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Engineering Curricula in Early Education: Describing the Landscape of Open Resources

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Abstract

National debate about K-12 Science, Technology, Engineering, and Mathematics (STEM) education has given rise to questions about appropriate materials for engineering education from prekindergarten through grade 12. Introducing engineering in the early years entails recognition of the need for teachers to understand its content and poses the challenge of preparing teachers to incorporate engineering education into their practice. Teacher preparation has historically included seeking information in books, journals, and magazines, and the professional development offered by universities, school districts, and other educational entities continues to provide the majority of formal options accessed by teachers. However, the advent of the Internet has expanded the ways that teachers undertake professional development and how they prepare to present new content. An online search for open source preschool through grade 12 (P-12) engineering materials revealed a wide variety of Web sites and online documents that included curricula, lesson plans, and descriptions of activities. Narrowing the search to the P-3 level revealed that the pedagogically and content-reliable sources available are limited in number and may be difficult to identify among the plethora of information. This study begins to describe the current landscape of open-access Internet materials in the field of early STEM with emphasis on engineering. The authors offer a guide-in-progress for selecting material for teachers and parents interested in introducing their young children to engineering. The authors also address emerging pedagogical fidelity and engineering content issues.

Background

As the United States faces a shrinking engineering workforce, the importance of kindergarten-12th grade (K-12) engineering education is increasingly emphasized (Houston, 2006; Katehi, Pearson, & Feder, 2009; Miaoulis, 2005). In response, numerous engineering- and education-related entities have proposed the integration of engineering into the K-12 curriculum (e.g., Bybee & Fuchs, 2006; Douglas, Iversen, & Kalyandurg, 2004; Ritz, 2006). While cautioning that earlier is not necessarily better, one argument for implementing this integration process is that early exposure to engineering may spark interest in and increase preparation to undertake engineering as a career. It is argued that this approach might reverse the declining numbers in the engineering workforce of the United States while addressing the issue of underrepresentation of women and minorities in engineering professions (Katehi, Pearson, & Feder, 2009). Consequently, engineering, which has been perceived as a college-level discipline for decades, is recently gaining in popularity in K-12 settings, including such varied initiatives as “Project Lead the Way,” FIRST programs (*For Inspiration and Recognition of Science and Technology*, which sponsors competitions such as FIRST Robotics), and the President’s “Educate to Innovate” campaign, which was launched in 2009. Discussing optimal implementation of engineering in K-12, Swift and Watkins (2004) argued that foundational engineering concepts are necessary for younger students, especially at the K-4 levels to enhance students’ mathematics and science abilities in later ages, and Perrin (2004, p. 29) suggested that early exposure to engineering would move younger students to learn science and mathematics without feeling overwhelmed.

The increasing call for attention to engineering education at the K-12 level has led to questions: What form would that type of education take? What would be the appropriate and most opportune times to implement this integration into the precollege educational level, and how soon should it start? Is engineering education even possible at the PreK-3 level?

Some efforts have been made to identify the form that K-12 engineering should take. Massachusetts, for example, has already developed a set of standards and has included engineering in its prekindergerten-12th grade (P-12) curriculum (Douglas, Iversen, & Kalyandurg, 2004). As this paper was being written, the National Academy of Engineering issued the first-ever report on national standards for engineering in kindergarten through 12th grade (Committee on Standards for K-12 Engineering Education, 2010). This effort complements an earlier study by the National Academy of Engineering and the National Research Council in 2009, through the Committee on K–12 Engineering Education, which underwrote the *Engineering in K-12 Education: Understanding the Status and Improving the Prospects* report, in which a framework for K-12 Engineering Education is presented (Katehi, Pearson, & Feder, 2009).

Responses to questions about the most opportune times for implementation are framed by the strong fundamental belief that early experiences are determinants of later experiences, which often makes early childhood education the focus of pressing demands for change. In fact, early childhood education is being examined as a starting point for reform in engineering education. The increasing volume of engineering materials developed for the PreK-3 level can be taken as evidence that an early exposure trend seems to have begun, using various types of formal or informal activities, including out-of-classroom activities, lesson plans, or early education curricula, primarily categorized as STEM (Bagiati & Evangelou, 2008).

