Finding Möjligheter: Creativity and Ill-Structured Problems

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Abstract

Centered around the concept of *Möjligheter*, this paper focuses on motivating the rationale for faculty to 1) add more authentic problems to their design courses, 2) foster more interdisciplinary challenges in their courses, or 3) approach design instruction in a more consistent, scholarly or philosophic way. As educators, we often show students how to do individual problems step by step, and find the one right solution but significantly less in helping them to develop the skills and knowledge needed to view a problem from multiple perspectives, understand the relationship of creativity to engineering design and employ these in ill-structured problems.

Möjligheter provide a framework for exploring both needs (problems) and benefits (value). In this paper, we argue how engineering faculty should instead, show how creativity can be used in the service of constrained, if ill-structured, projects, requires collaboration, and ultimately allows students to develop better solutions than when we teach design without explicitly addressing creativity.

Introduction

Ill-structured problems stimulate innovative engineering design. Defining and teaching the skillsets required to work on ill-structured problems is, in fact, its own ill-structured problem. For those who seek to 1) add more authentic problems to their design courses, 2) foster more interdisciplinary challenges in their courses, or 3) approach design instruction in a more scholarly or philosophic way, we offer the following framing, around the idea of *Möjligheter*. This Swedish word roughly translates as *possibilities*, but also connotes *feasibility* or *practicality*. In short, *möjligheter* is the wide range of options that would potentially work.

The skillsets necessary for managing ill-structured problems require more than linear rationality, and as we will discuss, well-formulated requirements open all *möjligheter* for a design team. Requirements, whether in the workplace or in our course assignments, should not dictate a specific solution. In fact, ill-structured problems inherently require creative exploration by those charged with their understanding and solution, and this implies more than one right answer. Acknowledging this should impact the learning objectives for developing engineers.

Consider the two dominant metaphors for learning: learning-as-acquisition and learning-as-practice [1]. We often think about learning as acquisition, gaining a thing, "putting a new tool in the tool box", and teaching as "delivering content." Due to the nature of engineering knowledge [2], and particularly, the aims of being an engineer, we as engineering educators should focus on learning-as-practice more often. We show students how to do individual problems step by step, and find the one right solution. How often do we give students practice at finding multiple solutions, of fully exploring the *möjligheter*?

This exploration requires asking good questions [3], and learning to view the problem from multiple perspectives [4]. In short, it requires understanding the relationship of creativity to engineering design. Creativity is often defined as the ability to develop something “novel and useful” [5,6], and therefore engineering design is deeply creative work. “Novel and useful” solutions, which is to say innovative ones, are often demanded of engineers [7], and the *Engineer of 2020* report calls engineering design a creative act [8].

Creativity can be treated as a skill that can be developed through practice, increasing a person’s likelihood of creative output both as an individual and as on a collaborator [9,10]. Rather than eschewing creativity as ephemeral, and therefore unreliable, as many engineering educators view it [11], we should instead, show how creativity can be used in the service of constrained, if ill-structured, projects, requires collaboration, and ultimately allows students to develop better solutions than when we teach design without explicitly addressing creativity.

The Role of Requirements in Engineering and in Training Engineers

Exploring the requirements of what is to be designed is central to ill-structured problems; often there are conflicts not just about how to solve a problem, but rather what problem to solve. This latter conflict may not arise often enough in engineering education. Students are accustomed to homework and projects that are clearly defined, or defined without consideration of external stakeholders.

Engineers need to know how to explore the constraints provided by technical, economic, business, political, social, and ethical issues involved, including *who* knows these constraints, and for whom they are constraints. In the same manner, there is the nature of identifying the problem that the devices, components, subsystems, systems and processes that engineers design must solve.

But it is not enough that an aspiring engineer knows how to explore requirements, or even can plan and carry out these activities on teams. For ill-structured problems, there is more to the problem than just gaining agreement on the requirements for the system being considered. Engineers need to be able to ask probing questions, to clarify and refine requirements, which can result in both opening up the solution space to cover more possibilities, as well as narrowing down other less interesting options.

