A Problem Solving Engineering Model with Comparisons to Problem Solving in the Arts

William E. Lee III¹, G. Douglas Lunsford², Jack Heller³, and Mernet Larsen⁴

Abstract - Engineers are problem solvers, although they may not employ a model of problem solving. While there is a literature on addressing the “technical” problem, other aspects such as the role of knowledgeable peers, society and cultural values, “aesthetics”, etc. are often downplayed if not totally omitted. A broad model of engineering problem solving will be presented that identifies the role of one’s technical community, the technical “culture”, the broader societal and cultural context, etc. This model evolved from a consideration of problem solving from first the engineering/technical problem, then branching out to consider insights gleaned from the psychology and educational literature, and finally incorporating observations from problem solving in the visual and performing arts. The last activity may be particularly insightful in that engineers can learn much about problem solving from their artistic counterparts. Engineering and the visual and performing arts examples will be included in the discussion.

Index Terms - aesthetics, arts, education, problem solving

INTRODUCTION

Problem solving skills are an essential element of the engineer’s “tool kit”. Most engineering problems deal with complex issues for which there may be a number of alternative paths that may lead to multiple possible answers. Constraints may include timing and economics. A common challenge is determining when the problem is in fact “solved”. Engineering are usually initially exposed to problem solving during their undergraduate training, often converging on a comprehensive design project in their senior year. After graduation, their problem solving skills grow in response to the demands of the current work environment.

For engineers, only passing references to societal and other nontechnical issues may be made. Problem solving is envisioned as a means to an end; there is no thought to any underlying philosophy or “aesthetics”. In reality, engineering problems are solved by humans often operating in groups as part of a profession. The problems exist within a society with certain values and aesthetics. It is all interactive. Petroski [1] observed that “…each engineering project is touched by the idiosyncrasies of individual engineers, companies, communities, and marketplaces. And there are questions of economics, politics, aesthetics, and ethics.” Similarly, Bloor has observed that social factors such as conventions, interests, and traditions play a role in terms of how knowledge advances [2].

Many feel that there has been a decline in the ability of engineering students to solve real world problems, a problem recognized as early as the late 1950’s [3]. One engineering educator has observed [1]: “Design has been a notoriously problematic aspect of the engineering curriculum.” With more faculty driven by research agendas, design per se has perhaps declined in terms of an identified area of educational focus.

Two ideas will be explored and developed in this paper. First, the solution to many engineering problems reflects an engineering “aesthetics” and depends on interaction with groups of individuals not directly associated with the problem, including a broader public with its own set of values. Second, engineers can learn from their colleagues in the arts who also have advanced problem solving skills, also in an environment where the art community’s values and the broader societal values play an important role. The parallels between the two “cultures” are not as disparate as one might think; in fact, there are many similarities in problem solving methodologies. Engineering educators can use these parallels to reinforce problem solving skills typically presented to undergraduate students.

BACKGROUND

General problem solving

Kahney [4] presents a definition of both “problem” and “problem solving”: “A person has a ‘problem’ when he or she has a goal which cannot be achieved directly. Any action taken by a person in pursuit of a blocked goal, whether physical or mental, is regarded as problem solving.” Psychologists and philosophers feel that problem solving is one of the most complex forms of cognitive activity, involving one’s accumulated knowledge and skills. General surveys of problem solving are readily found in

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the literature (for example, [5]-[6]). More focused treatments may stress various methodologies and strategies such as problem decomposition [7], working backwards means-end analysis [8]-[9], forward chaining [10], state-space solutions or tree diagram style approaches, heuristic or “rule of thumb” solutions, algorithmic solutions, etc. Good problem solvers are often good at deriving representations or models of the problem and its associated solution pathway(s) [11]. Indeed, one way to break through a period of limited progress is to find a new way of visualizing the problem [7],[12].

Psychologists have traditionally described problem solving as consisting of several steps or stages: 1) The information phase, involving background research and problem definition; 2) The ideation or incubation phase, where possible solution pathways may become identified; 3) The evaluation or judgement phase, where the ideas/leads/etc generated in phase two are critically evaluated, refined, etc.; 4) The implementation or action phase where the steps/action plan is executed, hopefully arriving at a solution; and 5) A verification phase, where the solution is verified [13]-[14]. This process may be iterative. Less sophisticated versions describe moving from start to finish in a more continuous fashion rather than through stages [15]. Other viewpoints include the Gestalt approach, involving the integrating of previously learned responses [16] and computer program models (algorithmic solutions) [17].

**Engineering problem solving**

Overviews of the engineering approach to problem solving are presented by Migliore [18] and Koen [19]. Engineers are usually more interested in “practical” problem solving rather than more philosophical aspects of general problem solving. Koen noted that while science has a well-developed literature of scientific method, engineering as comparatively very little in terms of literature that addresses “engineering method”.