PreK-3 engineering educational materials have been developed by universities, school districts, museums, engineering-related organizations, industry, and (in some cases) individuals. These new materials have been communicated via traditional methods, such as books, scientific or educational journals, and magazines, but the advent of the Internet and the development of numerous educational Web sites have also facilitated the transfer of information electronically. Parallel with the growing use of the Internet, open education movements are “part of a worldwide effort to make education both more accessible and more effective” (Cape Town, 2007), and as a result, a rising number of open educational resources that include “openly licensed course materials, lesson plans, textbooks, games, software, and other materials that support teaching and learning” (Cape Town, 2007) are widely available online, free of charge. These are sometimes referred to as “open resources.” Developers of educational engineering materials now have opportunities to expand beyond the limits of printed formats and to create educational content that is multimodal, audiovisual, and interactive.

Internet media may have increased access to engineering education content, but at the same time, concerns have been raised regarding the reliability of that content (UNESCO, 2002) and its pedagogical fidelity, including concerns about whether the content is appropriate both from an engineering and from a developmental standpoint, and whether the proper methods are used to implement it with children.

Despite the development of new material, early education teachers and parents are cautious in adopting the new resources, and many of them may remain untapped. Engineering content is often perceived as requiring deep levels of specialization in order for a teacher or a parent with a non-engineering background to be able to judge its fidelity. That concern, in combination with the sudden plethora of K-12 engineering educational content, which comprises a “broad array of materials ranging from curriculum to individual lesson plans and activities” (Bagiati & Evangelou 2008, p. 2) all with different terminology and “different definitions and perspectives regarding engineering and engineering education concepts” (Bagiati & Evangelou, 2008, p. 2), makes it difficult for teachers and parents to confidently identify appropriate sources that they could use either in class or at home.

To address these challenges, this study describes the current landscape of early engineering open educational resources provided by institutions formally recognized as educationally based entities. The authors also provide teachers and parents of young children with suggestions regarding how to identify appropriate engineering curricula, lesson plans, and activities embedded in open resources. The following questions guided this study:

- What is the current landscape of open resources for early engineering education within the PreK-12 years?
- What types of open engineering education resources related to PreK-3 engineering education have been developed and where can they be found?

Method

Definitions

This study is in part an extension of the research group’s previous examination of Web-based P-12 engineering curricula (Bagiati & Evangelou, 2008) and uses that study’s definitions to classify whether specific content examined for the study constitutes a curriculum. According to Toombs and Tierney (1993), “the curriculum is an intentional design for learning negotiated by faculty in light of their specialized knowledge and in the context of social expectations and students' needs.” In a curriculum, the “essential qualities are all there: faculty responsibility, specialized knowledge, intended outcomes, negotiated relationships, and a learning plan for students” (Toombs & Tierney, 1993). Heywood (2005, p. 177) complements this perspective, saying that curriculum is “the formal mechanism through which intended education aims are achieved.” In addition, when examining formally developed content, the research team adopted the definition proposed by Dodge and Colker (1992, p. 1) in *The Creative Curriculum*: an early education curriculum is a framework that “sets forth the program’s philosophy, goals, and objectives for children, as well as guidelines for teaching that address all aspects of a child’s development.” These definitions excluded from categorization as “curriculum” any resources that did not mention specific learning goals, implementation instructions, or relevance to previous or future engineering knowledge; such resources were categorized as “activities.”

Data Collection

In this study, sampling of online distributed open resources was two-pronged. The first part of data collection included the recording and examination of Web sites containing PreK-12 engineering educational material. The second included the search for and examination of online documents on PreK-12 engineering education, such as conference proceedings, articles in research journals, and articles in education magazines. From these two categories, resources for the PreK-3 level were identified and analyzed.

