# Using process mapping to understand engineering students' conceptions of innovation processes


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***Abstract* — This work in progress continues an ongoing project to understand and document engineering students' innovation identities. Prior studies have reported on how students separate their engineering and creative identities, on demographic differences in students' ideation processes, and on students' description of barriers that prevent them from practicing engineering more innovatively. Using process maps drawn by 32 undergraduate engineering students, we perform an inductive qualitative analysis of students' innovation process maps. We look specifically at features and characteristics that are common and different across the process map artifacts produced by students. The result is a coding protocol that researchers can use to characterize process maps or explanations of the innovation process. Future work will extend the coding protocol as a tool for assessing students' conception of innovation.**



***Keywords — Innovation, Visual Data, Process Map, Content Analysis***


## I. Introduction

Modern engineering education seeks to create more innovative engineers for their ability to think differently about problems and produce greater value for themselves, their employers, and society [1], [2]. However, the engineering education research that seeks to support development of innovative engineers typically takes one of two lenses. First is the lens of the expert innovator or entrepreneur where assessment of student innovation competencies is grounded in the opinions, actions, as well as knowledge, skills, and attitudes (KSA) of experts [3], [4]. The second common lens is through analysis of project deliverables as insightful artifacts that represent students' innovation understanding [5], [6].

In prior studies, researchers have reported on how students separate their engineering and creative identities [7], on similarities and differences in students' ideation processes based on gender composition of teams [6], and on students' description of barriers that prevent them from acting more innovatively [7]. Studies have also identified specific descriptions and articulations of engineering innovation projects by engineering students that focus on very different components of the innovation process than innovation experiences described by experienced engineers [8].

The purpose of this study is to report on preliminary findings of a novel approach to assessing students' conceptions of the innovation process using visual data. We report on the development of an analysis schema for documenting 'innovation process maps' drawn by students. This schema will serve as a baseline for further work that looks at whether students' visual documentation serves as an effect analogue for students' conception of the how innovation occurs.

## II. Use of visual data in qualitative research

The use of visual data in educational research is an evolving interest [9], [10]. Visual data often serves as either an alternative or supplement to more traditional forms of data [11]. The modern iterations include both visual data created by researchers in the course of a study [11], [12] and visual data created by research participants [9], [13].

In engineering education, few examples of visual data exist. These include the Draw an Engineer Test [14], [15] as well as Mosborg and colleagues' [16] investigation of experts' design process diagrams. Other fields, such as new product development have utilized expert-created process maps to compare innovation processes between industry and academia [17]. Visual data analysis in engineering education research is a necessity given the wide use of visual tools in engineering and other technical education classrooms to document systems, diagram concepts, and generally make visible abstract or hard to 'see' concepts and processes [18]–[20].

Visual data is, at a fundamental level, just another form of research data. However, researchers should pay specific attention to issues of perspective and epistemology [11]. When using participant created data, Banks notes that the researcher must be aware of the dualistic nature of the image as both data in itself and as a representation of the participants' choices in creating that data.

## III. Methods

This study uses an inductive approach to develop a coding scheme to quantify engineering students' conception of their innovation process. Using guidelines from existing literature on visual data [11], [13], [21], we collected and analyzed students' visualization of the innovation process. This section details the data collection method, the data used in this work in progress study, and the analytical steps that we have performed to date. While the data collection as part for the broader study included interviews, this work uses only the visual data in the form of artifacts called 'innovation process maps'.

### A. Data Collection

We collected the data for our study from spring of 2013 through the spring of 2014. Data collection included in person interviews and recording of "innovation process mapping task" using smart pens [22]. The process maps are in the form of black ink drawings on lined paper that we provided to students during the interviews. Examples of innovation process maps, drawn by students in the study, appear in Figures 2 through 5 in the results section.

During the innovation process mapping task, we prompted students to diagram the process that they would undertake to design an innovative product and take it to market. They then illustrated and explained their process map.

### B. Sample

In total, we analyzed process maps created by 32 students. The sample consisted of approximately equal number of male and female students. The participants were enrolled in engineering undergraduate degree granting programs at a public university and came from a variety of majors. The participants were either first-year or senior students.

### C. Methods of Analysis

We used an inductive approach to generate a set of codes that we will use in the larger study to quantify components of the process maps. The analysis involved three distinct stages [23]. The result of this initial analysis is a set of questions or codes that we will use in future work to characterize or assess process maps created using the data collection protocol.

#### 1) Initial pile sort

The analysis started by developing initial codes and categories using pile sorting [24]. In pile sorting, researchers physically organizing pieces of data into groups or piles which they then name and describe.

The pile sorting method is especially useful in visual data because all information can be analyzed as a whole, different from text, which requires reading, chunking, and other tasks to breakdown the data into individual coded fragments [16].

