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Material Topics in Engineering and Technical Programs

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Material Topics in Engineering and Technical Programs

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ABSTRACT

This research focused on the content and methods of teaching construction, engineering, and industrial materials. A random selection of program coordinators was surveyed. Information on approximately 15 materials topics was collected and included what topics are taught, how important they are, and if a laboratory exercise was used in teaching. Programs in the following accreditation bodies formed the population: American Council of Construction Education (ACCE), Association of Technology, Management, and Applied Engineering (ATMAE), Council for the Accreditation of Educator Preparation (CAEP), and both the Engineering Accreditation Commission (EAC) and the Engineering Technology Accreditation Commission (ETAC) of ABET (the Accreditation Board of Engineering and Technology, Inc.) It was found that both (a) courses focused on materials and (b) materials topics embedded in various courses are widely used. All topics were considered important. Those surveyed felt that some topics were more important than others. Laboratory experiences were used to teach all topics. Some topics were more likely to be taught in a lab than other topics. When comparing these results to 1998 research, the programs are teaching more of the topics and the use of dedicated materials courses is increasing. There were no significant differences due to accreditation body concerning the topics taught, the importance of topics, or the use of dedicated materials courses versus materials topics embedded in various courses. The results can be used as a snapshot of materials content and pedagogy for benchmarking and other purposes.

IMPORTANCE OF MATERIALS

The World

Materials relate to all aspects of our culture. Major divisions of human history are named after materials. Development of new materials, new uses for materials, and new ways to produce and process materials are the heart of most technological advances (Jayakrishnan, Vijayakumar, & Unnikrishnan, 2011).

Materials topics are central to engineering and technical (E&T) programs. To paraphrase the Engineering Technology Accreditation Commission (ETAC) of ABET, a thing is engineered from other things (ABETb, 2014). When we design, create, install, or maintain a thing—that thing is made of one or more materials. Additionally, materials are extracted or created using other materials. An item is created using tools made from materials. There are usually expendable material supplies used in creating, using, and maintaining an item. The material is usually the primary parameter that influences the design, the production method, and the use of the product. Every construction, manufacturing, or other technical process—processes a material and uses tooling, machines, and supplies made from materials.

In addition to cited sources, the authors examined more than a dozen of the latest editions of industry journals to which we and various colleagues subscribe (including automotive, construction, healthcare, manufacturing, packaging, quality, and others). Each journal had one or more articles focused on a new material or a new use of a material. On the average, there were several other articles in which materials were a prominent part. This is an anecdotal gauge regarding the prominence of materials. The body of knowledge concerning materials is expanding (Jayakrishnan, Vijayakumar, & Unnikrishnan, 2011). The total amount of materials knowledge needed by a practitioner is increasing because the development of new materials, new ways to produce materials, and new applications of materials is growing at a faster rate than older materials and associated production techniques and applications are becoming obsolete. Whether we use a new or an existing material, we are finding new ways to condition, process, and test that material (Tonicello, Girodin, Sidoroff, Fazekas, & Perez, 2012).

Society is using both new and existing materials to make things increasingly smaller and larger; this is true of objects and the structure of the materials. We are manipulating a material's structure at the nano level, creating new alloys, molecules, and composites (Jayakrishnan, Vijayakumar, & Unnikrishnan, 2011). On the large scale, we can build a bridge using structural 3-D printing of steel composites (Advanced Materials and Processes, 2015). The same *Advanced Materials and Processes* feature also reported the creation of artificial skin that can mimic the camouflage ability of a squid and a light bending polymer-titanium dioxide combination that effectively creates an invisibility cloak, both of which were science fiction a few years ago.

Conservation of materials and sustainability of their use (from creation of the material through the discarding or recycling of a product) are central to many economic and environmental concerns. International Technology Education Association (2007, p. 65) *Standards for Technological Literacy* state that the "Student will develop an understanding of the effects of technology on the environment." de Vries, Hacker & Burghardt (2010) completed a Delphi study that found that materials and sustainability were major sub concepts of technology and engineering education. Becerik-Gerber, Gerber, & Ku (2011), in a multidisciplinary study of architecture, construction, and engineering programs, found that about 70% of the programs offer a materials course related to sustainability and that over 80% of the programs surveyed planned to offer such a course.

