AC 2011-1183: THE USE OF CONCEPT MAPPING TO STRUCTURE A CONCEPTUAL FOUNDATION FOR SECONDARY LEVEL ENGINEERING EDUCATION

Jenny L. Daugherty, Purdue University

Dr. Jenny Daugherty is an Assistant Professor in the Organizational Leadership & Supervision Department in the College of Technology at Purdue University. Her research focuses on the design of technology and engineering professional development and the associated learning outcomes.

Rodney L Custer, Illinois State University

Dr. Custer is Associate Vice-President for Research, Graduate Studies, and International Education at Illinois State University. His research focus is on engineering-oriented, secondary level professional development.

Raymond A Dixon, CeMaST- Illinois State University

Raymond Dixon is a research associate for the Center for Mathematics Science and Technology at Illinois State University. His research focus is on expert cognition in engineering design.

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The Use of Concept Mapping to Structure a Conceptual Foundation for Secondary Level Engineering Education
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Numerous K-12 engineering initiatives have emerged across the U.S.\(^1\) These initiatives have generated considerable interest within the science, technology, engineering, and mathematics (STEM) education community and beyond. Potential positive outcomes include enhanced student achievement, increased awareness of engineering, and increased levels of technological literacy.\(^2\) However, a recent study of engineering-oriented teacher professional development projects detected some significant concerns.\(^3\) One disturbing finding was the lack of a well-defined concept base. In the absence of a conceptual foundation, pre-college engineering tends to focus on engaging design-based activities without an appropriate grounding in content, which poses serious problems for curriculum and professional development, assessment, and standards development.

In order to address this gap Custer, Daugherty, and Meyer,\(^4\) in a study funded by the National Center for Engineering and Technology Education (NCETE)\(^1\) (an National Science Foundation funded center for learning and teaching), identified thirteen engineering concepts deemed to be core to engineering and appropriate for the secondary level. A full report of that study is presented in the *Journal of Technology Education*, however an overview of this study is provided in this paper as background to the focus group study conducted to investigate the use of concept mapping in pre-college engineering education. As a next step to integrating a concept-driven approach, the researchers conducted the focus group with pre-college engineering education, cognitive science, and/or concept mapping experts to understand how concept maps can be used as learning and assessment tools in engineering education.

The study’s research questions were:
1. How can concept mapping be used to facilitate learning in secondary level engineering education?
2. How can concept mapping be used to assess learning in secondary level engineering education?

Conceptual Knowledge & Pre-College Engineering

Conceptual understanding is necessary for situating facts and ideas into a particular context providing a schema for knowledge that is crucial for learning.\(^5\) Concepts are organizing ideas that are timeless, universal, abstract and broad, represented by one or two words, and examples of which share common attributes.\(^5,6\) Concepts also organize content or discipline-specific knowledge into meaningful instruction.\(^7\) For the learner to develop a conceptual understanding of something means that they understand its operational structure and how it relates to associated concepts. Conceptual understanding allows learners to apply what they have learned to new situations and learn related information, and provides for the creation of a connected web of knowledge.\(^8\)

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\(^1\) This material is based upon work supported by the National Science Foundation under Grant No. 0426421. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.
The focus of secondary level engineering education, however, has largely been on process. The Standards for Technological Literacy (STL),\(^9\) for example, include design-oriented standards that can provide direction for pre-college engineering. However, the STL do not focus on specific engineering concepts but on the design process. Several studies have been conducted to identify K-12 engineering outcomes and competencies.\(^10,11,12,13,14\) Although there were some common outcomes identified across these studies,\(^2\) the focus was not on articulating the concept base for engineering at the secondary level but on identifying outcomes, dispositions, and skills. And as Childress and Sanders observed, given the large number of outcomes identified, it is a challenge “to create a framework that might be helpful in developing ‘engineering’ instructional materials for secondary schools”\(^11\) (p. 5). Given this, the Custer, Daugherty, and Meyer study\(^4\) identified a conceptual base for secondary level engineering education to assist in this effort.

