# Assessment techniques for contextual competence: A resource for teaching and learning engineering design

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CENTER FOR ENGINEERING LEARNING & TEACHING

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# 1 ASSESSING CONTEXTUAL COMPETENCE

***Context's importance in engineering design.*** In engineering education, there is widespread recognition that today's engineers must be prepared to consider the complexities, opportunities, and challenges of the contexts in which they do design. In other words, successful solutions to real-world engineering design problems depend on more than mastery of technical problem-solving; successful solutions also require *contextual competence*—the ability to recognize and consider the relevant interrelated aspects of a design problem's context, comprising the people, places, events, and socioeconomic systems that shape and are shaped by a particular engineering design process. This collection of assessment techniques is designed to help undergraduate engineering students at all levels and their educators gauge and facilitate the development of broad contextual competence. These assessment techniques were developed on the foundation of years of research on engineering design processes[1] and have been field-tested in several instructional settings (e.g., Atman, Hayes, Richey, Wang, & Campbell, 2013; Atman, Arnesen, Bulajewski, Chang, Jones, Lew, & Campbell, 2014).

***Complementing educational experiences that develop contextual competence.*** These assessment techniques are designed to complement the many engineering education experiences that can help students develop contextual competence, intentionally or otherwise, but are not always accompanied by formative and summative assessment specific to consideration of context. For example, capstones commonly feature design problems that are not only realistic in their scale and complexity but also for being presented in a rich context. Similarly, service learning typically involves real-world problems (and associated clients). Learning and problem-solving in a specific context is a critical element in problem-based learning.[2] Other educational experiences do not necessarily focus on design or problem solving but can still help students become more aware of and better understand aspects of context. Examples include study abroad, exchange programs, courses taken in non-engineering departments, and interdisciplinary courses. Finally, engineering students also cite a wide range of co-curricular and informal experiences as contributing to contextual competence (Yasuhara, Campbell, & Atman, 2014; Krause, Huneke, Yasuhara, & Atman, 2013). Examples include internships/co-ops and activities with clubs/societies like Engineers Without Borders. The assessment techniques presented here can be used in a variety of ways to enhance and gauge the effectiveness of all of these educational experiences.

***Focus on temporal and societal context.*** A realistically contextualized engineering design problem demands consideration of many aspects of context. For practical reasons, this initial set of assessment techniques primarily focuses on two aspects: *temporal* and *societal* context. Briefly, a design problem's temporal context comprises the events and activities that are relevant to the problem and take place (or are anticipated) before, during, and after the implementation of a solution. We define relevance to the problem to mean, "potentially affecting or affected by the problem and attempts to solve it." Societal context comprises the people (individually or in groups) and societal structures (e.g., government, economy, physical infrastructure) that are relevant to the problem. These aspects of context are detailed further at the start of Section 2, respectively.

***Trade-offs among multiple assessment approaches.*** The assessment techniques in this collection represent different ways of assessing contextual competence, each with relative strengths and limitations.

- *Design task assessments (Section 2):* The core set of techniques involves assessment of how much a student considers certain aspects of problem context when approaching an engineering design problem. In this sense, these techniques are performance based and attempt to strike a balance between practicality—in terms of time and effort required—and realism—in terms of providing a concrete and complex problem setting for demonstrating contextual competence. In these techniques, design tasks are accompanied by rubrics that can be applied to design-task answers to (self-)assess various aspects of contextual competence.
- *Self-reported contextual competence assessment (Section 3):* This survey question asks students to rate their preparedness with a wide range of important engineering skills/knowledge, including a number of

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[1] Selections of relevant publications are cited with individual assessment techniques in later sections.
[2] For more information, see http://www.en.aau.dk/About+Aalborg+University/The+Aalborg+model+for+problem+based+learning+(PBL)/

aspects of contextual competence. Unlike the above techniques, this question is asked in general terms, rather than with respect to a particular problem context.

- *Perceived importance of context in engineering practice (Section 4):* These survey questions are means of gauging students' perceptions of the importance of specific aspects of context, both relative to each other and to other elements of engineering practice.

Section 5 provides an additional set of assessment techniques whose focus is broader than just contextual competence. These techniques focus on student understanding of engineering design processes, as well as their conceptions of engineering practice more generally.

The assessment techniques in this collection vary in the trade-offs they make with respect to susceptibility to biases, time requirements, suitability for certain majors, and other qualities, as summarized in the table below.

| | **Design task assessments (Section 2)** | **Self-reported contextual competence assessment (Section 3)** | **Perceived importance of context in engineering practice (Section 4)** |
|---|---|---|---|
| Engages student in authentic design activity | somewhat | no | no |
| Suitable for self-assessment | more | less | less |
| Susceptible to social desirability bias | less | more | more |
| Requires more time for administration | more | less | less |
| Neutral to specific engineering major | less | more | more |

***Interpreting assessment results.*** Contextual competence is just one of many important types of competence in engineering design. Given the wide range of potential applications of these assessment techniques, rather than set arbitrary standards for interpreting responses, we leave them to educators to set, based on desired learning outcomes, level of student, expected level of contextual competence, prior opportunities for students to develop contextual competence, and other considerations. All of the assessment techniques provide measures of contextual competence, some with finer grain/resolution than others. The design task assessments have rubrics that yield counts of distinct context ideas considered. As such, a straightforward interpretation is that higher counts indicate broader consideration of context. Other options for interpreting assessment results are detailed in Section 2.

***Formative applications…*** These assessment techniques can be used in a variety of ways: formative vs. summative assessment, by the student themselves vs. by the educator. For formative purposes, an educator might employ some of these assessment techniques as diagnostics, before or early in an educational experience (e.g., course, project, co-op, study abroad). This could serve multiple purposes, including revealing (for both the educator's and students' benefit) students' strengths and weaknesses with respect to contextual competence, as well as motivating student interest in and raising awareness of context. Educators might choose to modify their teaching plans in response. Following the assessment with sharing and discussing assessment results can result in important learning opportunities, as can giving students the opportunity to revise their responses afterward.