Web Sites. Web site data collection began with a thorough Internet search using "*PreK-12 engineering curriculum*" as keywords in the Google and Yahoo search engines. The last of these Web searches was conducted in January 2010. For validity reasons, Web sites were included in the study only if they were created by universities, museums, foundations, institutions, and similar entities formally recognized to be related to education and curriculum development issues. A total of 32 Web sites remained after applying this criterion to the results of the search. All 32 allowed free access to their content, though some required an initial free user registration. Of the 32 Web sites, 9 were found to be merely portals to other Web sites and were excluded. Examination of the remaining Web sites to identify those containing PreK-3 engineering educational material resulted in identification of 12 Web sites for analysis. Commercial Web sites presenting and selling educational software or classroom manipulatives were not included and analyzed in the study but were noted as tools if they were mentioned in activities or lesson plans of the resources in the included Web sites.

Online Documents. The first round of sampling of documents purported to contain resources for PreK-12 engineering education was conducted to investigate the current PreK-12 landscape and the role of PreK-3 materials in that landscape. Among the conference proceedings included in this study were the American Society for Engineering Education (ASEE) conference proceedings from 1997 to 2010 (see http://www.asee.org/conferences/paper-search-form.cfm) and the ASEE/IEEE Frontiers in Education Clearing House conference proceedings from 1995 to 2009 (see http://fie-conference.org/). Online documents other than conference proceedings were identified through electronic databases (*Education Resources Information Center (ERIC), PsycINFO,* and *Social Science Citation Index,* a search engine in *Google Scholar*) and examination of references of articles. Online search keywords were combinations of the following: *kindergarten, PreK, K-3, K-5, K-6, K-12, elementary, middle school, high school, engineering*, *activities*, and/or *curriculum*. Table 1 presents general characteristics (Author, Topic, and Action) of the three types of identified documents (e.g., journal articles, conference proceedings, magazine articles).

A total of 686 documents (629 conference proceedings, 38 journal articles, and 19 magazine articles) were identified as potentially including PreK-12 engineering educational content. Each document was initially read by one researcher who selected documents that met the inclusion criteria set for this study; documents were included or discarded based upon agreement between two researchers.

Inclusion criteria for documents to address the second purpose of this study were

- document includes engineering curricula, lesson plans, or activities;
- document described activities that target young children in PreK-3rd grade; and
- document was developed and reported by credible groups such as researchers/educators affiliated with universities or teachers in PreK-12 schools.

After applying these criteria to the 686 documents, 24 documents remained and were included in the sample for the second research question. When a document did not incorporate the details of engineering activities but led to a Web site that contained those details, we counted the document as part of our sample. A total of 13 documents were part of this sample.

Table 1

Characteristics of Online Documents Identified

Document	Author	Topic	Action
Journal	Researchers or educators in higher	• Experimental research	• Applied engineering activities as experiment

	education		conditions • Reported results
Conference Proceeding	Researchers or educators in K-16 education	• Engineering activities • Outreach programs for K-12 students • Professional development for K-12 teachers • Course development for preservice teachers • Workshops for preservice and inservice teachers • Effect of implementation of development programs/workshops on participants such as K-12 students, undergraduate/graduate students, teachers, and fellows • Opinion about K-12 engineering education in general	• Developed engineering curriculum/activities • Implemented with K-12 students or preservice and inservice teachers • Reported processes and results
Magazine	Teachers in K-12 education, researchers, or educators in K-16 education	• Engineering activities	• Developed/introduced engineering activities • Implemented with their students • Reported processes and results

Data Analysis

Web Sites. The purpose of the analysis was to identify and chart open-access engineering material in relation to the age of the target group and to classify Web sites as curricula and/or sources of more-or-less isolated activities. Data gathered included 32 PreK-12 Web sites, of which 12 were identified as containing PreK-3 engineering educational material.

A review of related literature was then conducted to enable the researchers to identify categories that would help to answer the research questions and to develop criteria that could facilitate evaluation and categorization of the content presented on the Web sites that was intended to engage younger students and their teachers in interest development and knowledge acquisition around engineering education. Upon completion of the literature review, a database containing information collected from the Web sites and their embedded applications was created. (See Table 2 for database categories and their definitions.) Quantitative analysis followed for all data categories, and frequencies regarding data in all categories were calculated.