**Engineering Concepts for Secondary Level Education**

Custer, Daugherty, and Meyer\(^3\) deployed an emergent qualitative research design, which included an in-depth analysis of a broad range of engineering-related literature and focus groups with engineering educators and engineers. Four types of documents were reviewed including: (a) engineering and technology philosophy writings, (b) curriculum materials focused on secondary level engineering, (c) curriculum standards documents developed for the STEM disciplines and National Academy of Engineering reports, and (d) survey research studies relevant to K-12 engineering. A team of three researchers conducted a comprehensive review of the documents. Two of the three researchers, alternating the pair of researchers, independently reviewed each set of documents and identified “engineering themes” in the narrative.

Engineering themes were those elements in the narrative that were described as important to engineering and applicable across various engineering disciplines, as informed by the philosophy of engineering and technology literature. The decision was made to be inclusive, retaining themes that would later be analyzed and refined through a systematic, analytical procedure employed by the research team. The process generated over 100 themes. Each of the engineering themes identified in the literature were subjected to three criteria, including whether they were (a) appropriate for engineering at the secondary level, (b) core to engineering, and (c) conceptually robust. All three researchers independently applied the criteria to the list of themes. In order to be included in the listing of core engineering concepts, the theme was required to meet all three criteria by all three researchers on a consensus basis.

A series of focus groups was also conducted with 21 engineering educators and engineers. During these sessions, the participants generated their own lists of engineering concepts using the same criteria that were used by the researchers. They were then invited to reflect on similarities and differences between the lists that they generated and the outcomes of the literature-based analysis. This was another important input to the research process that resulted in the set of thirteen concepts that are outlined in Table 1. In addition to the list of concepts, column two contains a set of descriptive terms associated with each concept. These terms were drawn directly from the document sources and were used to define, clarify, or illustrate the concepts. The remaining columns provide an indication of where the concept was located within the five inputs. Careful records were maintained to track the sources of themes and concepts derived from all five inputs throughout the analysis.
Table 1
Core Engineering Concepts and Presence in Data Sources

<table>
<thead>
<tr>
<th>Concept</th>
<th>Terms</th>
<th>Curriculum</th>
<th>Philosophy</th>
<th>Standards</th>
<th>Focus Groups</th>
<th>Survey Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>analysis</td>
<td>risk, cost/benefit, life-cycle, failure, mathematical, decision, economic</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>constraints</td>
<td>criteria, specifications, limitations, requirements</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>design</td>
<td>iterative, technological, analysis based, experimental, ergonomic, universal</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>efficiency</td>
<td>key engineering goal, guiding principle</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>NP</td>
<td>NP</td>
</tr>
<tr>
<td>experimentation</td>
<td>testing, test development, trial and error</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>functionality</td>
<td>key engineering goal, usefulness, practicality</td>
<td>P</td>
<td>P</td>
<td>N</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>innovation</td>
<td>creativity, improvement, refinement, invention</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>modeling</td>
<td>mathematical, computer-based, technical drawing, physical</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>optimization</td>
<td>improvement, refinement, balancing, decision heuristics</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>prototyping</td>
<td>physical and process modeling and evaluation, preliminary</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>systems</td>
<td>input/output, process, feedback, component design and interaction, subsystems</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>trade-offs</td>
<td>conflicting constraints, negotiation, competing requirements or criteria</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>visualization</td>
<td>imagery, spatial and abstract representation, sketching</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>NP</td>
<td>P</td>
</tr>
</tbody>
</table>

Note. P indicates concept present in data source, NP indicates concept absent from data source.