***…and summative applications.*** Formative usage could be complemented with summative usage in the form of a second administration at a later time (pre/post style), as a means of gauging the potential impact of an educational experience on breadth of consideration of context. As a means of assessing contextual competence outcomes, these techniques could be useful for grading or for reporting to ABET and other engineering education stakeholders. In the list of ABET Criterion 3 student outcomes below, those that are most closely related to context are highlighted (ABET, 2013):

a) an ability to apply knowledge of mathematics, science, and engineering
b) an ability to design and conduct experiments, as well as to analyze and interpret data

- **c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability**
- d) an ability to function on multidisciplinary teams
- e) an ability to identify, formulate, and solve engineering problems
- f) an understanding of professional and ethical responsibility
- g) an ability to communicate effectively
- **h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context**
- i) a recognition of the need for, and an ability to engage in life-long learning
- j) a knowledge of contemporary issues
- k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

***Suggested format and administration.*** All of the assessment techniques are phrased and formatted assuming a usage scenario of individual student self-assessment administered either on paper or via web. Adapting most techniques for other usages should be straightforward, and some assessment techniques are accompanied by specific suggestions for adapted use. Most are suitable for administration in class or on students' own time. They are designed for individual assessment, but some techniques could be adapted for peer or even group assessment. In the sections that follow, assessment technique text that is intended for presenting to students is typeset in Times New Roman. Descriptions and guidelines for use are typeset in Franklin Gothic Book, the same sans serif font used here. Recommendations for space for written answers (e.g., "full page") assume U.S. letter size. Space for typed answers when administering via web assume roughly 60 characters per line.

**Administering multiple assessment techniques.** Educators interested in employing multiple assessment techniques with the same set of students should consider the order in and timing with which they are administered, given the likelihood of their interacting and biasing answers. This is particularly important if multiple task-based techniques or both task- and self-report-based techniques are used. In such cases, the general advice is to administer task-based techniques before self-report techniques, deferring any rubric-based self-assessment until after both are complete.

## 2 DESIGN TASK ASSESSMENTS

In this core set of assessment techniques, each assessment centers on a hypothetical design problem. For the given design problem, the student is first asked to engage in some part of their design process and record their answer. The student's design task answer then becomes the basis for the assessment of contextual competence, through the application of rubrics that focus on different aspects of context. The techniques feature five different design problems, formulated to be approachable by undergraduates in any engineering major, as confirmed in field testing. That said, each problem has an identifiable "home discipline," and educators should consider student major when using these assessment techniques with mixed-major groups, especially when interpreting results for summative assessment.

For practical reasons, the first step of engaging with a design problem is limited in both scope and time, e.g., only identifying information needed to solve the design problem. This represents a trade-off with the authenticity of the design activity, with the potential bias of favoring students who are able to think quickly and broadly about a design problem. Even so, field-testing experience suggests that these assessment techniques offer insight into students' consideration of various aspects of design problem context, at least in their initial design thinking.

***Rubrics focusing on contextual competence.*** The assessment techniques in this section are based on design tasks that require consideration of many aspects of context. In their current version, they are accompanied by rubrics that primarily focus on competence in considering two aspects context: *temporal* and *societal* context, as detailed below. A student or educator can use the rubrics to score a design task answer for contextual competence with a reasonable degree of uniformity. For summative assessment, instructional staff would typically be responsible for rubric application. For formative assessment, educators should consider the option of having students apply rubrics themselves, in order to develop some capacity for self-assessment. Students could apply rubrics to their own answers or swap answers with a peer. These assessment techniques are written with the assumption of individual students answering the design tasks and applying rubrics. However, groups of students could engage in these activities, as well. In fact, many of these techniques have been used as full-class exercises and discussions, providing opportunities for active learning on context and design. Finally, in any of these formative assessment scenarios, educators have the option of having students revise their design task answers after applying one or more rubrics, to immediately explore how attending to context can change approaches to design.

***Temporal context and life cycle phases.*** Briefly, a design problem's temporal context comprises the events and activities that are relevant to the problem and take place (or are anticipated) before, during, and after the implementation of a solution. We define relevance to the problem to mean, "potentially affecting or affected by the problem and attempts to solve it." One way of considering a design problem in temporal context is by recognizing that a solution is the result of many related activities over time. For example, in designing a computer monitor, engineers need to consider activities such as acquiring materials (e.g., metals, plastics, glass) and components (e.g., power supply), securing regulatory approval in target market nations, marketing the product to consumers, providing customer support (e.g., repairs), and what consumers could do with the device when they decide it has reached the end of its useful life (e.g., recycling). To borrow a formalism employed in life cycle engineering, each of the activities in this example belongs to a *phase* of the designed solution's life cycle. A generalized, simplified sequence of life cycle phases might comprise (1) research, (2) design, (3) prototyping, (4) acquisition of materials/components, (5) production/construction, (6) deployment/installation, (7) maintenance/support, and (8) recycling/disposal/retirement. Note that this simplified model can apply to a wide range of designed artifacts, from consumer electronics to bridges to software systems. The life cycle rubrics in this section provide a way of assessing how many life cycle phases are discussed in a design task response, where coverage of more phases indicates broader consideration of temporal context. Each of these rubrics includes a life cycle model that is customized for the corresponding design task. There are many advantages to comprehensive consideration of life cycle phases, including improved design solutions by highlighting complex interactions and unintended consequences. The structure that life cycle phases provide for thinking about an engineering design project can also facilitate thorough consideration of a wide variety of aspects of problem context. For instance, careful consideration of a solution's manufacturing requirements might lead to consideration of labor availability and the environmental consequences of acquiring raw materials.

***Societal context and stakeholders.*** Societal context comprises the people (individually or in groups) and societal structures (e.g., government, economy, physical infrastructure) that are relevant to the problem (with relevance defined as above for temporal context). Most of the societal context rubrics in this document are based on the notion of *stakeholders*, the people (again, individually or in groups) who might affect or be affected by the problem and/or solution. Each stakeholders rubric begins with an exercise in which students list stakeholders relevant to the design project. The assumption is that engineers who are able to quickly identify a wide range of stakeholders are better prepared to follow through with analysis of stakeholder relationships, principled prioritization of stakeholders, and, ultimately, better design decision making. Broad awareness of stakeholder relationships might, in some cases, warrant the use of design practices that are specifically formulated to attend to stakeholders, e.g., participatory/cooperative design, contextual inquiry.

| | | **Retaining wall** | **Smartphone** | **Street crossing** | **Microchip factory** | **Playground** |
|---|---|---|---|---|---|---|
| **Focal design activities** | | problem definition, gathering information | gathering information, adapting for new target market | generating ideas, gathering information, decision making, evaluation | evaluation | gathering information |
| **Aspects of context** | *General* | no | no | no | no | yes |
| | *Societal, general* | yes | no | yes | no | no |
| | *Societal, stakeholders* | yes | yes | yes | yes | No |
| | *Temporal, life cycle* | yes | yes | yes | yes | No |
| **Time required to administer (estimated, excluding rubric application)** | | 12 min. | 22 min. | 20 min. | 12 min. | 4 min. |

***Interpreting assessment results.*** The rubrics in this section yield results that can be interpreted in a variety of ways. With the life cycle rubrics, a larger number of life cycle phases roughly indicates broader consideration of temporal context. Analogously, with the stakeholders rubric, a larger number of identified stakeholders roughly indicates broader consideration of societal context. Educators might wish to assign differential weights to certain life cycle phases or stakeholders, e.g., in circumstances where a course or project puts particular emphasis on learning about certain parts of the life cycle or certain stakeholders, respectively.

