Indicators of Creative and Entrepreneurial Thinking Among Engineering and Technology Students

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Innovation Process Mapping Protocol: An Approach to Assessing Students’ Understanding of Innovation As a Process

Abstract

The assessment of knowledge, skills, and behaviors related to innovation is a challenging task. Current assessment approaches rely on idea generation tasks, surveys, or project deliverables each of which have limitations. In this paper, we present an alternative novel approach for assessing individual understanding of innovation process that we argue should be a learning outcome of any innovation education program or curricula. Our method, called the Innovation Process Mapping Protocol provides individualized assessment of knowledge and skills and takes about 30 minutes to complete. The data collected in the form of Innovation Process Maps are evaluated in two ways: using the innovation process mapping rubric and in the form of a Markov chain. We present results from two students and discuss how this instrument can be used in research studies and discuss its’ potential for use as a pre- and post-test to evaluate growth.

Introduction

Innovativeness, a critical skill for engineers and technologists, requires both creative and entrepreneurial thinking. Both engineers and technologists are called upon to develop unique and elegant solutions to challenging problems, identify need-based opportunities, and promote promising projects. The assessment of these skills, however, is challenging.

Many innovation and creativity researchers have attempted to identify student innovativeness and entrepreneurship through design projects or prototypes1-3, idea generation tasks4,5, or surveys6,7. These assessment methods often require a trade-off between evaluating actual knowledge and skills (rather than student perceptions of those skills) and ease of collecting and analyzing assessment data (see Table 1). Further, information rich evaluations such as team projects do not allow researchers or instructors to assess attributes of individual students or conduct pre/post comparisons. In this paper we present an alternative assessment tool, the InnovationMap, that measures individuals’ understanding of innovation while remaining easy to administer and score.

Table 1. Comparison of Assessment Methods

<table>
<thead>
<tr>
<th>Measures actual construct (as opposed to perceptions and self reports)</th>
<th>Measures at individual level (as opposed to team level)</th>
<th>Easy to score</th>
<th>Allows pre/post comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projects/Prototypes</td>
<td>✓</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Ideation Tasks</td>
<td>✓</td>
<td>✓</td>
<td>no</td>
</tr>
<tr>
<td>Surveys</td>
<td>no</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>InnovationMap</td>
<td>✓</td>
<td>✓</td>
<td>somewhat</td>
</tr>
</tbody>
</table>
Literature Review

Any attempt to assess constructs such as student’s knowledge and skills requires a clear definition of what is to be measured\(^5\). Thus, construct definition and delimitation are critical especially when dealing with complex topics such as innovation. Previous assessment methods focus on innovative outcomes of student work\(^2,4,5\) and student attitudes and perceptions of abilities and knowledge\(^6\). Another important aspect of innovation is the process by which it occurs\(^9,10\). While researchers have explored how experts describe their own approach to innovation\(^10\), few have studied student understanding of this process. The instrument we present in this paper aims to help instructors and researchers measure student understanding of the innovation process.

Concept maps provide a graphical representation of an individual’s understanding of a process or topic\(^11\). They consist of a series of elements (concepts, stages, people) and their interrelationships\(^11\). Concept maps have been used to investigate engineering students’ understanding of engineering design processes\(^12\) as well as innovators’ approaches to technology development\(^10\). The instrument described in this paper is based on a variation of a concept map called a process map. A process map contains a series of stages or actions diagramed in a sequential order. While concept maps can be assessed based on centrality of important topics and strength of described interrelationships\(^13\), process maps can be assessed based on inclusion of key elements, position of elements in relation to other elements (e.g., stakeholder analysis prior to idea generation), and structure of sequences (e.g., iteration vs. linearity). In the following sections we describe a process mapping task that can be used to elicit student understanding of the innovation process.

Description of Assessment Tool: Innovation Process Map

We provided students with a list of 20 terms (See Table 2) and asked them to use these terms to develop a map for turning an idea into something useful for society. Most of these terms were taken or modified from a larger set used in a similar process mapping task completed by expert innovators\(^10\). First, students arranged these terms by hand and then drew their process including these terms on a smart notebook using a smart pen. This process took about 30 minutes and resulted in handwritten notes and sketches. Additionally, the smart pen captured pen strokes as well as concurrent audio, resulting in a playable audiovisual recording of all notes and sketches. The process map drawings make up the primary data. These drawings are processed in two ways: (1) directly evaluated using a rubric (2) converted into a state diagram and then evaluated.