Click to View Table

Table 2
Category Names and Their Definitions regarding the Data Collected from the Web Sites

Online Documents. The 686 publications initially identified (conference proceedings, journal articles, and magazine articles) were classified by year to reveal the changing landscape of publication of open resources for PreK-12 engineering education. To answer the second research question, the set of online PreK-3 engineering education documents was isolated from among the 686 various PreK-12 engineering documents. Finally, 24 documents for PreK-3 engineering education were examined for target grade level, type of document, types of resources presented, engineering topics presented, related organizations, and supporting Web sites if provided.

Results

Current Status of Open Engineering Education Resources for PreK-3

Our first research question concerned the nature of the current landscape of PreK-3 open-access engineering education resources among the PreK-12 open engineering education resources' pool.

Web Sites. Analysis of the Web sites identified led to the following findings regarding the landscape of the open Web-based PreK-12 engineering education material. Nine out of the 32 Web sites identified (28.1%) were in fact directories or portals to other Web sites that presented links to educational material; these will not be further mentioned while presenting the results. Of the 23 remaining Web sites, Web material related to PreK-3 engineering education appeared in 12 (52.2%; see Figure 1).

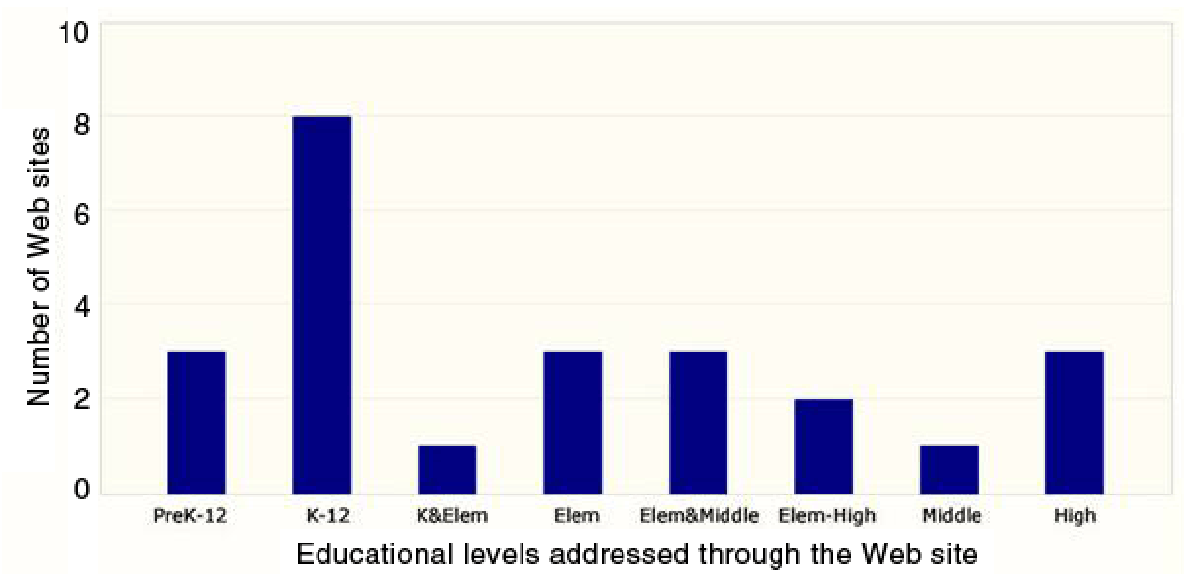

Figure 1. Number of Web sites in relation to the educational level addressed through Web site content.

Online Documents. Analysis of 686 online documents showed that 26 documents (3.8%) focused on only PreK-3 age levels, 99 (14.4%) on K-5, and 42 (6.1%) on K-8. The largest portion of documents (217, or 31.6%) addressed K-12 engineering education in general. The next largest portion addressed engineering education targeting high school students (162, or 23.6 %; see Figure 2). Documents related to K-5, K-8, and K-12 age levels included the K-3 level; most of them did not distinguish early engineering education (PreK-3) from the broad range of students' grade level. Figure 3 shows the number of documents published by year, reflecting increasing research interest in PreK-12 engineering education. The frequency of publication related to PreK-12 engineering education increased from the early 1990s, decreasing slightly after its peak in 2004.