***Extending the life cycle rubrics.*** We offer suggestions on how educators could extend these assessment techniques to not only gauge breadth of consideration of context but also depth. For instance, as given, the life cycle rubrics only record whether (not how much) a student considered each life cycle phase. In our field-testing experience, this reduces subjectivity and helps ensure uniformity in rubric application, especially when rubrics are applied by students in self- or peer-assessment scenarios. A natural trade-off is that a rubric in this form would not discriminate between a design task response that discusses multiple, distinct issues related to a particular life cycle stage vs. a response that only discusses one. These responses might be equivalent with respect to breadth of consideration of temporal context, in terms of coverage of life cycle stages; but the former arguably exhibits more depth or at least volume of discussion of the given life cycle stage. A straightforward way of adapting a life cycle rubric to be sensitive to such differences is by defining three or more levels of coverage for each life cycle stage. In the minimal example below, the three-level scale requires that the person applying the rubric reliably judge whether a design task response mentions one vs. multiple issues related to a given life cycle stage. Because of the time and subjectivity involved in judging how many distinct issues are discussed, we recommend using the minimum number of scale levels that would satisfy assessment and learning goals.

<table>
<tr><th rowspan="2">Number of distinct issues discussed in a design task response, for a given life cycle stage</th><th colspan="2">Rubric grain</th></tr>
<tr><th>yes/no<br>(two-level, as given)</th><th>three-level scale</th></tr>
<tr><td>none</td><td>(no check)</td><td>(no check)</td></tr>
<tr><td>one</td><td rowspan="2">✓</td><td>✓</td></tr>
<tr><td>two or more</td><td>✓+</td></tr>
</table>

***Extending the stakeholders rubrics for sensitivity to depth, not just breadth, of consideration of context.*** The stakeholders rubrics do not lend themselves to the same type of modification described above for the life cycle rubrics. However, the exercise of listing stakeholders can be extended to encourage students to provide details about how the design project interacts with stakeholders—i.e., how each stakeholder is affected by and/or affects design decisions. The suggested follow-up prompt for this extension is given as an optional question with each stakeholder rubric.

***Ordering rubrics for self assessment.*** For those design task assessments that have multiple rubrics, educators who wish to have students apply multiple rubrics are advised to give them in the order given in this document. In particular, the stakeholders rubrics are unusual in that they begin with a short exercise that, in some sense, is an extension of the design task that is specifically focused on context. Applying a context-focused rubric (particularly a societal context rubric) before engaging with the stakeholders exercise might artificially heighten their attentiveness toward context and bias the results of the stakeholders rubric.

## 2.1 Retaining wall design

Unlike the other design task assessment techniques, this one has two societal context rubrics. The first is the same stakeholders rubric that is given with the smartphone, street crossing, and microchip factory design tasks in the following subsections. The second is a simpler, checklist-based rubric that not only includes considerations of selected stakeholder groups but also other aspects of societal context. Using only the latter rubric would take less time, if the concept of stakeholders is not a priority.

As part of the Center for the Advancement of Engineering Education's Academic Pathways Study, this design task has been used with first- and third-year undergraduate students in a wide range of engineering majors in research on consideration of context (Kilgore, Atman, Yasuhara, Barker, & Morozov, 2007; Atman, Kilgore, Yasuhara, & Morozov, 2008). Rubrics were formulated based in part on the responses collected during this research, helping to ensure that they cover the range of responses expected from engineering undergraduates.

### 2.1.1 Design task

INSTRUCTIONS: Consider the design problem below and provide your answer in the space provided. You may spend up to 10 minutes.

Over the summer, the Midwest experienced massive flooding of the Mississippi River. What factors would you take into account in designing a retaining wall system for the Mississippi?

(The suggested amount of space to provide for an answer is about a full page when administering on paper or a text box with height of about 20 lines when administering via web.)

### 2.1.2 Stakeholders exercise and rubric

INSTRUCTIONS: Refer to but do not change your answer to the design task as you use the rubric below to assess your answer.

*Stakeholders rubric*. One useful way of considering societal context is by identifying stakeholders—people (individually or in groups) who might affect or be affected by the problem or solution. List all of the stakeholders you can think of who are relevant to the retaining wall design problem.

| | *Stakeholder* |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |

Now examine your design task answer and circle the number (left column) of each stakeholder that is specifically mentioned in your answer. How many stakeholders did your design task answer specifically mention?

Optional follow-up exercise: For each stakeholder, briefly describe at least one way in which the design task affects or is affected by them.

### 2.1.3 Societal context rubric

INSTRUCTIONS: Refer to but do not change your answer to the design task as you use the rubric below to assess your answer.

*Societal context rubric.* Engineering design can involve thinking about societal context—people and other elements of society (e.g., government, economy) that might affect or be affected by the problem or solution. In the list below, mark the societal context factors that your design task answer mentions.

NOTE: Only mark a factor if it is specifically mentioned in your answer. For example, if you wrote, "aesthetics" or "how it looks to people in the community" or "Is it going to be ugly?", you should mark "Aesthetics of wall" in the list. However, if you wrote, "peoples' opinions," it cannot be inferred that you meant peoples' opinions of how the wall would look, so you should *not* mark the item.

If you feel your answer addresses societal factors not listed below, mark "Other" and write them in.

- □ Aesthetics of wall
- □ Commerce, business, and industry on or near the wall, river, or surrounding areas
- □ Tourism on or near the wall, river, or surrounding areas
- □ Transportation on or near the wall, river, or surrounding areas
- □ Recreation on or near the wall, river, or surrounding areas
- □ Effects on people/communities living near the wall, river, or surrounding areas
- □ Safety issues, flooding-related or otherwise
- □ How people think about the flooding problem in the area
- □ Bridges and roads
- □ Farming
- □ Other:

How many societal factors did your design task answer specifically mention?

### 2.1.4 Life cycle rubric

INSTRUCTIONS: Refer to but do not change your answer to the design task as you use the rubric below to assess your answer.