Table 2. Terms Representing Innovation Stages or Elements

<table>
<thead>
<tr>
<th>Generate multiple product alternatives</th>
<th>Tradeoffs and optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determine product cost</td>
<td>Customer needs analysis</td>
</tr>
<tr>
<td>Design for manufacturability</td>
<td>Lifecycle cost analysis</td>
</tr>
<tr>
<td>Design for environment</td>
<td>Product meets actual user needs</td>
</tr>
<tr>
<td>Develop a product manufacturing plan</td>
<td>Reliability testing, test to failure, limit testing</td>
</tr>
<tr>
<td>Define market and its growth potential</td>
<td>Design modifications</td>
</tr>
<tr>
<td>Choose product design from multiple alternatives</td>
<td>Computer modeling and simulation</td>
</tr>
<tr>
<td>Create a schedule for the project</td>
<td>Research on material strength and other properties</td>
</tr>
<tr>
<td>Stakeholder analysis</td>
<td>Research on scientific principles</td>
</tr>
</tbody>
</table>
Evaluation Rubric

The evaluation of the process maps is guided by previous studies that show that successful innovation processes have key characteristics:

- Financial considerations such as market analysis and creation of customer value has to occur early in the process\textsuperscript{14,15}
- Change and flexibility are critical aspects of innovation and hence innovation is an iterative process\textsuperscript{16}

Table 3. Process Map Evaluation Rubric

<table>
<thead>
<tr>
<th></th>
<th>Level 3</th>
<th>Level 2</th>
<th>Level 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market Analysis</td>
<td>Market analysis comes during the first stage and before idea generation.</td>
<td>Market analysis comes midway in the process.</td>
<td>Market analysis is included in the final stage or not included.</td>
</tr>
<tr>
<td>Customer Needs</td>
<td>Customer needs are considered during the first stage before idea generation.</td>
<td>Customer needs are considered later in the process.</td>
<td>Customer needs are not considered.</td>
</tr>
<tr>
<td>Iteration</td>
<td>Process includes many iterative components and decision points.</td>
<td>Process includes some circular or few iterative components.</td>
<td>Process is linear.</td>
</tr>
</tbody>
</table>

Markov Chains

A Markov chain models the behavior of a system as a set of probabilistic transitions between states\textsuperscript{17}. A Markov chain consists of a collection of possible states and the probability of transitioning from each state to every other state. States can describe some underlying or observable makeup of the system including features, status, or in many cases behaviors. Transition probabilities represent the likelihood of moving from one state directly to another state without consideration of prior states\textsuperscript{17}. Markov chains can be represented visually in the form of diagrams. In such a diagram, the graph nodes represent states, e.g. observable behaviors of the system, and these nodes are linked by arrows describing the probability of transitioning directly from the current state to the destination state. Markov chains can be used to model everything from control systems and population growth. In our case, the Markov chain diagram will help identify the order of decisions and the amount of iteration presented in a process map.

We created Markov chain diagrams directly from individual process maps. Each element used in the map was first labeled as belonging to either opportunity, prototyping, testing, or production as defined in Table 4. These labels represent general phases an innovation process\textsuperscript{10}. In cases of uncertainty, we relied on audio taken from the smart pen recordings to clarify student meaning and likely phases for each element.

For each map, we then counted the number of transitions between each phase and every other phase. From these frequency counts, we calculated the transition probabilities and created the corresponding diagrams. Arrows represent the direction of each transition and are labeled with...
the probability of the transition from 0 to 1. Potential transitions without arrows, e.g. from Production to Opportunity in table 5 indicates that there was no direct connection from any Production element to any Opportunity element.

Table 4. Phases of Innovation/Entrepreneurship Process

<table>
<thead>
<tr>
<th>Phase</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>Opportunity</td>
<td>Defining need areas, market potential, and project scoping</td>
</tr>
<tr>
<td>Prototyping</td>
<td>Conceptual design of products, processes, or services including idea generation, rapid prototyping, and modeling/simulation</td>
</tr>
<tr>
<td>Testing</td>
<td>Testing prototypes for functionality, usability, and safety</td>
</tr>
<tr>
<td>Production</td>
<td>Manufacturing, introducing the product to market, and continuing project analysis</td>
</tr>
</tbody>
</table>

Examples from Actual Student Work

In this section, we present data from two students to illustrate how the tool can help evaluate students’ understanding of innovation. These examples are meant to demonstrate the tool rather than draw any conclusions about engineering and technology students’ views of the innovation process. One of the students (Alex) is a senior in a multidisciplinary engineering program with experience working in innovative companies such as Disneyland as an intern. The other student (Ben) is a junior in computer graphics technology who has worked as a web developer. He also is also pursuing a minor in art and design. These students individually completed the process mapping task as part of a larger study.

