Essential Components Found in K-12 Engineering Activities Devised by Engineering Educators

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Essential Components Found in K-12 Engineering Activities Devised by Various Types of Educators (Fundamental)

Engineering activities used in the K-12 classroom arise from a variety of sources. As engineering has the opportunity to penetrate farther into K-12, through the implementation of Next Generation science standards or through integrated STEM instruction, the proliferation of activities assigned the engineering moniker has increased tremendously. This paper describes the development of a method for examining activities from a variety of sources. The activities are categorized as to pedagogical technique, content standards addressed, engineering content taught, and other elements extracted from the literature. The goal of this analysis is two-fold: to determine trends with respect to content and type of activities that are being proposed and to perform a gap analysis. The sources used to locate activities are NAE, ASEE, and IEEE, as well as educator exchanges and related origins.

Motivation for doing the analysis

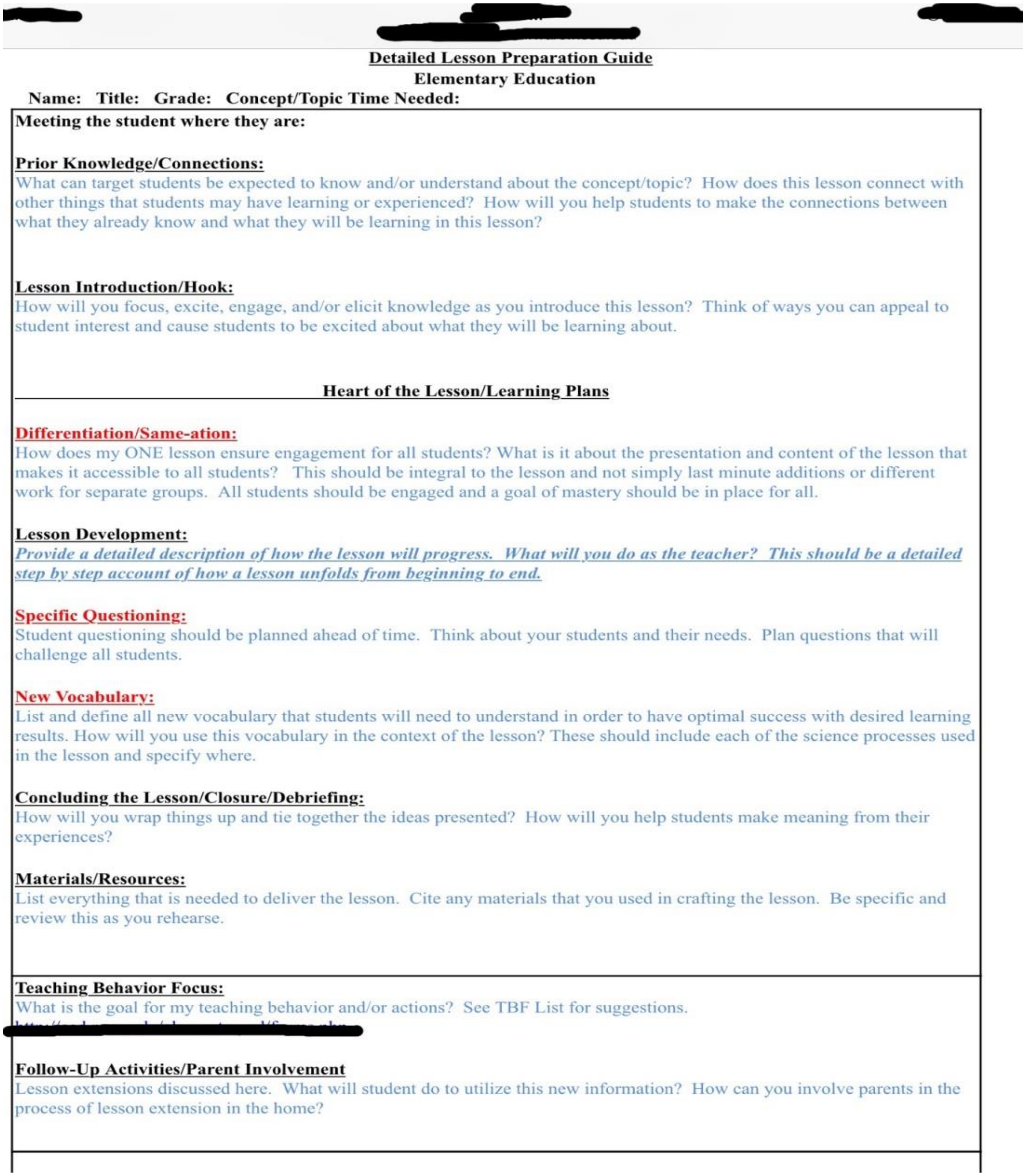
Engineering has made inroads to the K-12 classroom or the after school arena through a variety of avenues. Because they arise from such a variety of sources, "engineering" activities look very different from one another. This, alone, is neither positive nor negative; however, from the standpoint of engineering educators, it is desirable that these activities support positive learning. In addition, it is important that engineering not be misrepresented, especially as no agreed upon definition for engineering in K-12 exists. (Sources for vetted definitions include NAE 2009 and NAE 2017.)