Refining requirements can be seen as the first step in “problem finding”, precisely because the problem is “messy” or has “fuzzy boundaries.” Here requirements engineering has its value: the iterative and intertwined processes of elicitation, documentation, analysis, and validation of what is needed/wanted in a proposed system. There are two immediate issues that this approach raises: How does one explore requirements (e.g., processes and practices of requirements engineering) and more particularly in this context, the transition to design (e.g., when does requirements work end, and design begin?). The former, though rich, is well established, starting with Simon’s early comments in 1962 and continuing into the present [12]. Numerous books, articles and courses outline best practices.

The question of when requirements end and design begins is more complicated [13] and more rooted in philosophy than in consistency in practice. Many development approaches view this transition as normatively easy, with the design emerging mainly from a synthesis of the requirements analysis models created early in the development process. Iteration and refinement synthesize the analysis models into design models used for implementation. The transition to design can also be seen as distinctive in intent [2]. At issue is the question of orthogonality of requirements and design. Orthogonality is involved with the issues that show up in two dimensions: what and how. The 'what' – e.g., when some requirements map well to proposed implementation, and those that have little correlation to implementation. A similar issue exists in the 'how', e.g., that good system design is aimed at the artifact to be built, and is not intended to be structured to somehow guarantee that it is easy to see how requirements are in fact to be implemented.

From the designers' perspectives, the goal of requirements work is the development and agreement of the problem, which is the 'what' of building the right system. It is a process of trying to separate the world-to-be, that is, with the new system envisioned to solve the problem at hand, into two spaces: The set of acceptable solutions (ideally as large as possible for the designer to work in) and the set of unacceptable solutions, that is a solution that is not acceptable to the known stakeholders.

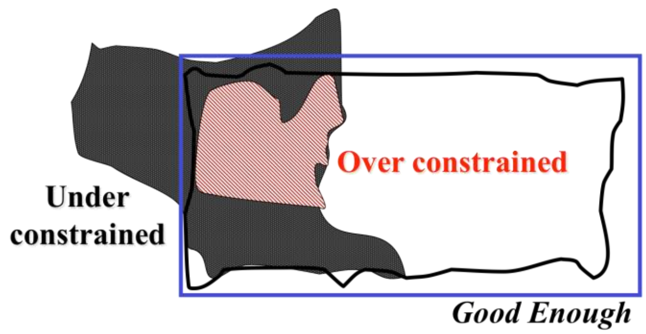

Figure 1. Requirements from the Designers' Perspective

As Figure 1 suggests, poor requirements are those that artificially restrict the design space, e.g., over-constrain the solution development. Alternatively, poor requirements are those that under-constrain the design, that is, it allows designers to expend resources building solutions that really are not acceptable within the known and knowable constraints. The design is the decisions documented as to how to build the system right. The goal is to document what is 'good enough' so that designers can succeed in solve the problem.

This is where creativity in exploring the problem is key: The boundaries of ill-structured problems are necessarily fuzzy, that there are multiple constraints and needs, and that the goal of good requirements is about finding 'good enough' requirements that identify this boundary in a useful, cost-effective way. 'Good enough' means creatively defining the knowable boundary between unacceptable solutions and acceptable ones - neither over constraining nor under constraining the design space.

The Problem with Problems

If we begin with the cross-disciplinary definition of design as the "conception and planning of the artificial" [14], which includes design as understood by the arts and other fields, engineering design becomes the conception and planning of the artificial in the service of a specific human need. It is a response to a problem. But what is a problem? Our traditional language for 'design' includes both the solution to a problem (e.g., puzzle solving), but also the 'good enough' determination of what the problem is (e.g., puzzle making)[15]. But this analysis of the core activities of a profession is still wanting. Even considering engineering design as both 'puzzle making' and 'puzzle solving' leaves out is the nature of what the 'puzzle' itself is.