In addition to the core engineering concepts, the research process used to identify and refine the concepts generated a rich set of discussions and observations that extend the outcomes beyond a simple list of ideas. This included thinking about ways in which the concepts connect with one another as a complex and interrelated set of ideas. To a large extent, the meaning of individual ideas and concepts is contingent on how they are connected with each other. For example, the notion of constraints is relatively simple until one begins to consider the trade-offs involved in attempting to optimize multiple constraints within complex technological systems. The researchers recognized the importance of further developing the conceptual foundation of precollege engineering beyond a simple list of 13 concepts.

The researchers also identified a set of broader contextual issues within which a conceptual base for engineering should be situated. A particular issue that emerged throughout the study had to do with engineering ethics and the grounding of engineering within its broader social and cultural contexts. Social constructivists (for example, Bijker, Hughes, & Pinch15) note
that engineering activity and outcomes are fundamentally a function of social values, needs, and priorities. Thus, while ideas such as ethics, values, and social norms are not considered to be engineering concepts, they can serve as essential contexts within which engineering ideas and concepts take on meaning. Engineering design does not occur within a vacuum. Design outcomes are a direct reflection of the context within which they were developed.

Finally, considerable discussion centered on the viability of an engineering ontology for secondary level education. An ontology is a theory or representative vocabulary about the objects, their properties, and relationships within a specific domain of knowledge. Ontological development involves thinking carefully about terminology and how ideas cohere and connect with each other, as well as ways in which they overlap with each other and with ideas from other disciplines. The outcomes and associated issues raised by this study represent an important step in that direction. (Note: a broader discussion of these issues, including pedagogical implications is presented in the Journal of Technology Education, reference number 4).

**Concept Mapping in Pre-College Engineering Education**

A next step to integrating a more concentrated focus on concepts is to understand how concept maps can be used as learning and assessment tools in pre-college engineering education. Concept maps have been well documented as research and evaluation tools in science education, guiding assessment and instructional materials, and as an aid to help students “learn how to learn”. For example, the American Association for the Advancement of Science’s Project 2061 developed the *Atlas of Science Literacy, Volumes 1 and 2* which provided concept maps based on the *Benchmarks for Science Literacy* to help guide K-12 science education. A focus group comprised of engineering, education, and cognitive science experts was convened to explore concept mapping in engineering education. The primary goal of the focus group was to explore the use of concept mapping to facilitate and assess learning in pre-college engineering education.

**Concept Mapping**

Concept maps demonstrate how people visualize relationships between various concepts. In its traditional form a concept map is a graphical node-arc representation of concepts and their relationships with each other. The nodes of the map contain the concepts. The links between the nodes capture the relationships among the concepts. Labeling the links provides information about the nature of the relationships. The links between the concepts can be one-way, two-way, or non-directional. The concepts and the links may be categorized, and the concept map may show temporal or causal relationships between concepts.

Different theoretical bases for concept maps have resulted in different terms, such as semantic networks, knowledge maps, and mind maps. According to semantic theory, knowledge is stored in a network format where concepts are linked to each other. This is referred to as the associative networks of knowledge and the more interconnected the knowledge representation, the higher the probability that a person will recall information when required. From a constructivist’s learning theory perspective, the learner attains new knowledge by integrating new information with existing knowledge structures. Therefore, the network mapping of concepts and their relationships externalizes how knowledge is integrated mentally.
A substantial amount of research has been done both in education on concept maps. For example, Willerman and MacHarg examined the use of concept maps as an advance organizer for eighth-grade students in a science unit dealing with physical and chemical properties. They found that using concept maps at the beginning of a unit resulted in a significant increase on a test administered when the units were completed. A study conducted by Kinchin highlighted the positive effect of concept mapping on students finding they have the potential to reveal misconceptions in learning that are not captured on traditional assessment tools. Concepts maps have been shown in education to be more effective in promoting knowledge retention than attending classes. Consistent with this perception, it is often seen as a viable assessment tool to determine gains in learning. Concept maps can be used as a procedure to measure student’s declarative knowledge; however, it has certain limitations. According to Ruiz-Primo and Shavelson, concepts maps are more directly related to the knowledge of facts and concepts, and how the concepts in a domain are related rather than how they are used in problem solving. Therefore, they are unable to indicate what students are able to do with that knowledge in a certain domain.

