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Analysing the integration of engineering in science lessons with the Engineering-Infused Lesson Rubric

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ABSTRACT
Science teachers are being called on to incorporate engineering practices into their classrooms. This study explores whether the Engineering-Infused Lesson Rubric, a new rubric designed to target best practices in engineering education, could be used to evaluate the extent to which engineering is infused into online science lessons. Eighty lessons were selected at random from three online repositories, and coded with the rubric. Overall results documented the strengths of existing lessons, as well as many components that teachers might strengthen. In addition, a subset of characteristics was found to distinguish lessons with the highest level of engineering infusion. Findings are discussed in relation to the potential of the rubric to help teachers use research evidence-informed practice generally, and in relation to the new content demands of the U.S. *Next Generation Science Standards*, in particular.

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Introduction

Science teachers are being called on to incorporate engineering into their classrooms. There are several motivations for an improved and integrated science, technology, engineering, and mathematics (STEM) education system. Integrated instructional approaches are considered more effective and thus a strategy offered to combat declining test scores (Brophy, Klein, Portsmore, & Rogers, 2008; Case, 2006; Katehi, Pearson, & Feder, 2009). Engineering is also expected to increase the number of students interested in pursuing STEM careers (Brophy et al., 2008; Clark & Andrews, 2010; de Vries, Gumaelius, & Skogh, 2016; Little & León de la Barra, 2009). With these motivations in mind, science teachers in the U.S. are being asked to focus on engineering practices, crosscutting concepts with science, and core engineering ideas with the adoption of the *Next Generation Science Standards* (NGSS) (Achieve, 2013).

Although engineering is not a new content area, science teachers may be unfamiliar with the engineering concepts they are now tasked with teaching (Cox, Reynolds, Schuchardt, & Schunn, 2016). The 'Engineering-Infused Lesson (EIL) Rubric' was developed to outline the defining characteristics of high-quality engineering lessons by reflecting

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the significant and unique role of engineering design in science instruction, drawing from documented best practices.

The EIL Rubric provides the opportunity for 'research evidence-informed practice', in which teachers use research evidence to make choices about their curriculum materials and teaching practices (Miller, Leach, Osborne, & Ratcliffe, 2008). One intended use of the EIL Rubric was as a framework for science teachers to use to plan for infusing engineering content and activities into their instruction. This is a similar approach to that of Engle and Conant (2002), who recommended formulating a set of guiding design principles to inform teachers' moment-by-moment decision-making.

The current study explored the utility of the EIL Rubric in relation to online materials. Online lessons are readily available, and thus a logical first step for teachers who are interested in integrating engineering into their instruction. Online materials often take the form of individual lessons, rather than entire units of instruction. Like other curriculum materials, online lessons offer teachers a starting place from which to make modifications in order to meet their instructional needs (Beyer & Davis, 2012). The purpose of this study was to investigate the utility of the rubric to document whether and how best practices from engineering education were infused into lessons for high school students. The following research questions guided the study:

RQ1: What are the strengths in how online biology and physics lessons infuse best practices from engineering education, according to the EIL Rubric? What are the missed opportunities?

RQ2. Which EIL Rubric components are most commonly associated with engineering-infused lessons?

Literature review

Engineering has had a presence in technology education's *Standards for Technological Literacy: Content for the Study of Technology* in the U.S. since 2000. The Committee on Standards for K-12 Engineering Education (2010) concluded that the best approach was the infusion of engineering into science, mathematics, and technology, as opposed to stand-alone engineering standards and courses. In 2012, Carr, Bennett, and Strobel conducted an extensive review of engineering-related state standards, finding that 41 U.S. states included an engineering presence within their academic and/or vocational standards. More recently with the release of the NGSS, engineering concepts and practices are included within science. With the inclusion of engineering in these standards, the educational community is wrestling with how to best integrate it.

The National Academy of Engineering and National Research Council convened a committee in 2014 to develop a research agenda for determining the conditions most likely to lead to positive outcomes of integrated STEM education. The committee concluded that 'there is growing recognition of the importance of the engineering design process and of concepts such as constraints, criteria, optimization, and trade-offs' (Honey, Pearson, & Schweingruber, 2014, p. 19). With regard to science learning specifically, research has confirmed the effectiveness of focusing on engineering design to learn science or design-based science (Crismond, 2001; Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004, 2005; Mehalik, Doppelt, & Schunn, 2008; Sadler, Coyle, &

Schwartz, 2000; Schnittka & Bell, 2011). However, research has also indicated that the impact on students depends on the instructional and learning strategies provided (Honey et al., 2014; Nadelson, Pfiester, Callahan, & Pyke, 2015).