Three members of the research team each conducted this step independently using the complete data set. One researcher was a faculty member, one was a graduate research assistant, and one was an undergraduate research assistant. The researchers identified as many themes as they deemed necessary to describe the innovation process maps effectively.

The goal of the pile sorting was not to generate a final code set that we could apply to all the process maps. Instead, the goal was to develop initial areas or categories [23] of similarity and difference. These categories would then represent concepts, principles, features, and observations that are useful

#### 2) Theme development

The goal of stage 2 was to reduce, synthesize, and align the groups of themes produced by all three researchers in step one. The graduate researcher and the faculty member conducted the second stage working together. They identified themes that were common as well as unique between the three pile sorts using an iterative process of combining and refining themes while checking them against the process maps that comprise our data [11]. These checks were designed to increase the quality of emergent themes [11].

#### 3) Development of question codes

The final step of the analysis process was the generation of a list of codes from the categories and revision in the previous stages [23]. In future work, we will use these codes to quantify process maps to explore the assessment capability of innovation process maps for understanding students' conceptions of innovation.

Because the process maps artifacts are unitary visual data (i.e., they are difficult to decompose into smaller codeable chunks [11]) they present slightly different challenges in coding and analysis. As a result, we treat the each process map as a sampled unit of data for analysis [23] and take a slightly atypical approach to the inductive creation of final codes. We plan to create a larger number of holistic codes in the form of yes no questions. These codes will be assigned to the entire artifact, rather than assigning codes to specific chunks.

The dichotomous (yes or no) questions pertain to the entire artifact, addressing concerns about operationalization of code books in visual data [23]. This also allows for a number of codes that is higher than would typically be applied, because each code only applies once, to the entire artifact, rather than to subcomponents or chunks.

## IV. Results

### A. Example process maps

To show the variation in the process maps, which comprise the raw data, we have included four examples in Figures 2 through 5. We selected these specific examples to represent the multiplicity of approaches that students' used to structure, populate, e, and elaborate their process maps.

These students include one aeronautical engineer, one civil engineer, and two chemical engineers. They represent the high variation in students' elaboration in the process maps (Figure 3 vs. the others), the use of a text heavy design vs. a more graphic design (Figure 2 vs. Figure 4 and 5), and the use of different content within the same approach (Figure 4 vs. Figure 5).

### B. Initial pile sorting

Using the pile sorting method, the undergraduate analyst identified five major categories, the graduate analyst identified six, and the faculty analyst identified six. All five of the themes developed by the undergraduate aligned with themes by the other researchers. Alignment of the other two researchers themes was also generally good.

### C. Revision and refinement of categories

The second step in the analytical process began with the themes identified in the previous section. We worked with the themes, the descriptions of themes, and the data that we had used in the first stage to generate a final list of categories in the process maps.

From the pile sorting results, we generated three groups of themes and 11 overall themes representing categories that we then developed into individual codes. Shown in Table 2, the three groups are; those that refer to the content of the process map, those that refer to the visual design, as well as those best identified by reading the text and visual layout together.

*Table 1 Coding Protocol: Combined and revised categories*

| Group | Categories |
|---|---|
| Content | Business creation and development *(including stages of business development)* |
| | Teams/People/Human resources |
| | Legal compliance |
| | Product design and development *(including stages of design)* |
| Visual Style | Elaboration |
| | Text vs. Visual focus |
| | Visual organization / shape |
| Mixed | Starting / ending point |
| | Driving stage |
| | Iteration *(and related subthemes about iteration)* |
| | Questions vs. stages |
| | Style/Organization |

### D. Developing codes

Using the categories in Table 2, the undergraduate and graduate researcher brainstormed sets of codes that could be applied to the process maps. The faculty researcher and another graduate researcher unfamiliar with the analysis to this point then reviewed the codes and offered suggestions for refinement. As described in the methods section, these codes take the form of yes or no questions that can be asked of the process maps as unitary data sources. In total, we created 94 questions / codes.

All questions began with a stem of "Does the innovation process that students describe…". The stem is them completed with a statement representing a specific code of interest (e.g., "contain elements or methods of idea generation" or "begin by forming a team"). In some cases, the initial brainstormed ideas were split to provide more nuanced characterization (e.g., "begin with idea generation" or "begin with an idea") to separate process maps that assume the presence of a component of innovation from those that specifically articulate building that component as part of the innovation process.

## V. Discussion and Future Work

As part of this work in progress paper, we described the development of a set of categories and codes for characterizing innovation process maps. Our next steps will include applying the final coding scheme to quantitatively assess and compare student conceptions of students' conception of the innovation process.