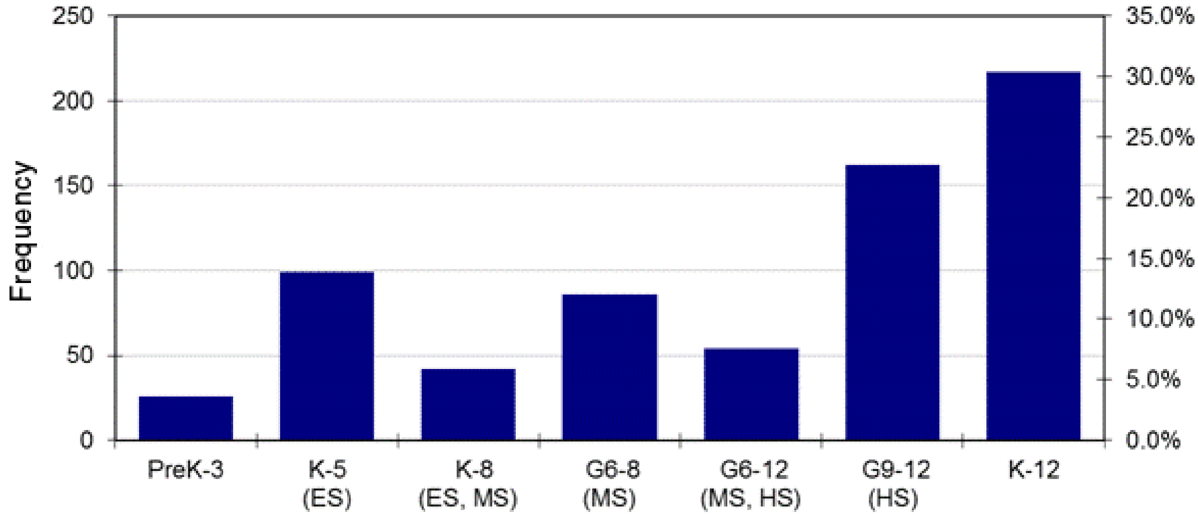

Figure 2. Online engineering education documents by students' educational level.