The safety and reliability of materials and the products and structures made from those materials are increasingly important. In addition to normal use, we are increasingly concerned about integrity during and after accidents and natural disasters (Murakami, Ohmura, & Nishimura, 2013). Consider all the publicized product recalls and lawsuits; it is often a material that fails, a material that is toxic, or a material that is otherwise at fault. Biological materials (genetically engineered or not) are but one category of materials that we didn't used to think of as a *material*. *Smart* materials are being developed. Many of these have biological components. The line between biological and mechanical is blurring. *Humanization* or *people-oriented* design uses smart materials to create products that consider emotion and not just form or function. With or without software, smart materials and products interact with users and anticipate the user's needs. Materials are being developed that can sense external stimulus and make appropriate adjustments, including repairing itself (Liu, 2014).

Academicians

Materials topics are taught via stand-alone courses with titles such as *engineering materials, industrial materials, and construction materials*. A catalog search of Purdue University's Materials Science program revealed 16 undergraduate materials courses focused on materials (Purdue University, 2014). Materials topics are also taught in various courses across E&T programs (diffused or embedded in various courses).

The major branches of engineering and technology disciplines are often named due to the material being dealt with or how materials are used. E&T programs with ceramic, metallurgy, and petroleum in their titles come to mind. However, Engineering Accreditation Commission (EAC) of ABET programs such as construction, environmental, geological, and industrial engineering specifically mention materials in their accreditation standards (ABETa, 2014). Some EAC of ABET programs, e.g., ocean engineering, mention specific materials. ETAC of ABET programs with accreditation standards that use the term *materials* include aeronautical, architectural, chemical, civil, marine, mechanical, and manufacturing, among others. It is also common for EAC and ETAC of ABET accreditation outcomes to not use the term *materials* but instead state a topic such as physics, chemistry, statics, strengths, mechanics, thermal and fluid dynamics, hydrostatics, optics, heat transfer, and others. It is obvious, for example, that *strengths* pertain to the strength of a material. It is the authors' opinion that EAC and ETAC of ABET accreditation outcomes a, b, c, e, and h, all directly require knowledge of materials.

E&T programs often include laboratory exercises and other forms of experiential learning. The standards of some accrediting bodies (American Council for Construction Education, 2014; The Association of Technology, Management, and Applied Engineering, 2011) specifically require laboratory experiences for the teaching of materials topics. Though EAC and ETAC of ABET do not specifically require laboratory activities, laboratory activities are common (Passow, 2012). Besterfield-Sacre, Cox, Beddoes & Zhu's (2014) research found that experiential learning and laboratories were each very significant in importance as a means of advancing the culture of innovation in engineering education and in practice. Furthermore, they concluded that science, technology, engineering, and mathematics (STEM) education could benefit from more experiential learning and laboratories. Russell and Stouffer (2005, April) found that one-half of construction engineering programs require a laboratory experience. They also found there was a curriculum cluster of strengths, fluids, statics, dynamics, and thermodynamics (though the term *material* was not used).

Knowledge of materials is prominent on most E&T professional licensure or certification exams. This is true of the Professional Engineer exam; it is also true for many of the American Society for Quality's exams (e.g., Quality Engineer), the Association of Technology, Management, and Applied Engineering's (ATMAE's) Certified Manufacturing Specialist (CMS) exam (ATMAE, 2014), the Society of Manufacturing Engineers' Manufacturing Engineer exam, and others. The ATMAE CMS exam assesses competencies for all materials topics in this study. This particular exam offers results based upon specific competencies making it useful for use in outcomes assessment strategies.

Most E&T professionals regularly work with materials. The scholarly and service activities of E&T professors involve materials. For those who teach in E&T programs, it is very important to determine which material topics to teach and how those topics are best taught. It is also important to benchmark other programs to validate what one is doing and to innovate beyond current practice. Individual faculty members, programs, and disciplines compare themselves to others and to standards to gauge where they are and where they should be. From a curriculum standpoint, questions such as *what topics should be taught* and *how should they be taught* are important to faculty members.

PURPOSE OF THE STUDY

Benchmarking is the prime motivation for this study. Hayden (1992) has conducted various research projects over the last 35 years to produce a snapshot of what *is happening* with materials. This research has taken many forms, e.g., review of literature, analysis of professional exam content, analysis of university catalog content, and surveys of employers or graduates. For example, the research for the conference presentation included a comparison of materials content and methods (Clyburn, Hayden, Johnson, & Nicoletti, 1998). In some institutions with E&T focused colleges, lab-based materials topics are a college-wide core curriculum element (English, Hayden, Hellman, & Minty, 2000).