*Life cycle rubric.* A design solution is the result of many related activities over time, from obtaining necessary materials to disposal of parts and materials that eventually wear out. For the retaining wall design task, the table below categorizes these activities into several life cycle phases. Mark the life cycle phases that your design task answer mentions.

NOTE: Only mark a life cycle phase if your answer specifically mentions an activity belonging to it. For example, if you wrote, "costs," it is unclear whether you are referring to material, construction, use, or recycling costs, so you should *not* mark any life cycle phase.

| | *Life cycle phase* | *Description* |
|---|---|---|
| □ | Material acquisition | Acquisition of materials needed for the retaining wall system and transportation of those materials to the construction site. Also includes selection of wall site. |
| □ | Construction | Process of designing/constructing the retaining wall system. Includes labor and energy needed for construction activities. |

| | | |
|---|---|---|
| □ | Use/Reuse/Maintenance | Includes operation, monitoring/testing, parts/materials replacement, labor and energy needed to operate and maintain. |
| □ | Recycle/Waste Management | Includes management of any waste materials, demolition/disposal. |

How many of the four life cycle phases did your design task answer specifically mention?

## 2.2 Smartphone design

This design task specifically prompts for consideration of national context and, implicitly, the many aspects of societal context that are associated with a nation (e.g., economic, linguistic, cultural). It is phrased below for use in the U.S. but is easy to adapt.

### 2.2.1 Design task

INSTRUCTIONS: You are asked to develop a concept for a personal communication device for the U.S. market. This product is portable and can facilitate all kinds of communications for the user through sending and receiving satellite signals; it can act as a mobile phone, radio, TV, GPS, and also an email and web browser. You may also incorporate any additional features that are important to you.

As a guide, it is suggested that you think around three different aspects of this problem: the user, the context of the use (where, when and how it is used), and the product itself.

Part A: What information would you gather in designing this product for U.S. users? Please be as specific as you can. You may spend up to 10 minutes.

Part B: Now consider the design of this product for users in Mexico. What information would you want to gather to revise this design to meet user needs in this different national context? Please be as specific as you can. You may spend up to 10 minutes.

(For each of the above parts, the suggested amount of space to provide for an answer is about half a page when administering on paper or a text box with height of about 10 lines when administering via web.)

### 2.2.2 Stakeholders exercise and rubric

INSTRUCTIONS: Refer to but do not change your answer to the design task as you use the rubric below to assess your answer.

*Stakeholders rubric*. One useful way of considering societal context is by identifying stakeholders—people (individually or in groups) who might affect or be affected by the problem or solution. List all of the stakeholders you can think of who are relevant to the smartphone design problem, considering both Parts A and B.

| | *Stakeholder* |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |

Now examine your design task answer and circle the number (left column) of each stakeholder that is specifically mentioned in your answer. How many stakeholders did your design task answer specifically mention?

Optional follow-up exercise: For each stakeholder, briefly describe at least one way in which the design task affects or is affected by them.

### 2.2.3 Life cycle rubric

INSTRUCTIONS: Refer to but do not change your answer to the design task as you use the rubric below to assess your answer.

*Life cycle rubric.* A design solution is the result of many related activities over time, from obtaining necessary materials to disposal of parts and materials that eventually wear out or become obsolete. For the smartphone design task, the table below categorizes these activities into several life cycle phases. Mark the life cycle phases that your design task answers mention, considering both Parts A and B.

NOTE: Only mark a life cycle phase if your answer specifically mentions an activity belonging to it. For example, if you wrote, "costs," it is unclear whether you are referring to material, production, sale, use, or recycling costs, so you should *not* mark any life cycle phase.

| | *Life cycle phase* | *Description* |
|---|---|---|
| □ | Acquisition of Materials/ Components | Acquiring materials (e.g., metals) or components (e.g., display panels, memory chips) needed to manufacture the device. Could include reference to availability or extraction of raw materials. |
| □ | Manufacturing | Manufacturing the device, including fabrication, assembly, and testing. Includes labor and energy needed for manufacturing activities. |
| □ | Sale | Marketing, packaging, transporting, and getting the device to consumers. |
| □ | Use, Support, and Maintenance | Includes consumers' operation of the device, including customer support and maintenance concerns (e.g., repair, part replacement). |
| □ | End of Life | Includes considerations of recycling or disposal of the device or its components. |

How many of the four life cycle phases did your design task answer specifically mention?'

