of knowledge, rather than fundamental questions.

A key component of the ISP model is that it addresses not only peoples' actions, but also their thoughts and feelings, when conducting a search for information. Acknowledging the confusion and uncertainty at the beginning of the search process can help students understand not only that those feelings are natural. Then, they can get through that stage to the much more satisfying focused search for information. If students skip steps in the process, frequently they end up with suboptimal resolutions to their information task (Kuhlthau, 2004). In particular, Holliday and Li (2004) found that Millennials, current students who have grown up as 'digital natives', with the widespread access to information on the internet, frequently skip the crucial early stages of initiation, selection, and exploration. This leads to some of the perceived decline in student performance on research projects. Head and Eisenberg (2010) also found that students report the biggest challenges are getting started, choosing a topic, 'developing a research strategy, and having a system for organizing information. Certainly, if one does not fully understand a problem, it is very difficult to find a solution to it.

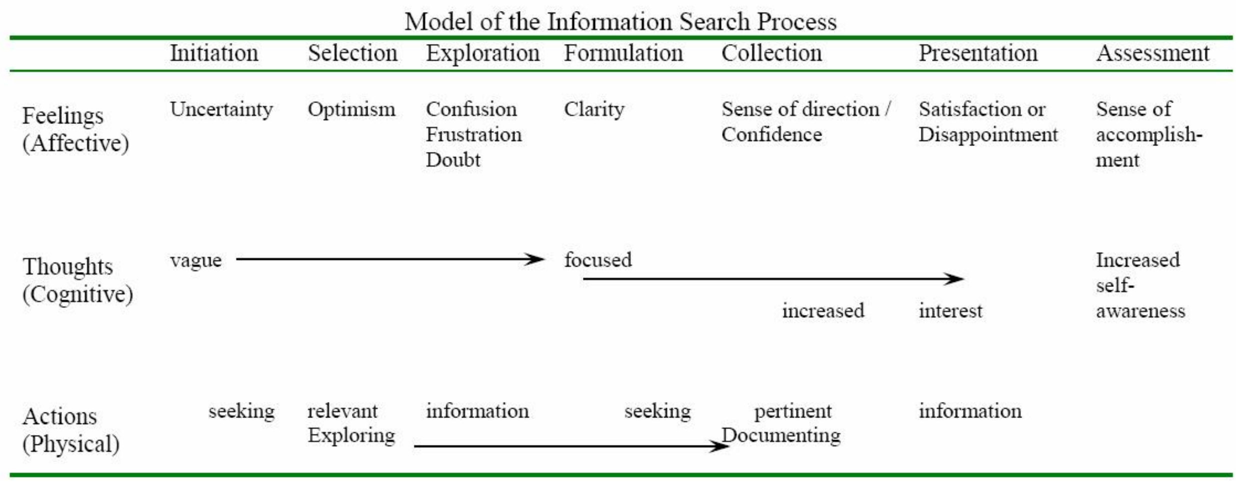


Figure 3: *Information Search Process (Kuhlthau, 2004, p. 82).*

Analysis

The Informed Design Model (Figure 1) will be used as a convenient example to show how IL competency standards are present in each stage of the engineering design process, to help illustrate these connections.

a. *Problem Clarification/Definition:* In the classical design model, this is the stage wherein students attempt to articulate what exactly the problem is that needs to be solved. Information needs to be gathered from clients concerning their expectations and the constraints and specifications of the project. Care must be taken not to jump to a particular problem statement or solution approach, but to consider the most fundamental nature of the question before looking for a solution. For example, if the fundamental problem is to bring potable water to a community, a design team might scope the problem as ‘increasing the efficiency of transporting clean water to the community,’ rather than considering the class of solutions wherein potable water is created on site.
b. *Research and Investigate the Problem*: This stage focuses on determining what kinds of solutions others have applied to this type of problem, how those technologies might work, and what variables affect the performance of the design. This is the classic information gathering step of the design process and can consist of several steps in the ISP. The focus at this point is on the Exploration phase of the ISP, typified by a search for preliminary background information that helps build a basic understanding of the field and ultimately helps focus the problem definition. As indicated above, these stages are iterative, as the preliminary information one finds can help refine ones understanding of the problem, further questions that need to be asked, etc.
c. *Generate Potential Designs:* Much like in the first stage, it is important to not stop with the first possible solution, but to continue brainstorming other approaches to see if a better alternative exists. During this process, students can still be consulting the literature to find more focused information related to each class of design solution and to uncover novel potential solutions to the problem.
d. *Choose Optimal Design:* Evaluate the options against the problem constraints and specifications. This is akin to the Formulation stage of the ISP, where the preliminary information is analyzed and a focused problem is arrived at. At this point the search for information becomes focused on a specific solution, rather than the previous