For this study, the authors chose to investigate a variety of E&T programs. The population was stratified by accreditation because (a) various accrediting bodies have different standards related to content and pedagogy and (b) various disciplines tend to align with different accrediting bodies. The specific questions of the study follow.

- Which material topics are taught?
- How important are those topics?
- To what extent are material topics taught via (a) dedicated courses about materials (b) material topics diffused throughout (embedded within) various courses?
- For the topics that are taught, is a laboratory activity part of the instruction?
- How have the answers to the preceding changed since a similar study in 1998?

METHODS

The study was delimited to programs accredited by the American Council for Construction Education (ACCE), the Association of Technology, Management, and Applied Engineering (ATMAE), the Council for the Accreditation of Educator Preparation (CAEP), the Engineering Accreditation Commission (EAC) of ABET, and the Engineering Technology Accreditation Commission (ETAC) of ABET, because those are the programs most closely related to the researchers' academic department, industrial experience, certifications, and professional activities. Only accredited programs were chosen based on the presumption that accredited programs have a verified type of quality and have consciously engaged in self-examination processes.

All accredited programs for each accreditation body were listed. Twenty programs from each accreditation body were then randomly selected. Therefore, the target sample size was 100. It was understood that because the number of programs accredited by each body varied from approximately 40 for CAEP to 1,800 for EAC of ABET that the sampling method would not be proportional. This could lead to unequal within-group variances. However, the researchers wanted the subsample sizes to be the same to aid between-group comparisons. The researchers were also more concerned about a descriptive snapshot than about inferential generalizability because they mainly wanted to benchmark the materials topics and methods in similar departments.

The survey was electronically sent to the coordinator of each program (or the department chair if no coordinator could be identified). Program coordinators often have a comprehensive perspective about their programs (Degree Directory, 2014). A follow-up reminder was sent two weeks later. The valid responses are summarized in Table 1. In retrospect, the response rate was greatest from accreditation categories most aware of the researchers' professional activities. Also, the researchers contacted a few program coordinators, especially CAEP, and inquired about their participation decision. The most common reason to not participate was summed up by a CAEP colleague who said "we don't teach anything about materials." The researchers posit that there are different understandings about the definition of *materials* and what is a materials topic.

The following are the variables and value levels in the study.

- Material topics: 15 topics (plus *other*, but no *other* topic was reported).
- Accreditation body: 5 bodies.
- Topic taught: Yes or no (for each topic).
- Topic importance: 1-5 rating scale (for each topic).
- Course type—courses focused on materials: Yes or no.
- Course type—material topics embedded in various courses: Yes or no.
- Lab used to teach a topic: Yes or no (for each topic).

Various descriptive and inferential statistics were calculated and are summarized later in this document. All statistical tests used a 0.05 confidence level. Several non-parametric tests were used due to small sample sizes, unequal variances, or the nature of data, e.g., proportions were being investigated. All analyses were conducted with all accreditation bodies pooled and with accreditation body as an independent variable. Accreditation body was not significant for any test. Therefore, this report will focus on analyses with all accreditation bodies pooled.

RESULTS

The Respondents

One hundred programs were surveyed; 57 responded. Table 1 shows the frequency of respondents broken down by accreditation body.