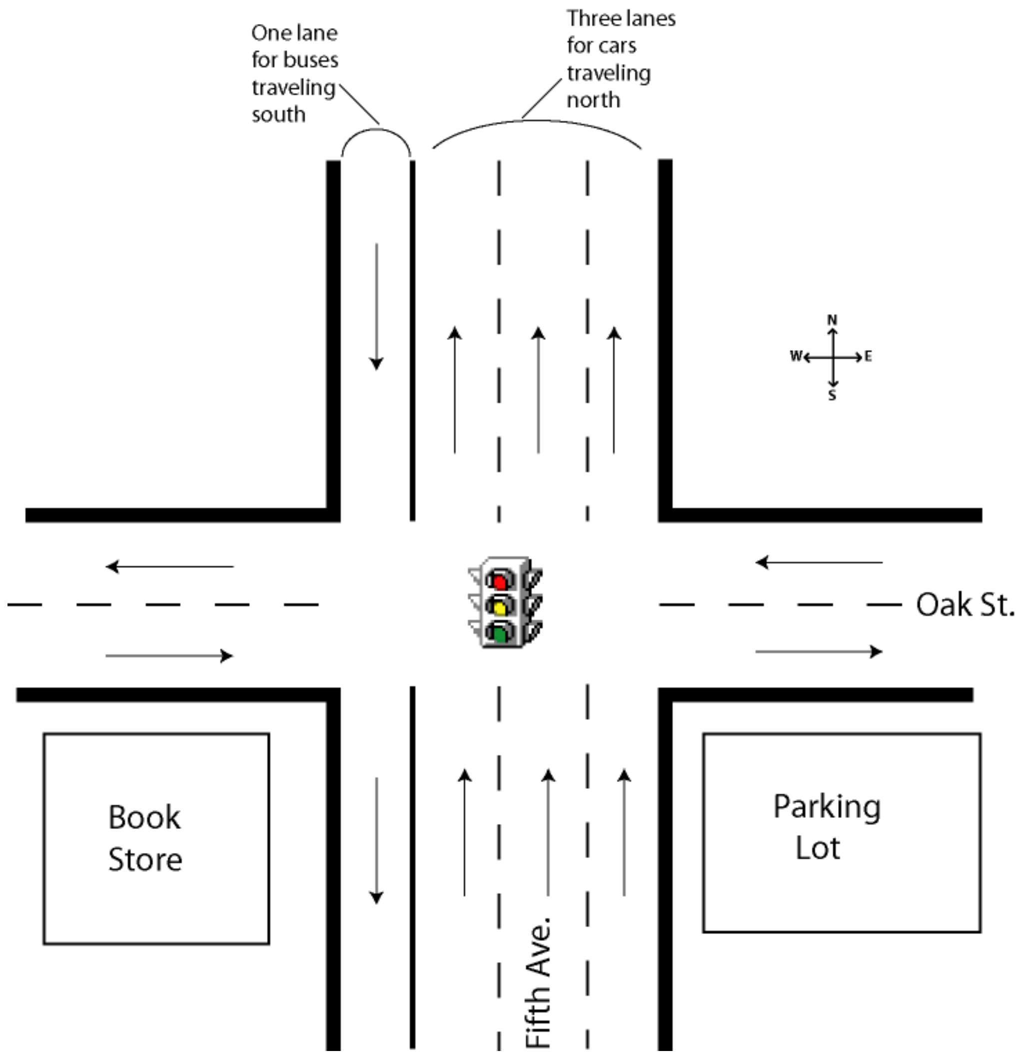
## 2.3 Street crossing design

This design task engages students in more design activities than just gathering information, although it accordingly takes more time. The design task has been used with second- and fourth-year undergraduate students in a wide range of engineering majors in a research study on consideration of context (Yasuhara, Morozov, Kilgore, Atman, & Loucks-Jaret, 2009; Kilgore, Jocuns, Yasuhara, & Atman, 2010), part of the Center for the Advancement of Engineering Education's Academic Pathways Study. Rubrics were formulated based in part on the responses collected during this research, helping to ensure that they cover the range of responses expected from engineering undergraduates.

### 2.3.1 Design task

As an engineer, you have been asked to solve a problem on the State University campus. Just like campuses across the country, the State University campus is often overcrowded with pedestrians crossing the streets.

One busy intersection on campus is the crossing of Fifth Ave. in front of the bookstore. Dangers at this intersection include heavy traffic and buses that run against the general traffic flow (diagram below). The University would like to design a cost-effective method for students to cross Fifth Ave. that would reduce the possibility of accidents at this intersection. You have been assigned to design a solution to this problem for presentation to the University Traffic Committee.



Part A: List the three best potential solutions for this problem. You may spend up to five minutes.

(For Part A, the suggested amount of space to provide for an answer is about one third of a page when administering on paper or a text box with height of about 8 lines when administering via web.)

Part B: Please list all of the kinds of information would you need to evaluate the alternative solutions you listed above. Please be as specific as possible. You may spend up to 10 minutes.

(For Part B, the suggested amount of space to provide for an answer is about two thirds of a page when administering on paper or a text box with height of about 12 lines when administering via web.)

### 2.3.2 Stakeholders exercise and rubric

INSTRUCTIONS: Refer to but do not change your answer to the design task as you use the rubric below to assess your answer.

*Stakeholders rubric*. One useful way of considering societal context is by identifying stakeholders—people (individually or in groups) who might affect or be affected by the problem or solution. List all of the stakeholders you can think of who are relevant to the street crossing design problem, considering both Parts A and B.

| | *Stakeholder* |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |

Now examine your design task answer and circle the number (left column) of each stakeholder that is specifically mentioned in your answer. How many stakeholders did your design task answer specifically mention?

Optional follow-up exercise: For each stakeholder, briefly describe at least one way in which the design task affects or is affected by them.

### 2.3.3 Societal context rubric

INSTRUCTIONS: Refer to but do not change your answer to the design task as you use the rubric below to assess your answer.

*Societal context rubric.* Engineering design can involve thinking about societal context—people and other elements of society (e.g., government, economy) that might affect or be affected by the problem or solution. In the list below, mark the societal context factors that your design task answer mentions.

NOTE: Only mark a factor if it is specifically mentioned in your answer. For example, if you wrote “Route less popular bus routes off Fifth,” in Part A, that is sufficient for marking “User behavior.” However, if you wrote, “resource availability,” in Part B, that is *not* specific enough to mark “Labor availability.”

If you feel your answer addresses societal factors not listed below, mark “Other” and write them in.

- □ Legal context: Regulations and zoning, traffic safety laws, school zone, speed limit, handicapped access
- □ Safety: Pedestrian safety, reference to traffic accidents
- □ Labor availability: Labor needed and/or available for the construction of your solution
- □ Stakeholders’ opinions: City priorities, bus driver opinions, contractor opinion, student opinions, public opinion, university priorities.
- □ User behavior: Bus routes and schedules, demand for buses, campus characteristics, population, high demand times, pedestrian behavior, pedestrian demographics, motorist’s intentions, students driving, parking on campus
- □ Commercial context: Nearby businesses and bookstore
- □ Aesthetics: How pleasing to the eye is the proposed solution?
- □ Other:

### 2.3.4 Life cycle rubric

INSTRUCTIONS: Refer to but do not change your answer to the design task as you use the rubric below to assess your answer.

*Life cycle rubric.* A design solution is the result of many related activities over time, from obtaining necessary materials to disposal of parts and materials that eventually wear out or become obsolete. For the street crossing design task, the table below categorizes these activities into several life cycle phases. Mark the life cycle phases that your design task answers mention, considering both Parts A and B.

NOTE: Only mark a life cycle phase if your answer specifically mentions an activity belonging to it. For example, if you wrote, “costs,” it is unclear whether you are referring to material, construction, operation, or demolition costs, so you should *not* mark any life cycle phase.

| | *Life cycle phase* | *Description* |
|---|---|---|
| □ | Acquisition of Materials | Acquisition of materials needed for the proposed solution and transportation of those materials to the construction site. |
| □ | Construction | Construction of the proposed solution, if relevant. Includes labor and energy needed for construction activities. |
| □ | Use/Reuse/Maintenance | Includes operation, monitoring/testing, parts replacement, labor and energy needed to operate and maintain the proposed solution. |
| □ | Recycling/<br>Waste Management | Includes management of any waste materials, demolition/disposal of solution. |

How many of the four life cycle phases did your design task answer specifically mention?

## 2.4 Microchip factory design

This design task focuses on a very specific activity in the design process: evaluating alternative solutions. A similar design task was administered to fourth-year engineering undergraduates in the Center for the Advancement of Engineering Education's Academic Pathways Study (Atman et al., 2008).