Turns, Atman, and Robins described how concept maps were used as a classroom assessment tool to “explore the incoming conceptions and to verify progress in the development of both technically sophisticated vocabulary and interconnections among the terms” (p. 166). The concept maps generated in the middle of the course as compared to the concept maps generated at the beginning of the course included more concepts and more cross-links. The maps also contained much more sophisticated domain-relevant terminology distributed across an increased number of levels of detail. According to Turns, Atman, and Robins, these differences in the maps suggested that the students were starting to see interconnections and were making progress in developing an integrated understanding of the course content.

For classes with novel formats and ill-defined learning objectives, concept maps can be used as an exploratory assessment of what students’ perceive they are learning in the course, apart from the stated expectations. Turns, Atman, and Adams indicated that when concept maps are used for this purpose, they provide an open-ended means for students to communicate what they see as important concepts, and they also convey their perceptions of the relationships among these concepts. The outcome of this analysis can result in the refining of the learning objectives and instructional strategies, and also the identification of appropriate assessments tool for understanding how the learning objectives are being realized by the students.

Studies have also compared concepts maps constructed by novices and those constructed by experts. For example, Lederman, Gess-Newsome, and Latz assessed the development and changes in twelve preservice teachers’ subject matter and pedagogical knowledge structures as they proceeded through a professional teacher education program. They found that preservice teachers’ initial knowledge structure representations were typically linear and lacked coherence. The preservice teachers’ knowledge structures however were susceptible to change as a consequence of the act of teaching. In addition, the subject matter and pedagogy knowledge structures were reported to exert separate influence on classroom practice, with the pedagogy knowledge structure having primary influence on instructional decisions. The complexity of the subject matter knowledge structure was more critical in determining whether the structure directly influences classroom practice.
Method

This focus group study was funded by the NCETE. The focus group participants were identified by the researchers as possessing expertise in either secondary level engineering education, cognitive science, and/or concept mapping. In order to maintain a manageable size to elicit discussion and participation, eight focus group participants were invited. An email was sent to each of the participants asking for their participation in the six-hour focus group meeting. After human subjects consent was obtained from the participants, the focus group meeting proceeded in the following primary phases:

- Discussion of engineering concepts from the Custer, Daugherty, Meyer study and the Hacker, de Vries, and Rossouw study.
- Creation of concept maps in pairs using a selected concept from the studies used to facilitate a discussion of concept mapping as learning and assessment tools.
- Presentation and discussion of the research related to concept mapping focused on how concept maps are developed and used in research and what techniques have been deployed to use them as assessment tools.

The focus group meeting was structured around a discussion of engineering concepts appropriate for the secondary level. In pairs, the participants selected an engineering concept to map; these included design, innovation, analysis, and systems. Each pair presented their maps and included a description of their process. Based on this experience and their own expertise, the focus group was asked to reflect on the issues related to developing engineering concept maps for learning and assessment purposes. The researchers documented the focus group proceedings with field notes by alternating between facilitator and recorder for each of the sessions of the meeting. The researchers’ field notes, concept maps, and participant’s handwritten notes were collected and analyzed according to the study’s two research questions. In addition, a short questionnaire was distributed and collected so as to better characterize the group according to degree specialization areas, length of time working and area of focus in K-12 engineering education, and concept mapping experience.

Findings

Based on the questionnaire, the focus group’s characteristics are described first, and then based on an analysis of the researchers’ field notes and the participants’ concept maps and notes, the focus group process is described. This is followed by a discussion of the primary themes that emerged in reference to the study’s two research questions. It is important to note that the development of concept maps during the session was secondary to the research questions, which are focused on the use of concept maps as tools for facilitating and assessing learning. The outcomes presented in this section are focused on the rich discussion and reflections generated by the process rather than on the maps themselves.