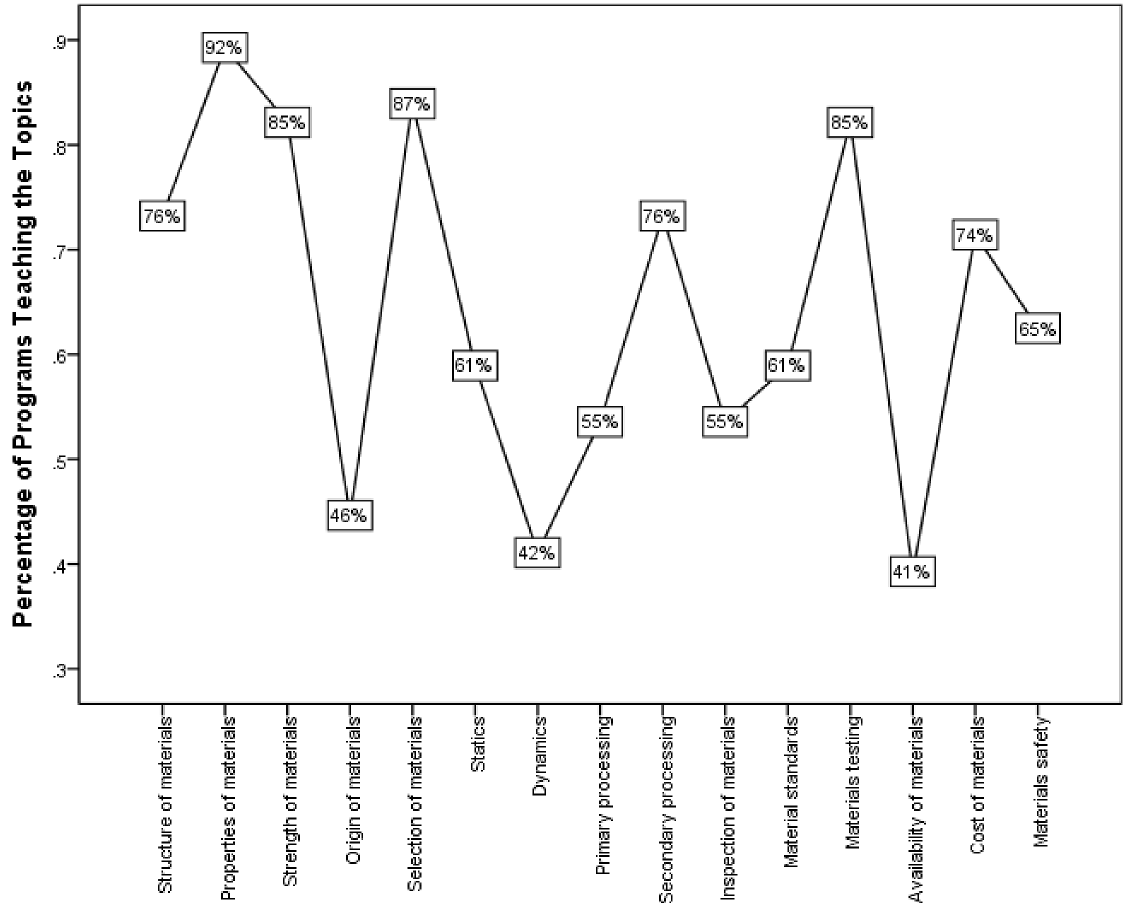
TABLE 1: FREQUENCY DISTRIBUTION OF THE RESPONDENTS BY ACCREDITATION BODY

Accreditation Body	Frequency	Percent
1. ABET EAC	13	22.8
2. ABET TAC	10	17.5
3. ACCE	11	19.3
4. ATMAE	18	31.6
5. CTTE	3	5.3
6. Other	1	1.8
7. No program accreditation	1	1.8
Total	57	100.0

What material topics are taught?

The topics (the horizontal axis in Figure 1) were presented to respondents and the respondents were asked to select whether that topic was taught in their program. The topics were identified by previous research (Clyburn, Hayden, Johnson, & Nicoletti, 1998). Figure 1 is a line graph of the percentage of programs that teach that topic. Using a one-sample proportion test (Rumsey, How to Compare Two Population Proportions, 2016) all the proportions were found to be significantly greater than zero. In a post-hoc comparison, each pair of proportions (Rumsey, Statistics for Dummies, 2016) are statistically different when the difference is approximately .25 or greater, e.g., structure of materials (78%) and origin of materials (46%) are statistically different.