### 2.4.1 Design task

You are an engineer working for a silicon microchip manufacturing company. Your company's current facilities in California are close to maximum capacity, and the company is out of land to expand at the current site. The company needs to build a new factory in a new location. Management has been in talks with officials in three potential sites: in the U.S., in rural Alabama or the suburbs of Chicago; or in Asia, in Thailand. You have been asked to evaluate the sites for locating the plant. List all the types of information you would consider in your evaluation of the sites. Please be as specific as you can. You may spend up to 10 minutes.

(The suggested amount of space to provide for an answer is about a full page when administering on paper or a text box with height of about 20 lines when administering via web.)

### 2.4.2 Stakeholders exercise and rubric

INSTRUCTIONS: Refer to but do not change your answer to the design task as you use the rubric below to assess your answer.

*Stakeholders rubric*. One useful way of considering societal context is by identifying stakeholders—people (individually or in groups) who might affect or be affected by the problem or solution. List all of the stakeholders you can think of who are relevant to the microchip factory problem.

| | *Stakeholder* |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |

Now examine your design task answer and circle the number (left column) of each stakeholder that is specifically mentioned in your answer. How many stakeholders did your design task answer specifically mention?

Optional follow-up exercise: For each stakeholder, briefly describe at least one way in which the design task affects or is affected by them.

### 2.4.3 Life cycle rubric

INSTRUCTIONS: Refer to but do not change your answer to the design task as you use the rubric below to assess your answer.

*Life cycle rubric.* A design solution is the result of many related activities over time, from obtaining necessary materials to disposal of parts and materials that eventually wear out or become obsolete. For the street crossing design task, the table below categorizes these activities into several life cycle phases. Mark the life cycle phases that your design task answer mentions.

NOTE: Only mark a life cycle phase if your answer specifically mentions an activity belonging to it. For example, if you wrote, “costs,” it is unclear whether you are referring to material, construction, operation, or demolition costs, so you should *not* mark any life cycle phase.

| | *Life cycle phase* | *Description* |
|---|---|---|
| □ | Acquisition of Materials | Acquisition and transportation of materials needed for factory construction. Also includes availability and cost of site. |
| □ | Construction | Construction of the factory, including labor and energy needed for construction activities and construction costs. |
| □ | Use/Reuse/Maintenance | Includes factory operation, monitoring/testing, parts replacement, materials, labor, and energy needed to operate and maintain the factory. |
| □ | Recycling/<br>Waste Management | Includes management of any factory waste materials, as well as factory demolition/disposal. |

How many of the four life cycle phases did your design task answer specifically mention?

## 2.5 Playground design

This design task has been used with first- and fourth-year undergraduate students in a wide range of engineering majors in a research study on consideration of context (Kilgore et al., 2007), part of the Center for the Advancement of Engineering Education's Academic Pathways Study. Most students should be able to complete their answer within three minutes. Responses to this survey question can be compared against multi-institutional data as published in the Center for the Advancement of Engineering Education's final report (Atman, Sheppard, Turns, Adams, Fleming, Stevens, Streveler, Smith, Leifer, Yasuhara, & Lund, 2010).

### 2.5.1 Design task

You have been asked to design a playground. You have a limited amount of time and resources to gather information for your design. From the following list, please put a check mark next to the FIVE kinds of information you would MOST LIKELY NEED as you work on your design:

- □ Availability of materials
- □ Body proportions
- □ Budget
- □ Handicapped accessibility
- □ Information about the area
- □ Labor availability and cost
- □ Legal liability
- □ Maintenance concerns
- □ Material costs
- □ Material specifications
- □ Neighborhood demographics
- □ Neighborhood opinions
- □ Safety
- □ Supervision concerns
- □ Technical references
- □ Utilities

### 2.5.2 Societal context rubric

INSTRUCTIONS: Refer to but do not change your answer to the design task as you use the rubric below to assess your answer.

*Societal context rubric.* Engineering design can involve thinking about societal context—people and other elements of society (e.g., government, economy) that might affect or be affected by the problem or solution. How many of the societal context items listed below did you mark in your answer?

- □ Body proportions
- □ Handicapped accessibility
- □ Legal liability
- □ Neighborhood demographics
- □ Neighborhood opinions
- □ Safety
- □ Utilities

## 3 SELF-REPORTED CONTEXTUAL COMPETENCE ASSESSMENT

This survey question asks students to self-assess their preparation with a wide range of engineering skills and knowledge, including some that are related to context. The item list was developed for a research study (Chen, Grau, Brunhaver, Gilmartin, Sheppard, & Warner, 2012) and covers the student outcomes and attributes described in ABET Criterion 3 (ABET, 2013) and the National Academy of Engineering's report, *The Engineer of 2020* (2004). Most students should be able to complete their answer within five minutes.

Compared to the design task assessment techniques above, this question provides a more general and self-reported assessment of a couple aspects of contextual competence. The trade-off is primarily with time, both for administration and interpretation of answers. For calibration, answers for the "Economic issues," "Global/societal context," and "Environmental context" items can be compared to answers to the other skills/knowledge items. We do not have sufficient data on the extent to which self-assessed contextual competence is related to contextual competence as assessed by design task-based techniques. As such, we recommend against relying on this survey question as the primary basis for assessing contextual competence. Instead, we suggest complementing design task assessment techniques with this question.

Please rate how well prepared you are to incorporate each of the following items while practicing as an engineer:

| | *Not at all prepared* | … | *Somewhat prepared* | … | *Very well prepared* |
|---|---|---|---|---|---|
| Analytical skills | ○ | ○ | ○ | ○ | ○ |
| Business knowledge | ○ | ○ | ○ | ○ | ○ |
| Communication | ○ | ○ | ○ | ○ | ○ |
| Creativity | ○ | ○ | ○ | ○ | ○ |
| Design | ○ | ○ | ○ | ○ | ○ |
| Planning/conducting experiments | ○ | ○ | ○ | ○ | ○ |
| Economic issues | ○ | ○ | ○ | ○ | ○ |
| Engineering techniques/tools | ○ | ○ | ○ | ○ | ○ |
| Environmental context | ○ | ○ | ○ | ○ | ○ |
| Ethics | ○ | ○ | ○ | ○ | ○ |
| Global/societal context | ○ | ○ | ○ | ○ | ○ |
| Leadership | ○ | ○ | ○ | ○ | ○ |
| Life-long learning | ○ | ○ | ○ | ○ | ○ |
| Management skills | ○ | ○ | ○ | ○ | ○ |
| Managing uncertainty | ○ | ○ | ○ | ○ | ○ |

| | | | | | |
|---|---|---|---|---|---|
| Math | ○ | ○ | ○ | ○ | ○ |
| Problem solving | ○ | ○ | ○ | ○ | ○ |
| Professionalism | ○ | ○ | ○ | ○ | ○ |
| Science | ○ | ○ | ○ | ○ | ○ |
| Teamwork | ○ | ○ | ○ | ○ | ○ |