Another motivation for this study is to examine whether there are elements and approaches that education trained classroom teachers include in activities that are substantially different from those of engineering educators and/or university science/math education faculty and/or STEM professionals. If so, do these elements imply any disconnect between the authors of activities and the classroom? If activities that are being prepared and proliferated are lacking in one or more respects, they are unlikely to be used with the very audience for which they are intended.

Many projects that are funded by NSF result in the production of lessons and activities. An examination of the literature shows that existing rubrics are designed to assess lesson plan quality, perhaps as a way to assess the effectiveness of professional development. Another set of rubrics can be found for lesson plans generated as a part of a preservice teacher program, which are designed to generate a grade. This paper looks at lesson plans differently, without an attempt to assess quality. Because so many constituencies are creating lessons around engineering, and those constituencies come from so many different academic backgrounds, the question of how they get their approach to creating these plans seems germane. Therefore, the purpose of this project was to first compile elements of lesson plans that are valued by the profession (based on the quality assessments found in the literature) and to compare lessons that were created by contributors of various backgrounds.

As a start, consider how teachers are taught to generate lesson plans when they are in a College of Education program. University preservice programs generally have a systematic approach to lesson planning that is often based on educational research and practice. For example, the elementary education program at North Carolina State University uses the template in figure 1.

This template has elements that are unique to the program, but are not tied to any particular subject area. Do teachers who are in the classroom use such a template? Do engineering educators have such an approach to publishing lesson plans? Do others, such as disciplinary engineers who create lessons for use in schools, have knowledge of such approaches? Are there elements that commonly appear in engineering lessons that are different from traditional education approaches? The answers to the above questions may be found in a variety of places, of course, and this paper looks at the forensic evidence found in lesson plans that have been created by each of the different types of authors.



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Detailed Lesson Preparation Guide

Elementary Education

Name: Title: Grade: Concept/Topic Time Needed:

Meeting the student where they are:

Prior Knowledge/Connections:

What can target students be expected to know and/or understand about the concept/topic? How does this lesson connect with other things that students may have learning or experienced? How will you help students to make the connections between what they already know and what they will be learning in this lesson?

Lesson Introduction/Hook:

How will you focus, excite, engage, and/or elicit knowledge as you introduce this lesson? Think of ways you can appeal to student interest and cause students to be excited about what they will be learning about.

Heart of the Lesson/Learning Plans

Differentiation/Same-ation:

How does my ONE lesson ensure engagement for all students? What is it about the presentation and content of the lesson that makes it accessible to all students? This should be integral to the lesson and not simply last minute additions or different work for separate groups. All students should be engaged and a goal of mastery should be in place for all.

Lesson Development:

Provide a detailed description of how the lesson will progress. What will you do as the teacher? This should be a detailed step by step account of how a lesson unfolds from beginning to end.

Specific Questioning:

Student questioning should be planned ahead of time. Think about your students and their needs. Plan questions that will challenge all students.

New Vocabulary:

List and define all new vocabulary that students will need to understand in order to have optimal success with desired learning results. How will you use this vocabulary in the context of the lesson? These should include each of the science processes used in the lesson and specify where.

Concluding the Lesson/Closure/Debriefing:

How will you wrap things up and tie together the ideas presented? How will you help students make meaning from their experiences?