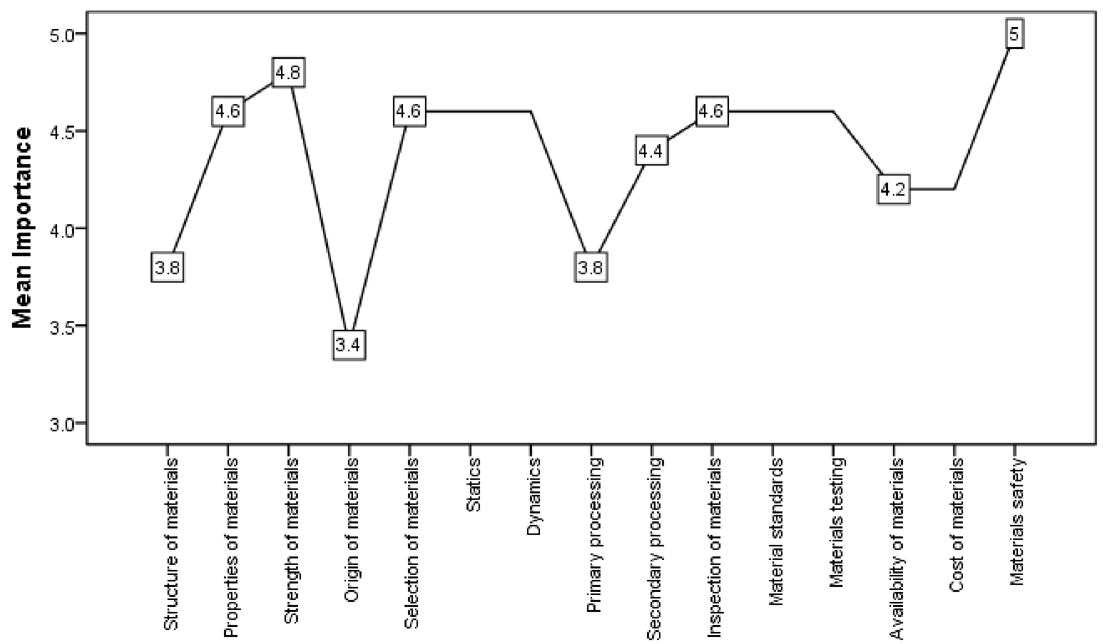
FIGURE 1: PERCENTAGE OF PROGRAMS TEACHING A TOPIC



How Important are the Material Topics?

If a materials topic was taught, the respondent was asked how important that topic was (on a 5-point) scale. Figure 2 shows the mean value of those responses. Using a one-sample t-test (Rumsey), each mean was significantly greater than zero. Using Kruskal-Wallis (Rumsey), there were no statistical differences among topics. A descriptive analysis reveals that each materials topic has an importance ranging from approximately 3.5 to 5. The lowest, *origin*, is, in the authors' judgment, least important for the programs surveyed. It did not surprise the authors, based on their experiences, that *safety* is the highest.

FIGURE 2: MEAN RATINGS OF THE IMPORTANCE OF MATERIAL TOPICS



Course Type

The respondent was asked if material topics were taught in their program via courses focused on materials and also if material topics were taught in their program by being embedded in other courses. Each question was answered independently; therefore, a respondent could answer yes or no to each question. Figures 3 and 4 display the results. Though, descriptively there appears to be differences based on accreditation body, using Kruskal-Wallis, there were no statistical differences among the accreditation bodies for teaching materials topics via (a) courses focused on materials or (b) embedding them in various courses. Using the proportion test, materials topics are taught more by (a) courses focused on materials than not being taught by that method (a). This is also true for the materials topics being (b) embedded in various courses. In other words, programs use each method more than they don't use that method. There is also no statistical difference between dedicated materials courses and materials topics embedded in various courses. Approximately 2/3 of programs have dedicated materials courses and about 2/3 of programs teach material topics embedded in various courses. About ½ of programs teach materials topics both ways. All responding programs taught at least some material topics (but some of the non-responders stated they do not teach any).