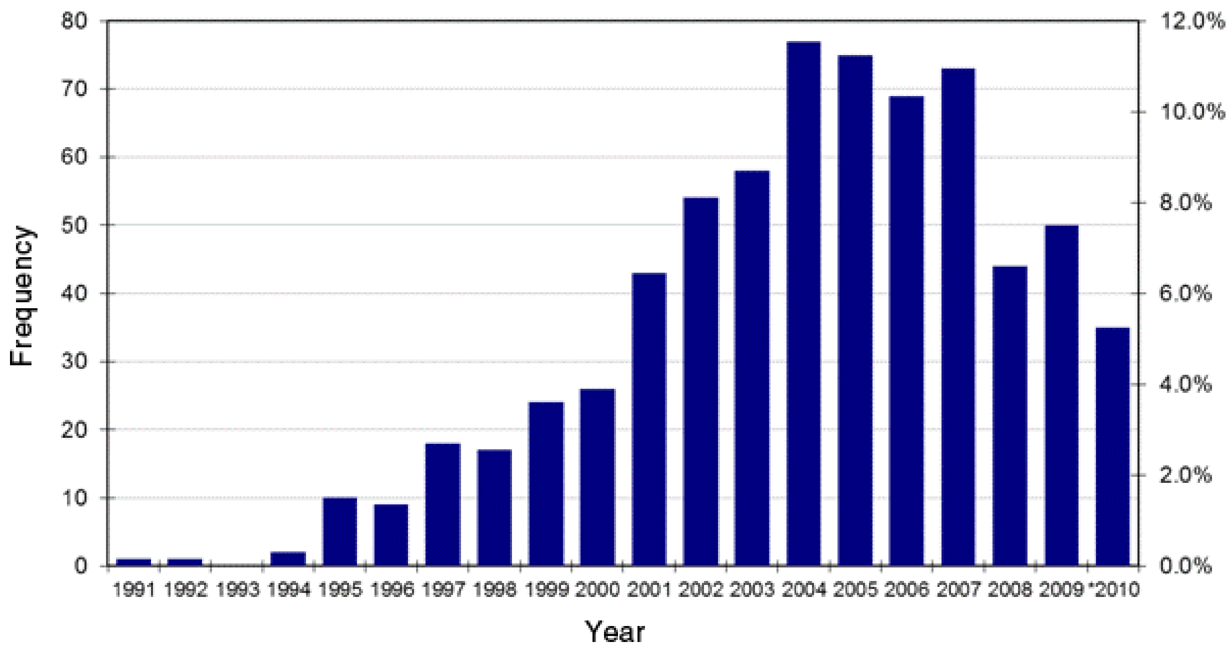

*Figure 3. Online documents on PreK-12 engineering education published by researchers and educators by year. *Sampling of 2010 documents contains documents retrieved until September 2010.*

Content and Location of Open PreK-3 Engineering Education Resources

The second research question was concerned with the content of open engineering education resources for PreK-3, and where they could be found.

Web Sites. During analysis of the content of the 12 Web sites identified as focusing on PreK-3, a trend reflecting lack of a coherent early educational engineering curriculum started to appear. Although all the Web sites were presented as containing engineering curricula, all 12 (100%) of them contained a small number of engineering activities that were unrelated to each other in terms of addressing relevant content or serving an organized or common learning plan; thus they did not fit the study's criteria for curricula. Five (41.6%) contained lesson plans and relevant assessment tools for grades 1-3 that were proposed as being able to be completed in one or two class sessions. None contained an actual curriculum as previously defined (see Figure 4).

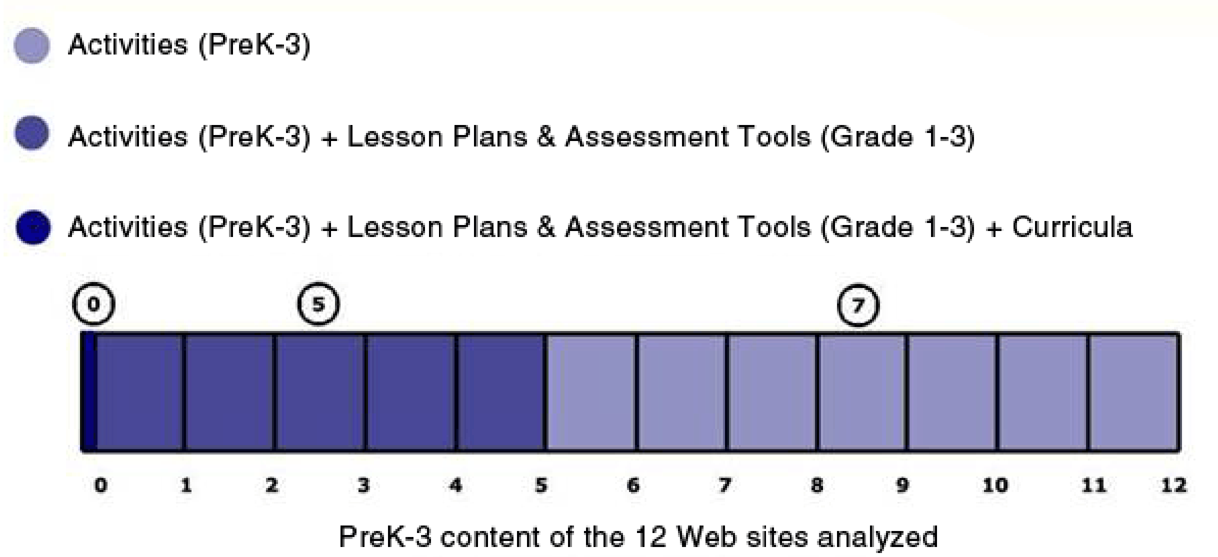

Figure 4. Content analysis of the 12 PreK-3 engineering educational Web sites.

The following list breaks the 12 Web sites containing open online PreK-3 engineering educational material into two sets. The first set includes only those sites that featured activities not connected to lesson plans and/or assessments. The second set contains those for which lesson plans and assessment tools were provided.