**Problem solving in the arts**

Problem solving is a common activity in the visual and performing arts. Musicians develop compositions, often interacting with other musicians and a critical audience. Often an iterative process, many versions of the composition may be considered. Visual artists may do a variety of smaller scale studies as they evolve their works, often seeking feedback from other artists while maintaining the public’s aesthetics in the process. Bloor observes [2]: “Consider a mundane example of art creation. An artist paints away in his studio on a canvas and after a while says to himself ‘It’s finished’, and he then signs the painting.” The artist exercises a certain type of authority in declaring ‘it is finished’, an authority described by Davies as [20] “...the authority to exercise an entitlement to employ art-making conventions.”. Dickie feels this “authority” can also reflect the artist’s knowledge or skill [21]. This also applies to the theater, dance, and even literature. Heller observes [22]: “The process of creating any work of art ... involves making an enormous number of aesthetic decisions about even the most minute details.”

Beethoven related [23]: “I alter a great deal, discard it and try again until I am satisfied. And then inside my head I begin to work it out, broadening it here, restricting it there, deepening it and heightening it; and since I am conscious of what I am trying to do, I never lose sight of the fundamental idea. It rises up higher and higher, and grows before my eyes until I hear and see the image of it, molded and complete.” Beethoven kept note books with him all the time, jotting down ideas and reworking themes; he worked on the 9th symphony for over six years [24].

Regarding the visual arts, Baxandall observes [25]: “The painter’s complex problem of good picture-making becomes a serial and continually self-redefining operation, permanent problem-reformulation, as soon as he enters the process of actually painting.”

Wordsworth worked on poems for years, constantly changing verse composition, often reflecting criticism from his peers [26]. Turchi has observed that writing consists of two separate activities. First is the act of exploration: “some combination of premeditated searching and undisciplined, perhaps only partly rambling. This includes scribbling notes, considering potential scenes, lines, or images, inventing characters, even writing drafts.” Second is presentation: “Applying knowledge, skill, and talent, we create a document meant to communicate with, and have an effect on, others.” Russo writes [28]: “Our struggles with our material are as individual as we are ...Cross-fertilization” - how figuring out the answer or solution to one problem makes the solution to later similar problems a little easier.”


**Group efforts**

The use of interdisciplinary teams is very useful in problem solving [31]. Team projects, including both within-discipline and interdisciplinary teams, are increasingly common in academics. Recognizing the value of team efforts, the Engineering Accreditation Commission (ABET) 2006-2007 criteria includes (Criterion 3): “an ability to function on multidisciplinary teams”. Historical psychological literature on creativity focuses on solitary activities. A more recent trend involves the sociocultural approach where learning and creative activities occur within social and cultural context, proposing that creativity is both an individual and group behavior [32]-[35].

Group creativity (including problem solving) is a characteristic of many creative efforts in 20th century music and theater, often involving “peer collaboration”[36]. Artists have often developed and relied upon supportive/collaborative peer groups, sometimes
establishing “artists’ colonies”. For example, late 1800's Paris saw a network of interacting artists including van Gogh, Gauguin, Signac, de Toulouse-Lautrec, and Serat [37]. The collaborations between Picasso and Georges Braque is another good example. Speaking of science, Ghiselin observes [38]: “In thus emphasizing the creative worker’s dependence on affective guides rather than on any explicit intellectual process, the mathematicians are in essential agreement with the artists.”

Sociology and cultural aspects

Creative individuals (and groups) work within societal and institutional frameworks. Baxandall observes [25]: “Painters cannot be social idiots: they are not somehow insulated from the conceptual structures of the cultures in which they live.” Gruber [39] observes that creativity involves an approach that is experientially sensitive: “The creator is not considered simply as the doer of the work, but also as a person in the world. Such a person has emotions and aesthetic feelings as well as social awareness of the relation of his or her work to the world’s work, its needs, and feelings.” Stein [40] defined creativity as a “process which results in a novel work that is accepted as tenable or useful or satisfying by a group at some point in time”. Adopting a sociological viewpoint, Bloor argues that knowledge is “... whatever people take to be knowledge.” [2]

The public aesthetic of the moment plays a significant role in establishing what art will be successful; artists often create their works with this in mind. Valéry wrote [41]: “At the very heart of the scholar’s or artist’s thought ... there is present some strange anticipation of the external reactions to be provoked by the work now in the making.” Helm notes [42]: “But in general, the composer writes with the intention of having his music performed for a body of receptors which we will call the public.” Helm goes on to subdivide the listening public into “... the small, intelligent elite and the less intelligent majority.” Picasso noted: “... a picture lives only through him that looks at it.” [43]

While many would argue that “culture” plays a significant role in how knowledge advances, it was not until recently that science was considered to be a part culture. Fischman observed [44]: “It is therefore reasonable to maintain that science has become part of our culture, our ‘inherited ideas, beliefs, values and knowledge, which constitute the shared bases of social action’.” Fischman argues that musicians should incorporate science into their compositions since “science” is a part of our culture.