In typical parlance, a problem is "applies to a question or difficulty calling for a solution or causing concern" [16]. Problems are easily considered as things to fix; something negative. They are about what is *not* desired in what is seen. Another problem with understanding what we mean by problem solving comes from mathematics: Here, the common definition of a problem is "a question raised for inquiry, consideration, or solution; a proposition something to be done" [16]. While broad, this implies strongly the 'puzzle solving' aspect, but not the problem discovery, or 'puzzle making' aspects.

The Gause and Weinberg definition of 'problem' can be helpful for engineering problem solving. If problems are indeed the 'difference between what is seen, and what is desired', then problems must include the visions of people who want something that isn't yet, that what is desired goes beyond the negative. Problems can be restated to something positive – to the opportunity they present. That problems, and 'problem solving' are only half of the motivation for engineering design. In the same sense that a problem always has the opportunity for it to be solved, so too does a new opportunity have the ability to be worded to describe what is missing in the world, for which the opportunity is the desired solution. Viewing engineering design as opportunity invites our students to engage their imagination more explicitly, and can generate unexpected learning and risk-taking in design [17]. Problems and opportunities can be considered (at least rhetorically), different sides of the same proverbial coin. But what do we call the coin? The root value or values that the solution may eventually provide? What is necessary for the success of the design?

This is in fact, what good requirements must make plain: what will count as success for the design. The process of design and requirements is naturally interactive – successive design decisions about how to meet some requirements inform and imply new requirements. These in turn, lead teams to consider new and different designs, and to reconsider both what are the possibilities for the design, what are the values it will better and best deliver, and for whom. These lead to requirements questions – framing and reframing the possibilities for the design, as well what is feasible and practical to achieve amongst all of the non-functional requirements as they are understood, especially the fundamental and interacting project constraints of time, cost, and quality. This is more than just 'problem solving,' as it is commonly understood.

Möjligheter

This is where stepping out of English can be useful. Consider *Möjligheter*. This is the Swedish word for "Possibilities", but also with the connotation of "feasible, practicable," e.g., that one will in fact get something done or make it work [18]. It can be translated, literally, as 'facilities' or 'wherewithal'. But in a technical, engineering sense, *möjligheter* is the crossover of problems and opportunities - what needs or wants to happen, in order to actually improve, make better, reach or exceed potential. To realize value from the endeavor to design and develop something new and introduce it to a situation.

Möjligheter come from what is wrong, with the opportunity of making it right; this means necessarily involving those people and organizations where the problem or opportunity exists. *Möjligheter* come from what is not yet, but only a vision for what might be. But in both cases *möjligheter* are about the realities of making this new vision, the new fix, the new system happen. People have *möjligheter*; just like people and organizations have problems and opportunities, often intermingled. The systems and processes that realize these opportunities and fix these problems have requirements that need to be elicited, modeled, documented analyzed and validated. The *möjligheter* concept extends Boehm's proposed value-based requirements engineering [19] which focuses on the creation of business value through the discovery of requirements and systems value propositions.

We find the concept of *möjligheter* helpful as we attempt to define the broad learning objectives of engineering design courses. Clearly, engineers who are able to explore more *möjligheter* before creating a solution are more likely to come up with valuable, novel solutions. Creativity is needed in both the development of the understanding of the problem just as much as in the development of one or more proposed solutions. As Einstein once noted:

> *The formulation of a problem is far more often essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle requires creative imagination and marks real advance in science.* [20]

What Einstein intuited in his own experience is borne out in practical engineering work as well as in research. Gill Pratt, a program manager at DARPA, shares that good engineers are the ones who do the equivalent of "write as well as solve an appropriate homework problem for the real-world situation you're dealing with" [21]. Researchers who study the development of expertise find that the categorization of problems, and more importantly, the ability to shift perspective across categories, is an inherently creative act [4]. This characterization of problems is important, both for the designer, and for the person learning how to design. The point of using a new word like *möjligheter* to describe the goal of design is to make it very clear that engineering design, particularly for ill-structured problems, is a creative endeavor that involves both the creative exploration of the problem space and the design space to optimize the many facets of value for the people who will benefit from the system. As psychologist Mihaly Csikszentmihalyi has noted, "an intellectual problem is not restricted to a particular domain. Indeed, some of the most creative breakthroughs occur when an ideas that works well in one domain gets grafted to another and revitalizes it"[22].