Materials/Resources:

List everything that is needed to deliver the lesson. Cite any materials that you used in crafting the lesson. Be specific and review this as you rehearse.

Teaching Behavior Focus:

What is the goal for my teaching behavior and/or actions? See TBF List for suggestions.

[redacted]

Follow-Up Activities/Parent Involvement

Lesson extensions discussed here. What will student do to utilize this new information? How can you involve parents in the process of lesson extension in the home?

Figure 1: Example lesson plan template for pre-service teachers

Approach

The educational literature contains many sources for assessing lesson plan quality. The following resources were used to come up with a list of features that was then compacted to form a rubric for this study. Because no attempt to assess quality or to compare the lesson plans on anything other than the presence or absence of features, the literature was scanned for sources that contain references to engineering or STEM and the various features assessed were noted. It was not deemed necessary to establish any way to rate the features other than by their presence or absence, although doing so might be a potential enhancement for a future study. This study sought to establish whether this approach might yield interesting information about how different types of contributors approach creating a lesson plan that they imagine will be used in a K-12 classroom.

Kaplon-Schilis (2016) uses a rubric for assessing teachers' Technological Pedagogical Content Knowledge (TPACK). The rubric is used to identify artifacts from the lesson plan that point to whether the activities are used to motivate, invoke demonstration of new knowledge, connect to practical application, to explore and/or experiment for new knowledge or provide students with deep conceptual understanding. The original use of these levels is to assess how teachers are using technology. This paper uses them to assess how a lesson uses engineering.

Sias, et al.(2016) analyzes in-service elementary teacher lesson plans for "educational innovations" gathered from a variety of sources (Hannafin (2012), Gruenwald (2014), Nadelson (2013), Pearson (2014), Nadelson (2012), Inan (2010), Liu (2009), Krajcik (2006), Martinez (2013), Dierking (1994), Berkowitz (2015), Abd-El-Khalik (2002), Nadelson (2015), NGA (2010), NGSS (2013), Bell (2010), Nadelson (2014), Partnership for 21st Century (2016)). These innovations are, for the most part, commonly recognized as desirable for teachers to engage in for the purpose of STEM teaching, an assertion with is supported by NGSS (2013), the National Governor's Association (2010) and the NAE(2009). The rubric in Sias uses both presence/absence and an eleven point scale for depth.

Guzey, et al. (2016) analyzes curricular materials designed by in-service teachers during a year-long professional development program. The tool developed by the authors, the STEM Integration Curriculum Assessment Tool, contains a number of elements. Each teacher-generated product is evaluated using a five point scale for each of the elements. The overall score is used to compare and rate the products.

Identification of sources for activities

Many potential sources for engineering-related lesson plans exist--which is part of the motivation for this project. Rather than differentiate among sources as web, print, etc., this project looked for resources from a variety of types of creators. For example, web resources, such as linkengineering.org and teachengineering.org have free, downloadable lesson plans from teachers, professional development providers, engineering graduate students and from engineering educators. Sites such as tryengineering.org have lessons created by engineers, who are members of engineering professional societies, who may also be engineering educators, but are typically not classroom teachers. NSTA lessons are usually created by classroom teachers, but may not be available for free to non-members.

The lesson plans for this paper were taken from each of the three sites mentioned above and also from pre-service classroom assignments, from professional development provider resources, and from practicing engineers as paper copies. Although this sample may not be all inclusive and may possess an element of randomness, for the purposes of this study, they provide a wide enough variety to allow for the testing of the check off rubric that was designed and to make comparisons.

First, a set of activities that had a similar purpose (that of bridge building; highlighted in yellow) was chosen. Then another set was chosen (highlighted in gray) to examine whether there were variations that might emerge from lessons that involve more diverse activities. Each of the lessons in the sets was compared, independent of those in the other sets, then the superset was considered. The intended result was a tool to use for the purpose of assessing lesson plans that optimize engineering as a learning tool for classroom needs.