ENGINEERING AND THE ARTS - COMMON THEMES

Table 1 examines several aspect of the activities that engineering and selected art disciplines (visual art, music, and theater) in terms of the purpose or goal of the work or project, types of activities that will occur to produce the work or project, the final product, the public presentation of the final work or product, and constraints that may apply. This reflects our claim that engineering can be thought of as an “art” very much in the same sense as the word is used in music, visual art, dance, theater, etc. Furthermore, an engineer’s “performance” is the presentation of

<table>
<thead>
<tr>
<th>Performer</th>
<th>“Art” objective</th>
<th>Composition activity</th>
<th>Finished “art”</th>
<th>Performance</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineer</td>
<td>- Better one of ... - New one of ... - New application of ...</td>
<td>- Problem identification - Problem analysis - Alternatives development - Analysis - Design</td>
<td>Final product, design, structure, plan, etc.</td>
<td>- Building the ... - Making the ... - Implementing the ...</td>
<td>- Economics - Client/user expectations - Societal values - Professional standards</td>
</tr>
<tr>
<td>Visual artist</td>
<td>- Creative work: - Academic art - Abstract art - Specific illustration, advertisement, etc.</td>
<td>- Problem identification - Problem analysis - Alternative possibilities - Piece production - Analysis</td>
<td>Finished work (painting, illustration, etc.)</td>
<td>- Gallery display - Art show - Print (magazine, advertisement, etc.)</td>
<td>- Economics - Client/user expectations - Societal values - Professional standards</td>
</tr>
<tr>
<td>Composer/musician</td>
<td>- Composition</td>
<td>- Problem identification - Problem analysis - Alternative possibilities - Composition - Analysis</td>
<td>Score</td>
<td>Music performance</td>
<td>- Economics - Client/user expectations - Societal values - Professional standards</td>
</tr>
<tr>
<td>Playwright</td>
<td>- Play</td>
<td>- Problem identification - Problem analysis - Alternative possibilities - Script production - Analysis</td>
<td>Script</td>
<td>Play performance</td>
<td>- Economics - Client/user expectations - Societal values - Professional standards</td>
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his/her work to the public, be it in the form of a finished design, product, structure, etc. It is also appropriate for both engineering and the arts to talk in terms of their “aesthetic”. Woodward (1989) describes the academic contributions of organic chemist Robert Burns (who won the Nobel Prize in 1965) to organic chemistry in terms of artistic aesthetics [45]. Ghiselin opines [38]: “But it is evident that in both art and science the inventor is to some degree incited and guided by a sense of value...” Finally, “poetics” has come to mean both the production of a literary work (historically poetry, but later expanded to any creative writing) and general aesthetics. Musicologist Zak observes that “poetics” involves aspects of feeling, intuition, creativity, and imagination and extends the concept to music, hence the phrase *musica poetica* [46]. It may seem appropriate to propose the phrase “the poetics of engineering” in this vein.

**PROBLEM SOLVING MODEL**

Figure 1 presents a problem solving model that follows from the discussed above. Several comments: First, the original source of the project may either be self-defined (often the case in the arts) or via assignment or commission (many arts and most engineering projects). Second, “feedback” (solicited or unsolicited) can come from the individual’s own aesthetics (easily extended to a group), knowledgeable individuals groups (further broken down into “inner circle” and “outside critics”), “history”, and the public (further broken down into the smaller “educated public” and broader “general public”). Third, the actual final product may be a “performance” or introduction of the final product into the public domain. Fourth, the iterative nature of problem solving is incorporated. Fifth, the possible influence of the current problem and its attempted solution on both the present and future is considered, recognizing both individual and “cultural” benefits.

Applicable to most disciplines, it is a matter of interpreting the model in terms of the specific discipline(s) being considered. For example, the “inner circle” could be co-workers, peers, etc. of comparable or advanced relevant knowledge and experience. Feedback from the “inner circle” may be for total internal consumption, i.e., there may be no communication beyond the group. “Outside critics” (or external reviewers) may include individuals not part of the designated working group but with similar credentials to the “inner circle”. “History” is intended to capture the essence of the relevant historical perspective and associated historical values, which may only extend back in time to a limited extent (“the current practice or style”) or possibly reflect an “established” viewpoint of longer extent (a “tradition”). Many technology projects begin with varying degrees of understanding regarding the “starting point”. This may not always be true within the arts; artists often experience some challenges in defining the problem initially. Thomas observed [47]: “The moment of conception of a piece is rarely definable. At first, it is often difficult to know exactly what is being conceived.” Thus, arts problem-solving may be highly iterative.