The Relationship between creativity and *möjligheter*

Although engineering knowledge is distinct from both scientific inquiry and artistic creation in many ways [2], we can still find commonalities in the creative process. Teaching skills in creativity has been shown to have positive effects across multiple disciplines, including engineering [23], and despite persistent myths about people being "born creative" or not, creativity has shown to be something people can grow or develop [9,24]. Investigations of creativity and intelligence have shown only a slight positive correlation between creativity and traditional measures of intelligence [25]. Factors that do appear to matter include effort, collaboration across disciplines, and thorough fluency in the problem space [9]. Effort is assumed as an engineering value that students can learn, and effort in the form of experimenting with multiple possible solutions is probably best reinforced through project-based learning [26]. Fluency and collaboration across disciplines, along with the underlying skills and values these require to be successful, can be learned.

Fluency: The idea of fluency counters the creativity myth of inspiration coming as a "bolt from the blue." Moments of great insight requires a thorough exploration of the problem space, with the pieces coming together in new, useful ways in that proverbial "a—ha!" moment. Real insights require work [27]. Greater fluency in the problem space also allows engineers to discover whether a given constraint might be misrepresented, misstated, or perhaps can even be safely discarded [28].

This fluency is developed by learning with and from those involved in the problem space: For the engineer this requires a shift in both attitude and technique. If the goal is *möjligheter*, then the project goal is not just to create a design, but to create the design that will bring value in the environment(s) where the new system will exist. This means developing a fluency about that environment and the people/organizations that act in it. Normatively, it means leaning on, learning from, and involving those who work in those environments to explore the *möjligheter*.

Two attitudes to fluency are common: 1) that the engineers involved are already an experts in the problem domain, having solved problems in these domains and built professional expertise around that domain; 2) that the engineers are already experts in the solution domain, and need to conform their solutions to the problem as they understand it. In both cases, this has the potential to lead to sub-optimal solutions. In both cases, the experience that the engineers bring to the problem can come across as the 'we build, you use' attitude. In the second case, it is even more likely, as the developers have less experience with the user 'language', motivations and/or objectives.

If the engineer takes the 'we build, you use' attitude, this exploration can succumb to a communication gap called the "User-Developer Syndrome" – because users and developers (engineers) come from different worlds, speak different languages, each having different motivations and objectives (Leffingwell and Widrig, 2003). Here is precisely where creativity, and creative processes, are most needed. The people who need a solution, those embedded in the situation(s) and environment(s) where the solution will be introduced, are also the same people who have fluency in the problem space. But the engineers developing the solution have both the responsibility and technical expertise to develop that solution.

For ill-structured problems in particular, this is the area where creative *möjligheter*-finding necessarily involves effort, collaboration across disciplines in order to develop and leverage the users' fluency in the problem space. The engineer is tasked with adding value by managing the collaboration. Hence the 'we build, you use' attitude is disastrous for the new engineer.

Collaboration Across Disciplines: The need for fluency is only resolved with the cooperation of those with deep knowledge of the problem space, and the value-add of the engineer is in fact the goal of seeking out the value(s) that underpin the need for some solution, and the expected constructive controversy that should ensue [29]. Consequently, the attitudes and techniques of *möjligheter*-finding set up both a precondition for creative problem solving as well as means to find the *möjligheter* themselves.

Möjligheter-finding may be point in the design process ripest for creativity. For example, in artistic work, it has been shown that the artists who spend more time finding their "problems" have demonstrably more creative output over those who spend less time, and that this practice of taking time to explore more of the problem space leads to more creative output not just on individual projects, but over the course of a career [30]. In contrast, a study of engineering courses found that even when creativity was explicitly addressed, it was almost always focused on convergent tasks, rather than divergent ones [31]. *Möjligheter*-finding demands divergent thinking; divergent thinking is best fueled by bringing together people from disparate expertise.