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Focus Group Characteristics
The focus group averaged 11 years of work experience in secondary level engineering education, with areas of focus ranging from cognition to curriculum development to teaching. As indicated on Table 2, all but two of the participants had engaged in some type of concept mapping before and brought these experiences to bear during the meeting. Most of the participants had experience with cognitive science. For example, one of the participants was involved with the National Research Council’s project, *How People Learn* (2000).

Table 2

<table>
<thead>
<tr>
<th>Degree</th>
<th>Discipline Area</th>
<th>Years in EE</th>
<th>Engineering Education Focus Area</th>
<th>Concept Mapping Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ph.D.</td>
<td>Industrial Education/Human</td>
<td>7</td>
<td>Cognition and Problem Solving</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Resource Development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ph.D.</td>
<td>Science Education</td>
<td>30</td>
<td>Curriculum &amp; Competition Programs</td>
<td>Yes</td>
</tr>
<tr>
<td>Ph.D.</td>
<td>Chemical Engineering</td>
<td>7</td>
<td>Curriculum Development and Professional Development in Technology Education</td>
<td>No</td>
</tr>
<tr>
<td>Ph.D.</td>
<td>Learning Sciences</td>
<td>15</td>
<td>Electrical Circuits</td>
<td>Yes</td>
</tr>
<tr>
<td>Ph.D.</td>
<td>Curriculum Studies</td>
<td>12</td>
<td>Curriculum</td>
<td>No</td>
</tr>
<tr>
<td>M.S.</td>
<td>Technology Education/</td>
<td>10</td>
<td>Secondary teaching and Teacher Preparation</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Mechanical Engineering</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.S. &amp;</td>
<td>Environmental Science and</td>
<td>3</td>
<td>Curriculum Development, Professional Development and Assessment</td>
<td>Yes</td>
</tr>
<tr>
<td>M.S.</td>
<td>Educational Statistics &amp;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Measurement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.S.</td>
<td>Technology in Education</td>
<td>7</td>
<td>Technological Literacy</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Focus Group Process. After the two concept studies were presented (Custer, Daugherty, & Meyer study, 2009 and Rossouw, Hacker, & de Vries study, 2010), the eight participants paired up and selected an engineering concept to map; these included design, innovation, analysis, and systems. The partners worked together to develop a visual map of their concept on large pieces of paper with markers for an hour. Little instruction was provided beyond a general definition of concept maps, which was described as a diagram showing the relationships among concepts. Suggestions were also provided to help the pairs create their maps, which included:

- Using a top down approach,
- Working from general to specific,
- Using a free association approach by brainstorming nodes and then developing links and relationships,
• Using different colors and shapes for nodes and links to identify different types of information,
• Using different colored nodes to identify prior and new information.

Each pair presented their maps and included a description of their approach to developing their maps. The concept maps developed by the pairs were largely different from each other, as indicated in Table 3. These differences appeared to be due to their approach to concept mapping as well as the concept they selected to map. For example, one pair, who selected innovation as their concept to map, had to first reconcile their different approaches to concept mapping. One of the partners focused on the process represented by the concept and the other partner focused on the relationships connected to the central concept. The pair decided to include both representations on their map. Innovation was included on the top of the map in large letters with a node connected at the same level labeled invention. Words that defined innovation and invention were included as well. Upon reflection, the pair shared their struggle to develop a detailed concept map of innovation given its smaller “grain size,” in comparison to engineering design or systems.