## 4 PERCEIVED IMPORTANCE OF CONTEXT IN ENGINEERING PRACTICE

These two survey questions provide information about the importance students ascribe to certain aspects of context. As such, neither is an assessment of contextual competence, but they complement the assessment techniques above. Assuming that students are less likely to learn things that they consider less important in engineering practice, these questions can provide useful perspectives on student motivation to develop contextual competence. To some extent, simply presenting these questions to students implicitly signals the importance of context, particularly with the second question, which is entirely focused on context. Educators could use these survey questions before a context-focused unit, using the responses to guide plans for motivating and teaching consideration of context.

Educators who intend to use both of these questions are advised to administer them in the order they appear below. Administering the context-focused question (Section 4.1.2) first is likely to cue greater consideration of context and might result in artificially inflated importance answers for the context-related items in the more general question (Section 4.1.1).

### 4.1.1 Conceptions of engineering practice

The first of the two questions is broader in scope and provides a rough but thorough picture of how a student conceives of engineering practice, including consideration of context. Students are asked to rate the importance of each of 20 engineering skills/knowledge items. The item list was developed for a research study (Chen et al., 2012) and covers the student outcomes and attributes described in ABET Criterion 3 (ABET, 2013) and the National Academy of Engineering's report, *The Engineer of 2020* (2004). For calibration, answers for the "Economic issues," "Global/societal context," and "Environmental context" items can be compared to answers for the other skills/knowledge items. This would provide some measure of relative importance of context within engineering practice.

Most students should be able to complete their answer within five minutes.

How important is each of the following for practicing engineers?

| | Not important | Slightly important | Moderately important | Very important | Extremely important |
|---|---|---|---|---|---|
| Analytical skills | ○ | ○ | ○ | ○ | ○ |
| Business knowledge | ○ | ○ | ○ | ○ | ○ |
| Communication | ○ | ○ | ○ | ○ | ○ |
| Creativity | ○ | ○ | ○ | ○ | ○ |
| Design | ○ | ○ | ○ | ○ | ○ |
| Planning/conducting experiments | ○ | ○ | ○ | ○ | ○ |
| Economic issues | ○ | ○ | ○ | ○ | ○ |
| Engineering techniques/tools | ○ | ○ | ○ | ○ | ○ |
| Environmental context | ○ | ○ | ○ | ○ | ○ |
| Ethics | ○ | ○ | ○ | ○ | ○ |

| | | | | | |
|---|---|---|---|---|---|
| Global/societal context | ○ | ○ | ○ | ○ | ○ |
| Leadership | ○ | ○ | ○ | ○ | ○ |
| Life-long learning | ○ | ○ | ○ | ○ | ○ |
| Management skills | ○ | ○ | ○ | ○ | ○ |
| Managing uncertainty | ○ | ○ | ○ | ○ | ○ |
| Math | ○ | ○ | ○ | ○ | ○ |
| Problem solving | ○ | ○ | ○ | ○ | ○ |
| Professionalism | ○ | ○ | ○ | ○ | ○ |
| Science | ○ | ○ | ○ | ○ | ○ |
| Teamwork | ○ | ○ | ○ | ○ | ○ |

### 4.1.2 Importance of specific aspects of context

The question below focuses on context, asking about the importance of each of 14 aspects of context. The list of aspects of context is based on numerous sources, including student outcomes as described in ABET Criterion 3, interviews with 35 engineering alumni, and answers from piloting earlier versions of the question. Rather than ask for subjective ratings of importance, the question asks students to estimate how often practicing engineers consider each aspect of context. Relative to the format of the first question, the trade-off here is that it might be more difficult for students to answer a question in this format, but this approach reduces the subjectivity of the response scale and yields an indirect measure of perceived importance. This question is a slightly modified version of one that was developed for the Engineering Pathways Study (Chen et al., 2012) and was administered to a sample of recent college graduates who majored in engineering. Although the question was originally developed for alumni, we have also used the version included here with first-year undergraduates.

Most students should be able to complete their answer within five minutes.

How often do you think practicing engineers consider each of the following in their work?

| | *Not at all* | *Once or twice a year* | *Once or twice a month* | *Once or twice a week* | *Daily* |
|---|---|---|---|---|---|
| Costs/benefits, return on investment | ○ | ○ | ○ | ○ | ○ |
| Ethics | ○ | ○ | ○ | ○ | ○ |
| General economic conditions | ○ | ○ | ○ | ○ | ○ |
| Global events/trends | ○ | ○ | ○ | ○ | ○ |
| Health and safety | ○ | ○ | ○ | ○ | ○ |

| | | | | | |
|---|---|---|---|---|---|
| Industry events/trends | ○ | ○ | ○ | ○ | ○ |
| Natural environment | ○ | ○ | ○ | ○ | ○ |
| Political environment and events (local, regional, or national) | ○ | ○ | ○ | ○ | ○ |
| Product/service viability | ○ | ○ | ○ | ○ | ○ |
| Societal issues | ○ | ○ | ○ | ○ | ○ |
| Sustainability | ○ | ○ | ○ | ○ | ○ |
| Systems-level issues | ○ | ○ | ○ | ○ | ○ |
| User needs and interests | ○ | ○ | ○ | ○ | ○ |
| Your organization's policies, goals, or environment | ○ | ○ | ○ | ○ | ○ |

# 5 SUPPLEMENTAL ASSESSMENTS RELATED TO DESIGN

The remaining assessment techniques are not specifically related to contextual competence but focus on the many activities that engineers engage in during design. The first is based on extensive research on variation in students' design processes. The second is a survey question that provides a rough characterization of what students think engineering design entails.

From a teaching perspective, educators might find these techniques valuable for providing students with broad conceptualizations of engineering design, along with vocabulary for design activities. This sets the stage for detailed discussion of when and how consideration of context can helpful throughout the engineering design process. For instance, gathering information and, more generally, problem scoping are key opportunities for consideration of context.