Activities:

- PBS Teachers: http://www.pbs.org/teachers/sciencetech/
- DuPage Children's Museum: http://www.dupagechildrensmuseum.org/online_play.html
- eGFI: http://teachers.egfi-k12.org/category/lessons/grades-k-5-lessons
- Stanford University: http://manufacturing.stanford.edu/
- National Engineers Week Foundation: http://www.eweek.org/EngineersWeek/DiscoverE.aspx
- Center for Innovation in Engineering and Science Education: http://www.ciese.org/currichome.html
- Virginia Department of Education: http://www.doe.virginia.gov/instruction/early_childhood/index.shtml

Lesson Plans:

- STOMP Network: http://www.stompnetwork.org/stomp-resources
- Teach Engineering: http://teachengineering.org/
- Teachers' Domain (Requires registration): http://www.teachersdomain.org/search/?mode=refined&query=engineering

- NASA Educators: http://www.nasa.gov/audience/foreducators/index.html
- Engineering Is Elementary (Requires registration): http://www.mos.org/eie/

"Engineering Is Elementary" was the only Web site to mention having been developed based on any standards (in this case, the Massachusetts K-12 standards). It was also the only one of the 12 Web sites to present findings after testing the materials in class settings.

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Table 3
Curriculum/Activities for PreK-3 Students That Appeared in the Documents

Online Documents. Among26 online documents focusing only on PreK-3 and the other documents broadly focusing on various grade levels, 24 documents met all of the criteria discussed in the methods section. Table 3 refers to documents that contained or linked to PreK-3 level curricula and/or activities and described the types of documents, organization, grade level, topic, and Web site if applicable. Most activities were hands-on and covered various engineering topics, such as biomedical, chemical, civil, mechanical, electrical, and software engineering, as well as applying engineering concepts to science and mathematics. Most of the documents contained activities with short-term goals rather than a curriculum or a unit of lessons with a long-term goal. For example, a total of 17 lessons with short-term goals appeared in 7 documents (Lee-Desautels, 2004; Mora, Negron, McGahern, & Brown, 2010; Sigmon, 1996, 1997; Thode, 2004; Torres & Casey, 2001; Torres, Casey, & Loker, 2002). Two teaching units (Cooney & Mueller, 2000; Polaha, 1999), and four curricula (Kearns, Rogers, Barsosky, Portsmore, & Rogers, 2001) were found, with long-term goals presented in the latter four documents (see Figure 5).

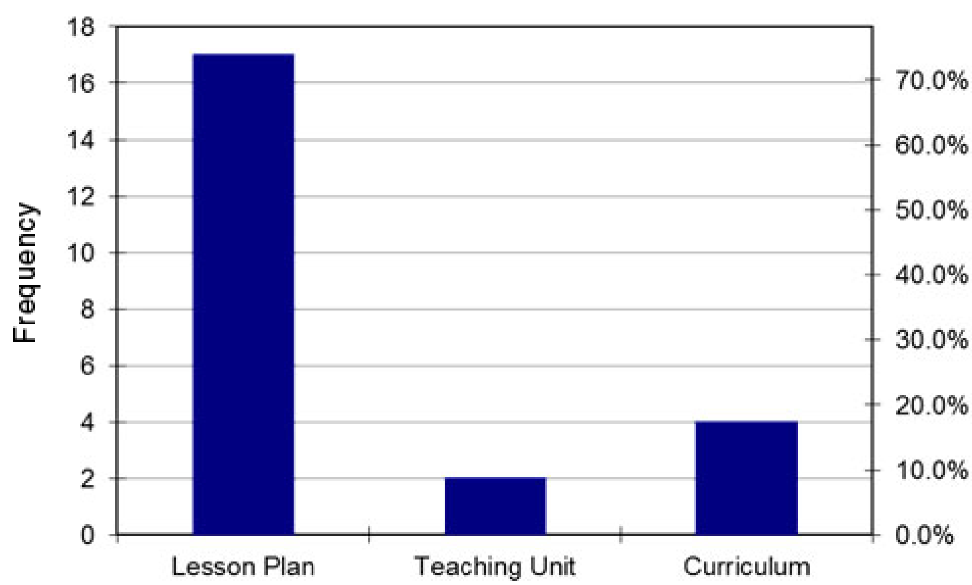

Figure 5. Content analysis of the PreK-3 engineering educational online documents.