Table 1: Activities examined

Activity number	Activity name	Source	Author type	Intended audience	Topic
1	Building a paper bridge: An introduction to problem solving	Learn NC (web) Walston, S. (n.d.)	Teacher	8th grade mathematics class	Building a bridge and measurement
2	Lesson Plan for Bridge Building	Beam UCLA (web) Mulchandani, A. (n.d.)	Engineering graduate student	Not stated	Building a bridge
3	Build a bridge	Teaching Ideas (web) Warner, M. (n.d.)	Teacher	Ages 7-11	Building a bridge with a materials budget
4	Paper bridges	Exploratorium (2000)	Engineering educator	Not stated	Building a strong bridge with paper and learning about strength of materials
5	Engineering a bridge	Scholastic (2017)	Educator	Not stated	Build a strong bridge
6	Popsicle bridge	Tryengineering.org IEEE (n.d.)	Engineer	8-18	Build a bridge to specifications
7	Building our Bridge to Fun	Teachengineering.org Suescun, E. (2013)	Engineering graduate student	4th-6th grade	Build bridges with various materials
8	STEM Ventures in	Paper copy McCoy (2017)	Engineer	4th grade	Build an autonomous

	Robotics				car with Lego Mindstorms NXT
9	20/20 Vision	Teachengineering.org College of Engineering and Applied Science, University of Colorado Boulder. (2016)	Educator	5th grade	Calculate average vision for a class
10	Save the Ferrets	Linkengineering.org	Engineering educator	4th grade or middle school	Use electric circuits to design a town the doesn't impinge on habitat

A brief summary of the lesson plan contents is given in table 3.

Lesson number	Plan content
1	One sheet of paper, limited tape, create longest unsupported span; no facilitation notes; no background information; mathematics goal of applying and using indirect measurement
2	Marshmallows and toothpicks, create a truss and a beam bridge from a plan; background information and pictures included of multiple bridge types; stated goal to create stable and efficient bridge; facilitation procedure outlined; no curriculum links
3	Paper and paper clips; materials assigned a cost; build to span a gap and support given weight; no facilitation procedure; no curriculum links
4	Paper and paper clips; create a bridge to span a gap and see how much weight it can hold; repeated trials with data collection; draw cross sections and silhouettes; background information and facilitation procedure supplied; no curriculum links
5	Foam board, Popsicle sticks, pipe cleaners, bendable rods, glue, paper, pushpins; build bridge type of choice and test with weights; facilitation procedure and background supplied; no curriculum links

6	200 Popsicle sticks and glue; span distance and hold given weight; minimize supplies; facilitation and background supplied; follow up questions; NGSS and technology standards linked
7	Paper, spaghetti, glue; build bridge and measure deflection under weight; detailed procedure and background; uses Lego Mindstorms to measure; data collection and analysis; math, science and technology standards linked
8	Build autonomous robotic car from Lego NXT; no facilitation procedure; no curriculum links
9	Measure eyesight, determine class average; no engineering; facilitation procedure and background; math, science and technology standards linked
10	Create model electric grid; extensive background, motivation, and facilitation procedure; links to NGSS

Developing the rubric

Several sources were used to extract elements that were candidates for comparing lessons. The sources were chosen, because they listed elements that were considered to be quality components for engineering or STEM lessons. It was not the purpose of this study to develop new elements, but to examine how lessons created by various authors might compare in their inclusion of the elements described as quality by the literature.

A check off rubric was developed that adapted elements from four distinct sources: NAE (2009), Sias (2016), Guzey (2016) and the NGSS (2013). Finding eight from the report NAE (2009) lists three important aspects of curricula that emphasize integrated instruction. They are scientific investigation and engineering design, mathematical analysis and modeling and technological literacy and engineering education. The first two of these are elements that are potentially identifiable in an individual lesson. In addition NAE (2009) lists six engineering habits of mind. These overlap with the 21st century skills (2016) and include communication, collaboration (both also in Guzey), optimism, systems thinking, ethical thinking, and creativity.

The innovations, listed in Sias, that are used in this paper as a part of the check off rubric developed are student-centered learning, place-based learning, integration of instructional technology, project-based learning, family involvement, inquiry, and STEM practices. Only two innovations from Sias, et al. are not included, 21st century skills, because it overlaps with another element chosen from another source, that of engineering habits of mind, as defined by the NAE (2009) and curriculum integration, because Guzey includes integration as well.