## 5.1 Design-process timelines exercise

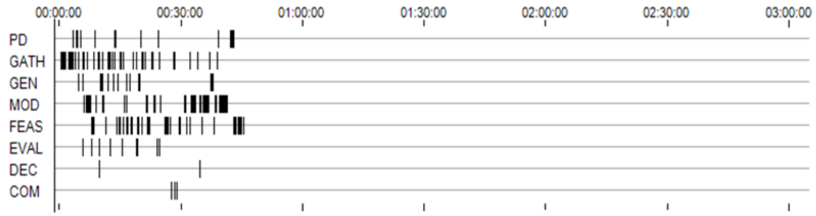
This exercise is best suited for students who have had at least one substantial design-project experience, usually upper-division students. This exercise appears in a workshop described by Borgford-Parnell et al. (2010) and Atman, Eris, McDonnell, Cardella, & Borgford-Parnell (2014). It is based on over a decade of research on engineering design processes and has been found to help engineering students visualize, understand, analyze, and reflect on design processes.

Most students should be able to complete their answer within 10 minutes. (The suggested amount of space to provide for an answer is about half a page when administering on paper or a text box with height of about 20 lines when administering via web.)

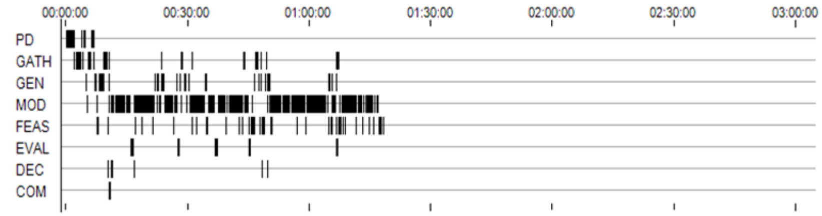
Consider the representations of six engineering students' design processes shown on the next page. All of these students engaged in the same design task, designing a playground. Each timeline represents the activities the student was engaged in while doing the design task. The key below the timelines lists the design activities and corresponding abbreviations. Design researchers rated each student's design work and computed a "quality score" on a scale of 0 to 1, where a higher score is better.

In the design process timelines shown, what similarities and differences do you see between the freshman and senior engineering students? Do these similarities also involve the quality scores? How so?

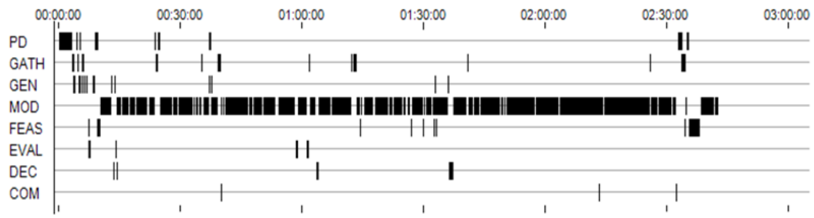
Freshman #1 (Quality Score = 0.37)



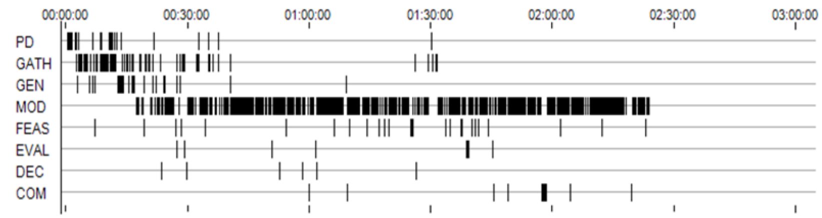

Senior #1 (Quality Score = 0.38)



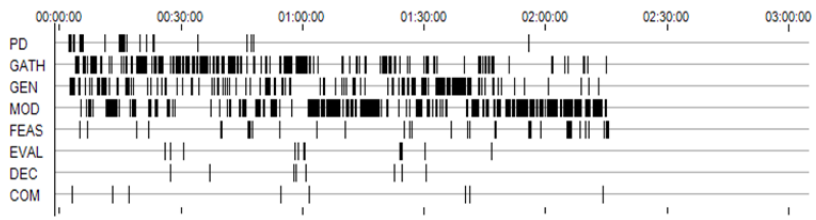

Freshman #2 (Quality Score = 0.45)



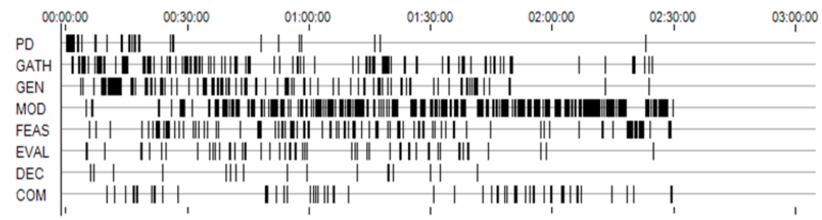

Senior #2 (Quality Score = 0.53)




Freshman #3 (Quality Score = 0.62)




Senior #3 (Quality Score = 0.63)




**PD, Problem definition:** Defining the details of the problem

**GATH, Gathering information:** Collecting information needed to solve the problem

**GEN, Generating ideas:** Thinking up potential solutions (or partial solutions)

**MOD, Modeling:** Detailing how to build solution or parts of a solution

**FEAS, Feasibility analysis:** Assessing possible or planned solutions (or partial solutions)

**EVAL, Evaluation:** Comparing two or more solutions within constraints

**DEC, Decision:** Selecting one idea or solution

**COM, Communication:** Revealing and explaining design elements to others

## 5.2 Conceptions of engineering design

This survey question provides a quick means of determining how students conceive of engineering design. It asks students to identify the most important activities in design, and most students should be able to complete their answer within two minutes, with an additional two minutes for the optional follow-up question.

This question was administered as part of the Academic Pathways Study and has been used in multiple engineering education research projects. Students and educators interested in comparing response data with those collected at multiple U.S. institutions are referred to the final report of the Center for the Advancement of Engineering Education (Atman et al., 2010) and a paper by Yasuhara, Chen, Lande, Campbell, Atman, & Sheppard (2011).

Of the 23 design activities below, please put a check mark next to the SIX MOST IMPORTANT.

- □ Abstracting
- □ Brainstorming
- □ Building
- □ Communicating
- □ Decomposing
- □ Evaluating
- □ Generating alternatives
- □ Goal Setting
- □ Identifying Constraints
- □ Imagining
- □ Iterating
- □ Making decisions
- □ Making trade-offs
- □ Modeling
- □ Planning
- □ Prototyping
- □ Seeking Information
- □ Sketching
- □ Synthesizing
- □ Testing
- □ Understanding the problem
- □ Using creativity
- □ Visualizing

Optional follow-up: Please provide a brief explanation of your answer.

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