Discussion and Recommendations

This study involved review of Internet open resources containing engineering educational material intended for young children in preschool through grade 3, as part of the landscape of such resources available for use with prekindergarten through grade 12. Findings showed that, for example, the number of online documents (not Web sites) related to PreK-12 engineering education published annually showed an upward trend between 1991-2004, particularly from 1998-2004. Since then, the number of online engineering education documents published has dropped off, but not to pre-1998 levels. Findings also suggest that when compared to open-access engineering education materials available for other grade levels, particularly for high school, a relatively small number of resources (Web sites or online documents) have been developed for implementation at the PreK-3 level. Of those, most do not take a systematic approach involving long-term goals and assessments but instead suggest one-time or sporadic activities. Analysis also revealed that most of the resources found during this study did not include information related to how and if the suggested materials or activities met or addressed content area standards.

This study highlights several important concerns. First, introducing engineering in the early years entails recognition of the need for understanding its content and poses the challenge of preparing teachers to incorporate it into their practice. Teacher preparation has historically included seeking information in books, journals, and magazines, and the professional development offered by universities, school districts, and other educational entities continues to provide the majority of formal options accessed by teachers. However, the advent of the Internet has expanded the ways that teachers undertake professional development and how they prepare to present new content. Even though researchers and educators acknowledge the importance of early exposure to engineering, and there is a critical need for educators of young children to become familiar with the field of engineering, an insufficient number of open-access engineering education materials are available for educators or parents of children in PreK-3rd grade.

Second, generating and implementing a cohesive engineering curriculum is recommended rather than the piecemeal utilization of different activities, as is currently the norm in the Web sites and online documents analyzed here. Having observed the related fields of science, technology, and math, which have a longer and well-established history as part of early education, it seems safe to say that use of an engineering curriculum is likely to be more effective at consistently and systematically reinforcing engineering concepts in young minds than is use of the variety of activities (many presented without stated goals) available from open resources for PreK-3 engineering education. The Appendix presents some recommendations for practitioners regarding selection of online open-access engineering materials based on the literature review undertaken for this project. However, creation of a complete developmentally appropriate selection criteria list is still a work in progress.

Third among the concerns raised by the findings of this study is the need for careful consideration of standards for engineering education and the potential use of those standards when creating resources for engineering education in PreK-3rd grade. Engineering is an interdisciplinary subject, so it can be used to leverage other subjects, such as science, math, and technology within the current educational standards. However, most engineering resources considered during this study did not address or include information related to how and if the proposed materials or activities met or addressed such standards.

Finally, there is still a need for empirical and experimental research on applying engineering education for young learners at the various developmental stages. Overall, this emerging new emphasis on early STEM creates a number of important developmental, pedagogical, and subject-matter-related questions that the field of early education should try to address theoretically as well as empirically.

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Appendix
Recommendations for Practitioners with regard to Selection of PreK-3 Engineering Educational Material from Open Resources

Because of the rapid development of PreK-3 engineering, questions about pedagogical fidelity and content validity of educational content have emerged. To facilitate teachers' and parents' identification of content validity of online open resources such as Web sites and online documents, the following recommendations are proposed.

- To ensure engineering content validity, it is recommended that content should be offered from universities, museums, foundations, institutions, and other such entities formally recognized to be related to engineering, education, and curriculum issues.
- To ensure pedagogical validity, determining the setting and time requirements for the activities described should be a first step. In addition, clarifying whether the content will be used in a formal educational setting or as an extracurricular complementary activity should be considered. If content is intended to be used in a class, it is of great value if the resource presents content as a detailed lesson plan followed by an assessment tool to be used to assess students' individual

learning.

- To ensure overall long-term learning validity, it is recommended that content presented comes with a report regarding prior application and evaluation in a classroom setting.
- To ensure that the necessary software or hardware are properly installed and ready for use, it is recommended that technology requirements be reviewed before selecting lesson content that will involve the use of technology (i.e., an online engineering game or specific software).