FIGURE 3: MATERIAL TOPICS TAUGHT VIA COURSES FOCUSED ON MATERIALS

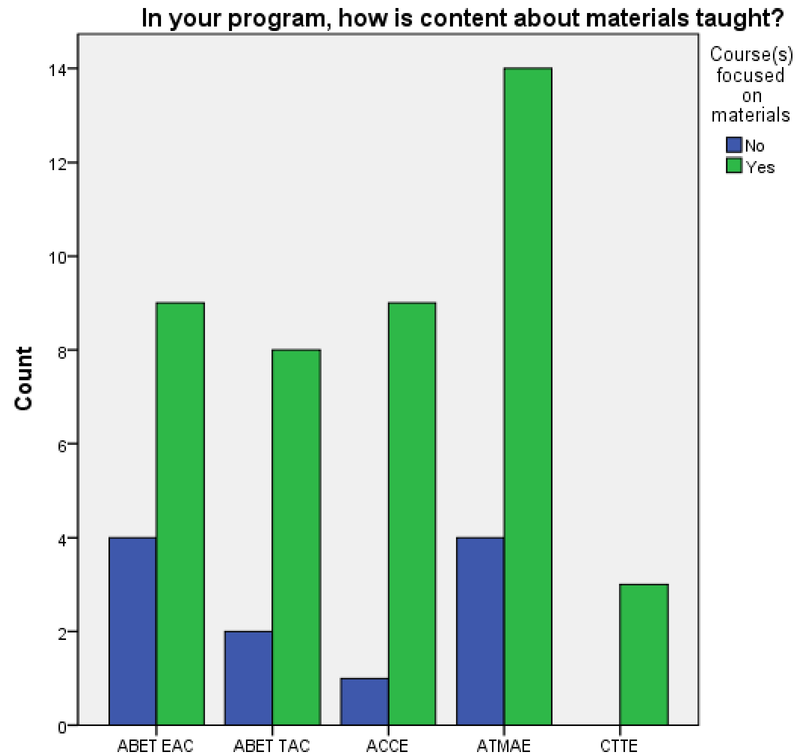
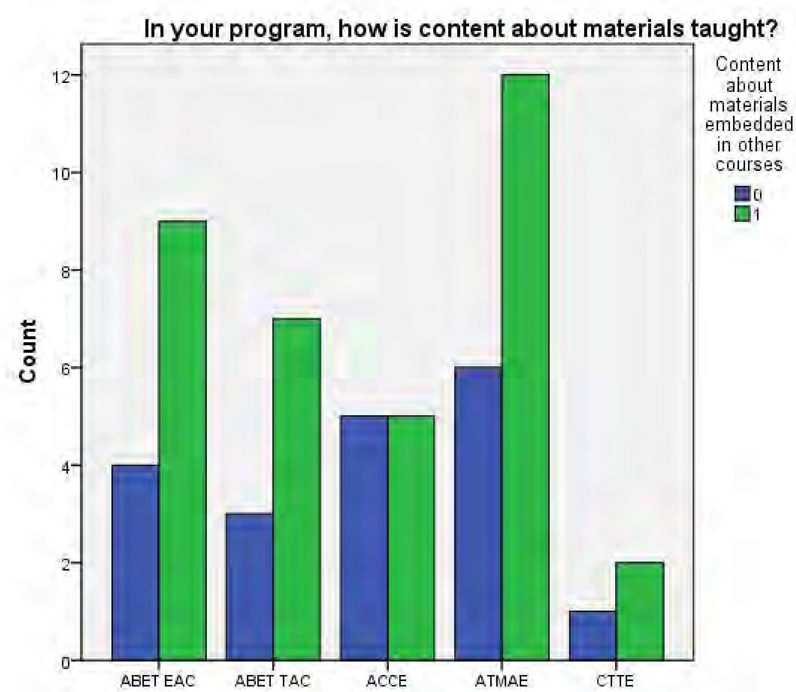