Guzey (2016) lists twelve elements that apply directly to the needed rubric. They fall into four larger categories: lesson content (engaging context, engineering challenge, science integration, mathematics integration, assessment), instructional strategies (student-centered, hands on/minds on, multiple representations), lesson implementation (teamwork, communication) and lesson organization (learning goals, clear flow). Although the original reference uses a five point scale to assess a form of quality, for the purposes of this analysis, only presence or absence of the elements is noted.

Finally, the NGSS engineering practices include a few elements that are not included in the sources above. These are defining problems, using models, carrying out investigations, analyzing data, computational thinking, designing solutions, arguing from evidence and evaluating information. Additional elements were added from the elementary education lesson plan template in figure 1.

From this set of sources, the check off rubric in table 2 was developed. In the table, the source which supplied the element is indicated by superscript as follows: 1=NAE, 2=Sias, 3=Guzey, 4=NGSS. Many of the elements appear in more than one source. Some of the elements arguably overlap to some degree, but they were kept separate for the sake of potential differentiation between lesson plans. It is possible that the rubric could be refined further if many more lessons were evaluated, but, for the purposes of this study, it was not necessary. Recall that the purpose of this study is not to derive any information about quality of resources, but to simply investigate whether there are differences that correlate with author and type of source. A few elements were added to the list for that purpose. However, because the sources from which this list was derived do evaluate quality to some degree, it is felt that this list might serve as a guide for elements to include when creating a good, integrated STEM lesson with engineering underpinnings.

To collect the data in table 2, lessons were collected from a variety of sources. The topic of bridge building was selected as a stereotypical engineering activity to examine, and the age level was chosen to be late elementary or middle school, when specified in the activity. With these two elements held constant, activities were retrieved from seven different sources, listed in columns 1-7 of table 1. Two were created by teachers (orange highlight), two by engineering graduate students (no highlight), one by an engineer/non-educator (green highlight), and two by engineering educators (red highlight).

Table 2: Activity rubric for bridge activities: Elements present by activity number

Element	Sub-element (if applicable)	1	2	3	4	5	6	7
Scientific investigation[1]			X					X
Engineering challenge[1,3]		X		X	X	X	X	X
Modeling[1,4]					X	X	X	
Habits of mind[1,3,4]								
	Optimism[1]							
	Communication[1,3,4]					X	X	
	Teamwork[1,3]	X	X	X	X	X	X	X
	Creativity[1]	X (?)					X	
	Systems thinking[1]							
	Ethics[1]							

Student centered learning[2,3]		X		X	X	X	X	
Place based learning[2]								
Curriculum integration[2,3,4]								
	Math[1,3]	X		X		X		X
	Science[3]							
	Other				X		X	
Integration of instructional technology[2]						X		X
Project/problem based learning[2]					X	X		
Inquiry[2]					X		X	
Engaging context[3]					X	X		
Hands on/Minds on[3]		X	X	X	X	X	X	X
Multiple representations[3]					X	X		
STEM practices[2,4]								
	Defining problems[4]	X					X	
	Data analysis[4]					X	X	X
	Computational thinking[4]							
	Arguing from evidence[4]						X	
	Evaluating information[4]		X		X	X	X	X
Assessment[3]		X						X
Learning goals[3]		X	X					
Clear flow[3] (how to execute activity)			X	X	X		X	X
Family involvement[2]								
Background/supplemental information			X		X		X	X
Curriculum alignment		X				X	X	X

Both of the activities in the table created by graduate students share similar elements. They contain more scientific investigation than engineering design and do not focus on habits of mind (other than teamwork). Even though teamwork shows up on all of the activities considered, as students work in teams to complete an activity, none of the activities actually involves teaching any elements of teamwork. The engineering educator and engineer-created activities alone contain modeling. In addition, the activities created by engineering educators have engaging contexts and problem-based learning. Contrary to expectations, multiple representations are included only in the activities created by engineering educators. Some of the elements are more likely to be dependent on the web site that hosts the activities than the particular authors. For example, teachengineering.org has a particular lesson write-up that includes things like curriculum alignment and assessments.