general-level information search. While the previous information searches would have focused on introductory-level sources, in this and the next stage, more technical information needs to be consulted. The idea needs to be turned into something practical, which may include compliance with codes and standards, property information of the materials or products being used in the design, etc.

e. *Develop Prototype:* Fabrication of a model of the design implementation follows in this stage. As fabrication proceeds, there may be the need to check interoperability of parts, sufficiency of materials properties, etc.
f. *Test and Evaluate Design Solution:* For example, ASTM standards might govern the testing of the prototype, and information about the performance of a system this design is supposed to replace might be available through a search.
g. *Revise solution:* Comparing performance of design against specifications can show where improvements can be gained. An information search into different alternatives for a specific part of the system can help uncover alternate materials, parts, or designs for underperforming aspects of the design. Depending on how much improvement is needed, the brainstorming or selection phase might have to be revisited.
h. *Communicate:* Once the solution has been designed, built, tested, and optimized, the results need to be communicated to the target audience. This could be through report writing, posters, or in-person or virtual presentations. Important in this stage is appropriate documentation of resources used throughout the project, which is a quite familiar topic for librarians.

Toward An Integrated Model

Figure 4 summarizes the analysis in the previous section, drawing a correlation between stages in the information and engineering design models. By identifying the kinds of information that a student might need at each stage, one can then develop instructional interventions to help students address a particular need, using the best practices from both disciplines. This figure, then, provides a translation tool between the engineering education literature and the IL, so librarians and engineering faculty can apply their own body of knowledge to the challenge of student learning and the teaching of the design process.

As an example of the utility of the model, if an instructor identifies that students are having trouble with Step 1, below, a librarian can understand that this means the 'initiation' phase of the problem solving process need work and can apply an activity from their own teaching toolkit to help the students clarify the 'research question' they have.

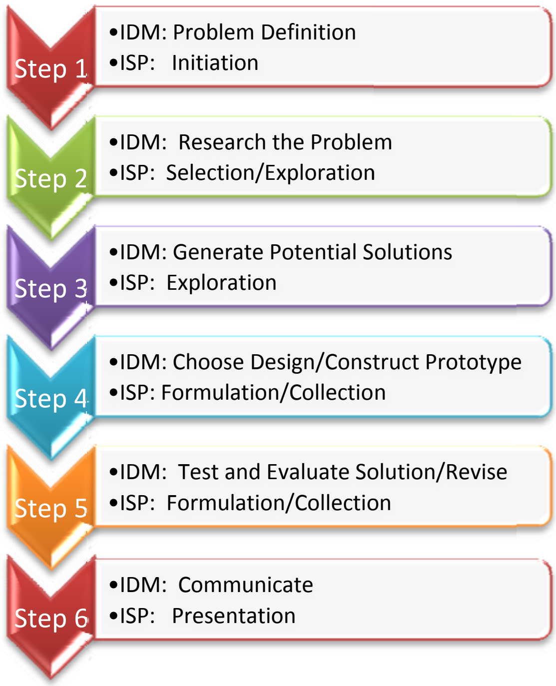


Figure 4: *Comparison of Informed Design (IDM) and Information Search Process (ISP) models*.

Conclusions

Clearly, both student outcomes and integration of information skills need to be improved as applied to engineering design. Explicitly breaking down the engineering design process into stages and identifying the information gathering stages relevant during each stage will encourage deeper and more productive conversations and collaborations between engineering faculty and librarians. Librarians will understand better how engineers solve problems. Engineers will better understand the role information gathering, integration, and application can play in improving student performance. Information gathering activities do have a place throughout the engineering design process. Information skills can be more deeply integrated into design activities with a common language to express the kinds and purposes of information needed at each stage,. The ISP is a robust conceptual model for the mapping between engineering design and information gathering.

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