As shown in Figures 1 and 2, both students included market and customer needs analyses. Ben’s process map listed these elements earlier in the process, indicating stronger alignment with expert view of innovation. Both students also demonstrated some, but not the desired level of, iteration in their innovation process mapping task. Analysis of the Markov chains provides additional insights.

Alex’s Markov chain diagram demonstrated strong forward and backward connections between Opportunity and Prototyping indicating an iterative loop between the problem and solution space. One interpretation of this loop is that Alex emphasizes early stages of the innovation process and encourages flexible views of problem scoping and conceptual design, with changes in each causing reflection and potential changes in the other. Alex also showed no link between Production and Opportunity, potentially indicating a view of innovation with finite beginning and end states.

Ben’s Markov chain diagram demonstrated a more sequential view of the early process stages with strong return loops for both Opportunity and Prototyping. His diagram also contained frequent transition for Testing and Production back to Design, indicating frequent iteration during later stages of the process. The closed loop from Production back to Opportunity may indicate a more cyclic view of the innovation process.
Figure 1. Alex’s Understanding of Innovation As a Process

Innovation Process Map

- **Idea Generation and Development**
  - Generate multiple product alternatives
  - Customer needs analysis
  - Stakeholder analysis
  - Tradeoffs and optimization

- **Concept Selection and Refinement**
  - Choose product design from multiple alternatives
  - Product meets actual user needs
  - Define market and its growth potential
  - Product design to meet government mandate
  - Regulatory certification/compliance
  - Create a schedule for the project
  - Tradeoffs and optimization

- **User testing**

- **Design Modifications**
  - Design modifications
  - Design for manufacturability
  - Design for environment

- **Reliability Testing/Lifecycle Analysis**
  - Reliability testing, test to failure, limit testing
  - Lifecycle cost analysis

- **Plan of Manufacturability**
  - Develop a product manufacturing plan

### Holistic Evaluation Using Innovation Process Mapping Rubric

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### Markov Chain Evaluation
- repeated iteration between opportunity finding and prototyping
- no link from production back to opportunity finding (i.e. the innovation process completes once a product has reached market)
Figure 2. Ben’s Understanding of Innovation As a Process

Innovation Process Map

- **Create the project**
- **Restrictions**
  - Product meets actual user needs
  - Tradeoffs and optimization
  - Design for environment
- **Testing**
  - Reliability testing, test to failure, limit testing
  - Lifecycle cost analysis
- **Manufacturing**
  - Develop a product manufacturing plan
  - Design for manufacturability
  - Design modifications
- **Government**
  - Product design meets government mandate
  - Regulatory certification/compliance

**Holistic Evaluation Using Innovation Process Mapping Rubric**

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<td>Customer needs are considered later in the process but before idea generation.</td>
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**Markov Chain Evaluation**

- frequent cycles from testing and production back to prototyping
- frequent recursive loops in both opportunity finding and prototyping,
- a moderate link from production back to opportunity finding
Discussion

It was not surprising to see the students who developed the Innovation Process Maps were not at Level 3 for all areas. Neither of them had been through a targeted innovation and entrepreneurship education program. Our future work will include students who has been in such programs and participated in innovation competitions to gather validity evidence for our instrument.

The joint use of Markov chain diagrams and rubric assessment of process maps is a novel approach toward identifying student understanding of the innovation process. The Markov chain diagrams were helpful in assessing not only amount, but patterns, of iteration as well as favored states and sequences in each student’s ideal development cycle. The rubric helped identify strengths and weaknesses in each student’s process.

The Innovation Process Map instrument has the potential to capture differences in expertise or educational levels engineering students, but it needs to be implemented with a larger sample of students in order to provide evidence of reliability and validity evidence for both Markov chain analysis and the rubric assessment. Future studies should explore student understanding of the iterative nature of innovation as well as the need for market and customer needs analysis, as well as other differences between the views of experts and novices.

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Bibliography