Overall, the lessons were missing many of the elements in the rubric. For some of these elements, particularly those that could be added through lesson facilitation, the lesson plan template in figure 1 is instructive. Most of the lessons examined in this study do not have detailed facilitation notes included, which is a weakness often found in shared resources. None of the lessons referred to place-based learning, which would involve rooting lessons in students' own surroundings. (For example, a bridge lesson might be motivated by describing a nearby community that wants a footbridge over a highway.) None of the lessons addressed ethics. From an engineering perspective, ethics could involve equitable distribution of resources for the activity or involve a discussion of whether one group's design uses elements of another, and whether that is ethical. Optimism was also not included explicitly. How this element could show up in a lesson plan is not clear, as is more easily incorporated through the facilitation of a lesson. Parent involvement was also not referenced. Finally, computational thinking was not a part of any of the lessons. Perhaps the topics selected do not lend themselves to including algorithm development or pattern extraction, as one might find in a lesson that was designed to include computational thinking.

Because building a bridge is not something that is explicitly found in any curriculum, some additional activities were assessed on different topics. Activities 8, 9 and 10 were chosen specifically from an engineer retired from IBM known in the area for effective work with diverse populations and from two web sites known to have particularly high quality activities: linkengineering.org (National Academy of Engineering) and teachengineering.org (National Digital Library). The results in table 3 illustrate that the engineer and engineering educator-developed activities have more components that relate to traditional "engineering," such as engineering habits of mind and an engineering challenge. However, no conclusion can be drawn from this discovery, as the sample is hardly scientific. It does show that variability exists among resources otherwise judged to be of high quality.

Table 3: Activity rubric for assorted activities: Elements present by activity number

Element	Sub-element (if applicable)	8	9	10
Scientific investigation[1]			X	X
Engineering challenge[1,3]		X		X
Modeling[1,4]		X		X
Habits of mind[1,3,4]				
	Optimism[1]			
	Communication[1,3,4]	X		X
	Teamwork[1,3]	X		X
	Creativity[1]	X		X
	Systems thinking[1]	X		X
	Ethics[1]			X
Student centered learning[2,3]		X		X
Place based learning[2]				X

Curriculum integration[2,3,4]				
	Math[1,3]	X	X	X
	Science[3]	X	X	X
	Other	X	X	X
Integration of instructional technology[2]		X		X
Project/problem based learning[2]		X		X
Inquiry[2]				X
Engaging context[3]			X	X
Hands on/Minds on[3]		X	X	X
Multiple representations[3]				
STEM practices[2,4]				
	Defining problems[4]			X
	Data analysis[4]		X	X
	Computational thinking[4]	X		
	Arguing from evidence[4]			
	Evaluating information[4]		X	X
Assessment[3]		X	X	X
Learning goals[3]		X	X	X
Clear flow[3] (how to execute activity)		X	X	X
Family involvement[2]				
Background/supplemental information		X	X	X
Curriculum alignment			X	X

Conclusions

Engineering related lessons and activities are widely available on the web and from other sources. They are authored by classroom teachers, by engineers, by engineering educators, and by others. Although the proliferation of activities such as these can be potentially useful, especially in the light of NGSS adoption, whether they contain elements that make them useful in the classroom is a very important determination to make. This study set out to answer this question. One possible outcome could be the goal of finding whether there are things that should be done to establish common ground, to change professional development approaches or to provide training for engineering educators, so that engineering activities might find a permanent home in the classroom and provide the maximum benefit for young learners.

For this paper, ten activities that are advertised as being engineering activities were analyzed using a rubric built from several sources that cite elements that should be included in a high quality engineering or integrated STEM lesson. Limitations of the analysis include that only one researcher completed the rubric for each activity. So, what lessons can be extracted from this analysis of ten lesson activities? Patterns in the bridge activities show that activities shared by teachers on educator exchanges can be limited in their engineering content and/or integration. The activities created by engineering graduate students suggest that, when preparing engineering students to work with K-12 classrooms, training might include preparation in inquiry rather than analysis alone. Another noteworthy conclusion is that many of the elements judged by the literature to be important for engineering education are missing from all of the activities considered.

In addition to its use as a tool for comparison, the rubric can also serve as a guide for teacher educators and engineering educators with regards to what might be included in an engineering lesson. With a guide such as this, thoughtful lesson creation can focus on the teaching and learning objectives desired.

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