Table 3

Participants’ Approaches

<table>
<thead>
<tr>
<th>Concept</th>
<th>Participant’s Approach to Concept Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovation</td>
<td>Included process dimensions and relationships to other concepts.</td>
</tr>
<tr>
<td>Design</td>
<td>Detailed the design process model and questions that a designer must address when engaged in the design process.</td>
</tr>
<tr>
<td>System</td>
<td>Approached mapping as a brainstorming activity spending time individually developing ideas and then agreeing on how to proceed with the map</td>
</tr>
<tr>
<td>Analysis</td>
<td>Approached mapping as a brainstorming activity searching for key terms associated with analysis and categorized them as pertaining to what and why questions and process.</td>
</tr>
</tbody>
</table>

The pairs that developed concept maps for design and systems generated much more intricate and detailed maps. For example, the pair that developed the concept map for design created a very detailed map that included elements of a design process model and questions that a designer must address when engaged in the design process. Both pairs emphasized the need to present and describe their maps since, in the absence of interpretation, the maps would be difficult, if not impossible, for others to understand. The pair that mapped systems approached it as a brainstorming activity where they spent time individually developing thoughts and ideas and then agreed on how to proceed in including these ideas on the piece of paper graphically. Similarly, the pair that developed the concept map focused on analysis approached it as a brainstorming activity searching for key terms associated with analysis and categorized them as pertaining to what and why questions and process.

**Concept Mapping to Facilitate Learning.** The focus group participants also stressed that concept mapping can be a valuable tool in facilitating the learning of engineering concepts in K-12 contexts. The focus group agreed that concept mapping can be a useful mechanism for learners to demonstrate their mental models of important engineering concepts. Maps can trace
levels of sophistication in understanding, they can demonstrate procedural or “how to” knowledge, or demonstrate the relationships between ideas. Thus the goal of using concept maps as a learning tool needs to be made explicit to the learner. In addition, several other important issues emerged during the discussion including: (a) context, (b) learning progressions, (c) reflection, (d) misconceptions, and (e) implementation.

The focus group discussed at length the importance of context. Mapping engineering concepts in isolation or abstraction from a particular context is challenging and perhaps not as helpful to the learner. A context, whether it is an engineering design project or a scenario, provides something for the learner to reference in building a concept map and also the nature of the context helps to determine which concepts are important to include in a map. The linking words and descriptors included on such a map provide the detail needed to indicate understanding. This approach indicates that a given concept map will be a function of a specific context or project. For example, concept mapping of engineering concepts may well be quite different when thinking about an algae farm system than when working with a robotic system.

The focus group discussed the potential of concept maps being used to demonstrate the learner’s progression of understanding. From a definitional understanding of a concept (the what), to being able to provide a richer explanation or rationale of the concept with examples, (the why), to being able to articulate concepts are applied in various situations (the how). Closely related to the demonstration of progression, the focus group pointed out the need for the learner to provide a verbal explanation of the map because, in isolation, the map may not be self-explanatory. In the absence of some kind of understanding of the thought processes and decision rules that were involved in the map development process, it is likely that much of the value of the learning and mapping process will be missed.

The demonstration of a learner’s conceptual understanding via a concept map led to the discussion of identifying learners’ misconceptions. Concept mapping may be of value in helping engineering educators understand any firm conceptual “rules” associated with K-12 engineering, which, in turn, could be of value in identifying misconceptions. For example, the notion that “all” constraints can be optimized is a misconception as is the notion that all constraints can be of top priority. Another example is the notion that there is only one correct design solution for any given situation.

The focus group discussed a few specific issues associated with the implementation of concept mapping. One of the important issues is determining what concept can or should be mapped and which concepts are central. Some of the engineering concepts, such as design or systems, are of large enough scale and are arguably central to engineering. These ideas are big and robust, thus warranting the development of maps to indicate a learners’ understanding of these core concepts. Other concepts, such as constraints or analysis, are less expansive in scope and are probably best depicted as part of a larger conceptual mapping structure. This is important since one approach to the process is to name a central concept at the outset, requiring that the learners maintain the centrality of the concept in their maps. Another approach is to issue a set of concepts initially, with the learners making decisions about which concepts should be viewed as central and depicting their interrelationships. Related to this issue is determining what
instructions are provided to the learner, such as the type of map, how it is to be created, and the level of detail required.