Two engineering examples

A historical example that illustrates the applicability of this model to engineering design is the design of the Forth Bridge by

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**FIGURE 1**

A PROBLEM SOLVING MODEL

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engineers Benjamin Baker and John Fowler [25]. This was a 19th century project that sought to connect two regions in Scotland. Baker was an unusual engineer who possessed a historical knowledge of bridge design in addition to being current on contemporary design strategies. The bridge design proceeded through several evolutions (see [25]) that included interactions with “knowledgeable peers” and public aesthetics of the time (including “critics”). The final “performance” was the construction of the actual bridge. Baxandall compares the process of designing the Forth Bridge to Picasso’s evolution of the production of several works, including Les Demoiselles d’Avignon and Portrait of Kahnweiler.

A second and more contemporary example relates to the various proposals to replace the World Trade Center in New York City. Stephens presents a detailed summary of this design activity, documenting various official and unofficial designs for the site [48]. This activity definitely incorporates design alternatives, peer feedback, public aesthetics, etc. per Figure 1.

DISCUSSION

It is important for engineers to recognize the influence of the factors identified in the model (Figure 1) as real contributors to engineering problem solving. Other creative individuals have recognized the influence of culture/society and have become more effective problem solvers. Failure to do so may result in a problem solution that is technically (or “artistically”) sound, but of limited practical value, i.e., a technical/artistic success but economic and/or societal failure.

In 20th century philosophy of art, the institutional theory of art is a dominant viewpoint. This theory is based on a cultural viewpoint where works of art are produced and derive meaning and value in terms of a variety of culturally-defined roles. George Dickie outlines the basics [49]:

1. An artist is a person who participates with understanding in the making of a work of art.
2. A work of art is an artifact of a kind created to be presented to an artworld public.
3. A public is a set of persons the members of which are prepared in some degree to understand an object which is presented to them.
4. The artworld is the totality of all artworld systems.
5. An artworld system is a framework for the presentation of a work of art by an artist to an artworld public.

This approach is readily translated into the engineering world, with the equivalent statements proceeding:

1. An engineer is a person who participates in the design or production of a work of technology.
2. Technology is an artifact of a kind created for presentation and consumption to a technology-conscious public.

3. A technology-conscious public is a set of persons who to some degree understand the technology that is presented to them (and used by them).
4. Technology is the totality of all technology disciplines and subdisciplines.
5. A technology discipline is a framework for the presentation of a work of technology by an engineer to the technology-conscious public.

The form of these statements was chosen to deliberately mimic the art statements presented above. Thus it is possible to talk of an “institutional theory of engineering art” that links the engineering activity with its public domain within which it practices. The engineers have already accomplished this within their world. A philosophy is actually very consistent with the “pragmatic” viewpoint commonly held by engineers.

Analyzing engineering problem solving within the framework of arts-based problem solving may appear challenging to some engineers/technologists. Ferguson observed [3]: “Most engineers today are happy to be called scientists but resist being called artists”. It is a matter of a cultural shift of sorts, for one to think outside the box. As Ghiselin reflects [38]: “The creative process is not only the concern of specialists, however; it is not limited to the arts and to thought, but is as wide as life.” Creativity, problem solving, etc. are not the exclusive property of any single intellectual discipline. Ackoff observes [31]: “The more philosophy and science I tried to bring to bear on problem solving, the more I came to realize that even together they can assure us no more than adequate solutions to problems. They cannot provide exciting solutions, ones that we call ‘beautiful’. Only the kind of problem solving that involves art can do this. And art implies creativity.”

CONCLUSIONS AND RECOMMENDATIONS

Engineering (both students and professionals) can indeed learn from the arts. Educators may invite professional artists, musicians, etc. to capstone engineering design classes to discuss their problem solving experiences and demonstrate that the model (Figure 1) works for both the arts and engineering. Such experiences also help to break down barriers between the “two cultures”. Also, educators should analyze problems that were not successfully solved in terms of the model in order to appreciate its functioning (“learning from mistakes” - for more discussion, see[50]).

Bellinger observed [51]: “Once we embrace the complexity we have created, and find the simplicity on the other side, we no longer need to be victims, for we can use our understanding to change our actions, and thereby our world.” Smith-Autard states [30]: “In the arts, to compose is to create - to make something which, for each particular artist, has not been in existence before. Artists who attain the highest peaks of perfection in composition - dance: the choreographer, music: the composer, art: the painter or sculptor, drama: the dramatist or playwright, literature: the poet or novelist - are inspired people.

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of imagination and vision.” This quote is absolutely applicable to engineers and their “art” as well.

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