The analysis presented resulted in a large set of codes that represent components of students' innovation process maps. The extensive list of codes generated in the third stage of the inductive analysis represents a way of thoroughly documenting the content and organization of innovation process maps created by students. This represents the inductive category and code development component of the larger study that we are pursuing, shown in Figure 1.

The codes that we created are common across most students but often expressed uniquely by each student. As shown in the process maps on the next page, common themes are apparent. However, they appear in very different ways depending on how students choose to draw their map. We anticipate the codes generated to remove variance in how ideas are expressed and characterize the completeness and efficacy of individual process maps. We will perform that process more deductively by applying the final coding protocol to each map.

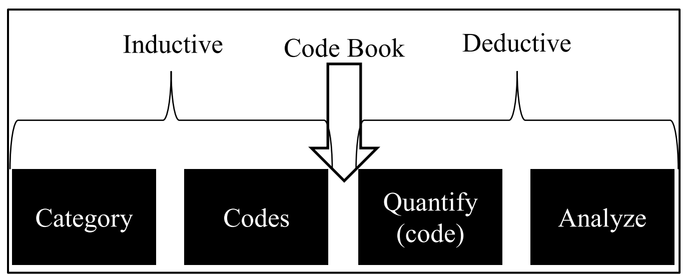


*Figure 1 Current and planned future work analyzing process maps as an assessment method.*

Utilizing process maps allows students to visualize and document the complex interrelationships. Allowing students to express their understanding in this form presents enormous potential benefits. Further, Innovation Process Mapping tool allows students to be assessed on a form of media that is common in engineering [18] innovation, and design.

While designed as a research tool, instructors could potentially use Innovation Process Mapping to assess students' authentic expressions rather than constrained mediums by which students demonstrate competence (e.g., testing). Future research, however, is necessary to study valid uses of the tool for instructional purposes.