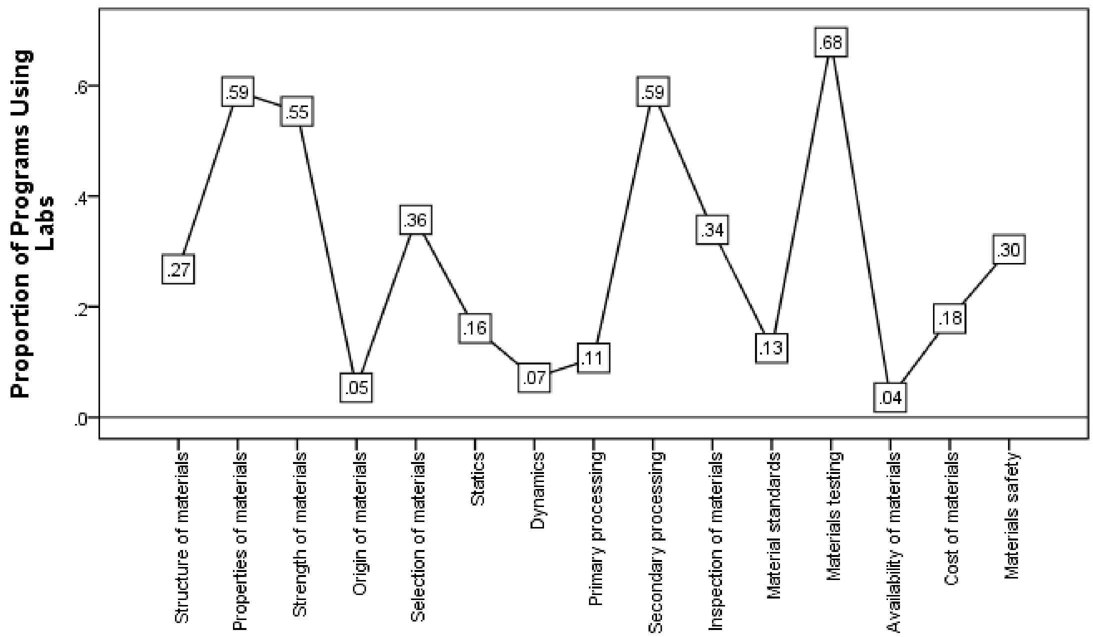
FIGURE 4: MATERIAL TOPICS EMBEDDED IN VARIOUS COURSES



Lab Use

If a topic was taught by courses focused on materials or by being embedded in various courses, the respondent was asked if a lab exercise (not merely a demonstration) was used. Figure 5 shows to what extent labs are used to teach a topic. Using Kruskal-Wallis, there were no statistical differences in lab use among the material topics. It appears that labs are used more with topics such as properties, strengths, secondary processing, and testing, but these differences are not significant. Labs are used less with topics such as origin and availability.

FIGURE 5: PERCENTAGE OF PROGRAMS USING A LABORATORY EXERCISE TO TEACH MATERIAL TOPICS



Comparison to Previous Research

This study replicated parts of a 1998 study (Clyburn, Hayden, Johnson, & Nicoletti, 1998). The population and sampling procedures were the same as the 1998 study. Among other things, both studies looked at the proportion of programs that taught various materials topics, if materials topics were taught via courses focused on materials and/or materials topics embedded in various courses, and if laboratory exercises were used. Table 2 compares some results of the 1998 study to this study. The difference in the proportion test shows that the coverage of most materials topics has significantly increased. The use of dedicated materials courses has also increased. No materials topic significantly decreased. The proportion of materials topics embedded in various courses and the use of lab exercises were statistically unchanged.

TABLE 2: CHANGES IN PROPORTION OF SURVEY RESULTS FROM 1998 TO 2014

	Proportion 2014 Survey n = 56	Proportion 1998 Survey n = 99	z statistic	Two-tailed Probability
Materials Topic				
Structure of materials	0.73	0.54	2.321	*0.020
Properties of materials	0.89	0.64	3.361	**0.001
Strength of materials	0.82	0.63	2.469	*0.014
Origin of materials	0.45	0.47	-0.239	0.811
Selection of materials	0.84	0.57	3.418	**0.001
Statics	0.59	0.37	2.635	**0.008
Dynamics	0.41	0.28	1.650	0.099
Primary processing	0.54	0.39	1.798	0.072
Secondary processing	0.73	0.52	2.551	*0.011
Inspection of materials	0.54	0.45	1.073	0.283
Material standards	0.59	0.45	1.668	0.095
Materials testing	0.82	0.61	2.698	**0.007
Availability of materials	0.39	0.34	0.621	0.534
Cost of materials	0.71	0.42	3.461	**0.001
Materials safety	0.63	0.47	1.910	0.056
Average of all materials topics	0.65	0.48	2.016	*0.044
Pedagogy				
Dedicated materials courses	0.8	0.5	3.385	**0.001
Materials topics embedded in courses	0.64	0.58	0.492	0.623
Laboratory exercises are used	0.43	0.57	-1.620	0.105

*Significant at the .05 level; 95% confidence interval.

**Significant at the .01 level; 99% confidence interval.

CONCLUSIONS

All the topics are taught and are rated by program coordinators to be important. Experiential lab activities are commonly used. The teaching of most materials topics has increased since 1998. Topics can be taught by dedicated materials courses or by embedding those topics in various courses. The use of dedicated courses to teach materials has expanded since 1998, while the teaching of materials in various courses has not declined. Perhaps because of the small sub-sample sizes, there were no statistically significant differences found (a) among topics taught, (b) between dedicated course and embedded content structuring, (c) lab use among topics, or (d) among accreditation bodies. This and other studies can be replicated with larger sample sizes to lower the Type II error rate and effect size. There could be a non-response bias related to the definition of materials or material topics. This topic warrants further investigation. The results of this study can be used by programs as a snapshot of materials content and methods in similar programs.

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