**Concept Mapping to Assess Learning.** The focus group concentrated less directly on the use of concept mapping for assessment purposes. However, one important insight that emerged from the discussion was that a primary value of concept mapping may be to facilitate learning with assessment of learning being secondary. This said, concept maps have strong potential for use in formative assessment, and perhaps even in summative assessment, if used in conjunction with other tools. The assumption is that significant learning about concepts will occur through the learning process based on instructional interventions. Given this, it seems reasonable to think that the concept maps would reflect that change in learning and then be assessed as such. Rather than using an approach where the learner’s concept maps are compared to an ideal or expert map, assessment should rather focus on the observed changes that occur pre and post to instruction. The focus group did indicate that if concept mapping was used for assessment purposes, the instructions and scoring process needs to be made explicitly clear to the learner.

**Recommendations and Implications for Research and Practice**

This manuscript focuses on the identification and implementation of a conceptual base for pre-college engineering education. The researchers summarized a study that identified a list of core engineering concepts, as well as important issues that need to be explored to further define and refine the concept base. The findings from the focus group indicate the strong potential for the use of concept mapping to help facilitate learning, as well as provide evidence of understanding needed to track a learner’s progression in understanding engineering concepts. The identification of engineering concepts and the exploration of using concept mapping to assist in learning and assessment raise important recommendations and implications for research and practice. As has become clear through this work, a simplistic and disconnected list of concepts is, by itself, of little value and fails to grasp the depth and complexity of the ideas. To be meaningful, engineering concepts must be (a) situated within their larger social and cultural contexts and (b) viewed as interconnected elements in a larger conceptual structure.

In most cases, the conceptualization process appears to include an aspect of context, since most learners think of examples to help make conceptual linkages, decisions, and definitions. Context-free abstract conceptualization is not helpful; thus, curriculum development and teacher professional development efforts should focus on authentic and meaningful contexts within which to embed concepts for instructional purposes. A recent Delphi study conducted by Rossouw, Hacker, and de Vries identified nine contexts that included shelter (‘construction’), artefacts for practical purposes (‘production’/ ‘manufacturing’), mobility (‘transportation’), communication, health (‘biomedical technologies’), food, water, energy, and safety. In terms of concept mapping, it seems important to provide the concept-mapper with a specific application to use as a context for the mapping or conceptualization process. It appears reasonable then that a given concept map will be a function of a specific context or project. For example, concept mapping of engineering concepts may well be quite different when thinking about an algae farm system than when working with a robotic system.

Given the contextual nature of engineering concepts and that there are often numerous legitimate ways of conceptualizing and representing the interrelationships among concepts, the
educational applications of concept mapping needs further exploration. For example, the validity of concept maps depends on the extent to which the definitions of concepts are clearly understood. While the meanings of engineering concepts can be developed generally, a one exact definitional understanding of the concept is not perhaps appropriate given that concepts are constructs (and therefore functions of academic and social communities). For assessment purposes, this is particularly challenging. One approach to evaluating concept maps could be for an expert or panel of experts to develop and validate a “correct” map that could be subsequently used as a standard by which other maps could be evaluated against. Another approach could be the development of a sequence of concept maps over a span of time to track changes in a learner’s understanding of the concept, from definitional terms to its connections to other concepts.

As precollege engineering education progresses in K-12 educational settings, the researchers’ believe it is important that the conceptual core of engineering be central to its further implementation. The question of how concepts drive curriculum, instruction, and assessment needs further work. Appropriately answering this question is certainly a large undertaking. Additional work is needed to further define those engineering concepts that are core to a robust understanding of engineering and the appropriate contexts within which meaningful and age appropriate learning can be developed. An effort similar to the AAAS’s *Atlas of Science Literacy* would greatly assist this effort. This groundwork is important for future curriculum development, pre-service teacher preparation, and teacher professional development efforts so that they operate from a common base of conceptual development.

**References**