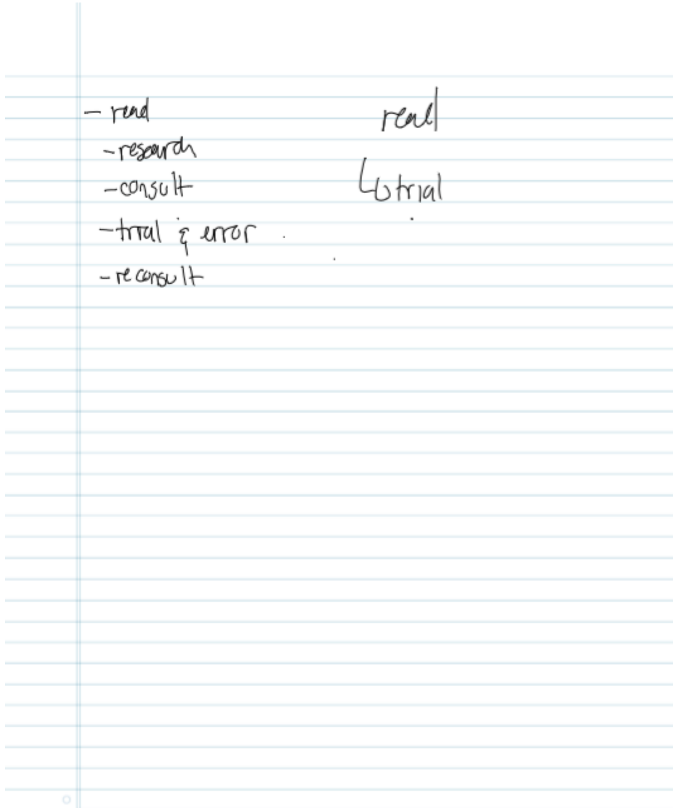


*Figure 2 Process map by a chemical engineering student*

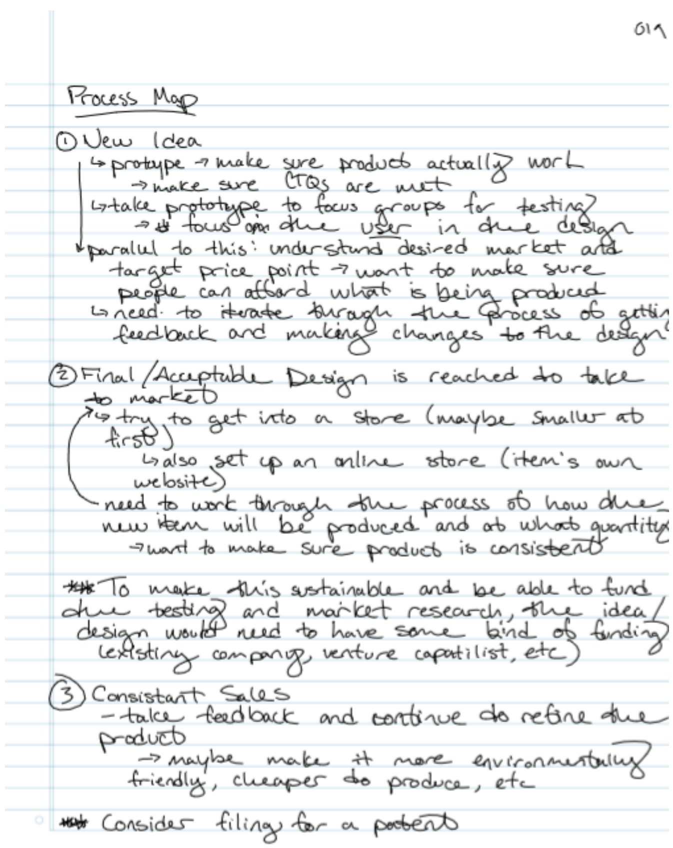


*Figure 3 Process map by a civil engineering student*

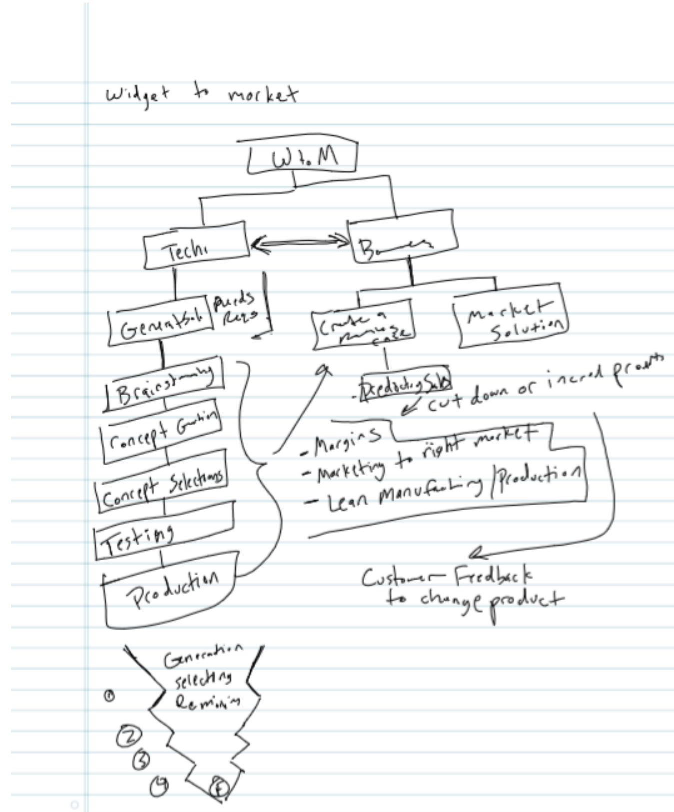


*Figure 4 Process map by a aeronautical engineering student*

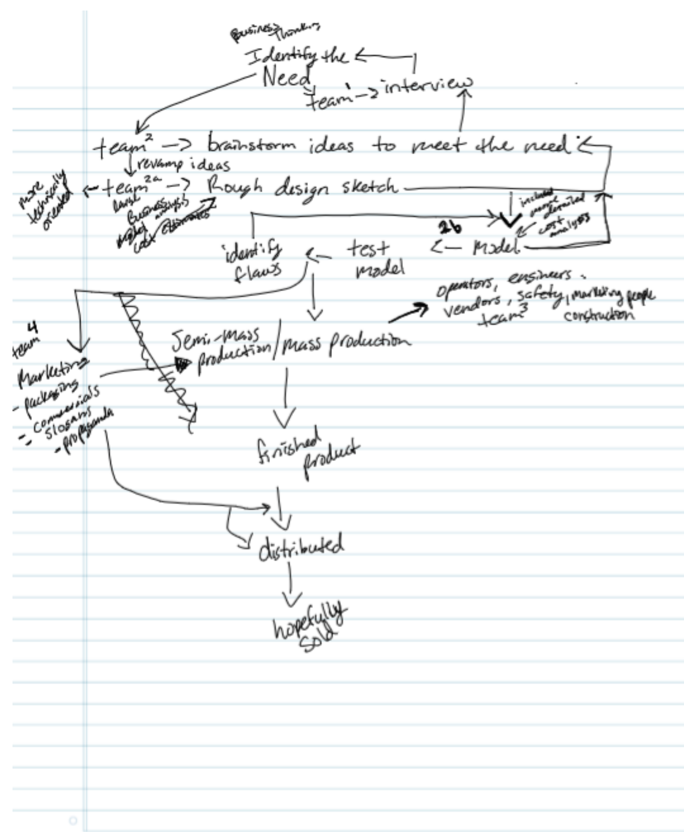


*Figure 5 Process map by a chemical engineering student*

## VI. Acknowledgements

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