Experiments in integrating students from engineering and design backgrounds to focus on a systematic collaboration in a synthesis/design project have confirmed the value of these collaborations. Moving between convergent and divergent thinking, these teams would suggest modifications for the current products, they would provide reasons and possibilities from a broad aspect of the product perspective. This included usage, user perspective, engineering possibilities, material and manufacturing possibilities, future product sketches, and eventually yielded rich and qualitatively better product specifications [32].

The collaborative back-and-forth requires taking another's perspective and reflection [29]. This develops solutions in an improvised fashion that, in retrospect, might appear inevitable to outsiders. As learning scientist Keith Sawyer puts it, "when it's over, it appears more predictable than it actually was" [10] This is a common response to seeing a creative thought in action, which Sawyer calls *script-think* – presuming there was a script to follow when in fact, there was none. It is creative engineering work in *möjligheter*-finding that distinguishes for the development team the difference between acceptable and unacceptable solutions, leaving the 'script,' if there was one, to be the process of developing an acceptable solution.

Teaching *möjligheter* finding

Developing product *möjligheter* includes envisioning the product's novelty, value and/or surprisingness [33]. While these are necessarily contextually situated, it means that these types of attributes, and how they can/should inform the requirements requires exploration – finding them situated with the stakeholders and their issues, as well as potentially conflicting needs and desires.

Because *möjligheter*-finding is such an important, if under-valued, part of the creative process, it becomes important to both 1) give students an extended opportunity to explore problem spaces and 2) explicitly define creative problem-finding as a learnable skill that will only increase in importance after graduation. Explicitly detailing the importance of *möjligheter*-finding may help retrain students acclimated to diving directly into solving problems. Educating students about the importance of reflecting on their thought process (generally termed meta-cognition) has been shown to improve the transfer of what they learn from one setting to another [34].

Problem solving, then, particularly for ill-structured problems requires both convergent thinking – in order to "hone in" and select a promising solution, and also divergent thinking, in the wide-ranging task of *möjligheter* -finding. In other words, even engineering design courses that recognize the need to explicitly teach the habits of creativity often skip the first step, that intersection of requirements and problem-solving that is the most prolific arena for innovation. In these settings, especially when challenged with multi-disciplinary exploration to address fluency issues, students benefit greatly from the diversity of disciplines and perspectives [32].

Conclusions and Next Steps

We know that project and design based courses are challenging for educators. The assignments we construct are often intended to aim the students toward a particular answer. We do this partially out of a need to have gradable assignments and out of a desire to prevent students from working on known dead-ends. We sometimes try to create high-stakes assignments in order to replicate the stresses and incentives present in engineering work, but a high stakes event, such as an exam, does not replicate *authentic* stakes. Design courses give us the opportunity to recreate *authentic* high stake situations for our students, where "real people" will see and/or use their solution. In project-based learning and design courses, there is a temptation to create toy problems, "whose size and complexity are managed at the expense of authenticity" [35]. The answer is complex – to give students workable (and flexible) heuristics, not algorithms, for finding *möjligheter* and potentially developing multiple solutions.

Based upon the wealth of research on creativity and on engineering requirements and design, we would like to encourage continued research and course transformation in the following ways.

1) Understand and incorporate practical daily habits that can improve students' creativity.[1]
2) Find and teach case studies that demonstrate the need to fully explore a problem space. This will help undo the "script-think" that makes the problem definitions, locked-down requirements, and final solutions look inevitable.
3) Develop assignments that focus on exploring a problem-space deeply, without an expectation of a solution, preferably placed in the curriculum well before a capstone course.
4) Edit current design course assignments so that there is an explicit problem-finding phase.
5) Find ways to assess the learning that takes place, even if the final design solution does not work.

In short, we hope that students might practice finding multiple *möjligheter* before attempting to design solutions. The task of finding ways to teach this – that becomes the hunt for *möjligheter* for us as engineering educators.

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[1] We recommend Keith Sawyer's book *Zig-Zag* (2013), because it is research-based yet written at a very accessible level.

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