An essential component of effective integration of engineering into science is the design of quality instructional materials that make explicit links to science learning outcomes. Students 'do not spontaneously integrate what they learn across representations and materials or across multi-day lessons, so integration cannot simply be assumed to take place simply because of temporal or spatial juxtaposition' (Honey et al., 2014, p. 90). The intended learning outcomes need to be explicit, interconnected, and scaffolded across the curriculum. A recent review indicated that this may be a challenge, given that explicit connections to science (and mathematics) concepts were largely absent in primary- and secondary-level engineering curricula (Welty, Katehi, Pearson, & Feder, 2008).

Research indicates that 'effective teachers hold an analytical stance toward curriculum materials, critiquing and adapting them to achieve productive instructional ends' (Beyer & Davis, 2012, p. 131). Curriculum is considered 'inert' with teacher interactions determining the implementation of materials (Powell & Anderson, 2002). Curriculum adaptation is dependent on teachers' subject matter knowledge, pedagogical content knowledge, and knowledge of teaching and learning. As Beyer and Davis (2012) argue, teachers 'who do not know how to analyze curriculum materials in productive ways may fail to recognise the strengths and weaknesses in materials' (p. 131). Given their lack of exposure to engineering, many science teachers may not be equipped to modify engineering-based curricula if needed. The EIL Rubric is a tool that can potentially help teachers bridge that gap by providing them with a list of research evidence-informed practices that can be used to assess the strengths and missed opportunities in existing lessons. The missed opportunities, in particular, provide key characteristics that teachers might enhance as they prepare the lesson for use with students.

Method

This study identified and coded a representative sample of the engineering-infused biology and physics lessons for secondary students available online in spring 2016.

Sample

A number of lesson repositories are available online and were used to create a sample of lessons for the study. Lesson repositories were nominated for consideration by the project team and web searches were completed to identify a comprehensive set of 12 sites that included filters for content related to engineering and at least one of the following: biology, life science, physics, and physical science.

A search of these sites resulted in a shorter list of five repositories that allowed a teacher to search for engineering lessons by scientific discipline. These repositories were considered the most user-friendly and thus the most likely for teachers to use: eGFI, How to Smile, NNIN, Teach Engineering, and Try Engineering.

Two additional criteria were used to help narrow the list of lessons further. The first concerned student age. Many lessons listed a target age range that included, but was not limited to, secondary-level students. To restrict the field to the lessons that were most likely to be a direct fit for these students, only those with differentiated, secondary school-specific procedures in the lesson plan were considered eligible. This criterion was applied to a random sample of approximately 20% of the lessons from each of the five repositories. Two repositories, How to Smile and Try Engineering, were eliminated from the study because their materials did not meet this criterion.

The second criterion was alignment to the NGSS. A small number of additional lessons from the three remaining repositories were eliminated from the sample based on this criterion. In the end, a total of 175 lessons remained (58 biology and 117 physics). Teach Engineering was the repository with the greatest number of lessons by far, with a total of 167 lessons from site. Five were from eGFI and the final three were from National Nanotechnology Infrastructure Network (NNIN). A random number generator was then used to select 40 lessons from each discipline to code, for a total of 80 lessons.

Instrument

The EIL Rubric was developed as a framework to help teachers infuse engineering content and activities into their lessons. The rubric is divided into three sections: (a) curriculum materials; (b) design-centred teacher practices; and (c) engagement with engineering concepts. The protocol assumes that science concepts are included in the lesson, and thus focuses on the characteristics of engineering infusion alone. The codes in the rubric build on this assumption by identifying how science and engineering concepts are framed, and the addition of engineering-based pedagogical practices. Throughout, best practices were those that helped students make explicit rather than implied connections between science and engineering (Honey et al., 2014). The full coding scheme is presented in Table 1; specific codes are referenced parenthetically in the description below.

Curriculum materials

The first section of the protocol is dependent on the need for materials to include engineering concepts. Lessons in the sample were selected to meet this prerequisite. Codes were then used to identify those that were standards-based or aligned, in that they derived their learning objectives from the identified standards (International Technology Education Association, 2005; Wiggins & McTighe, 2005). The presence of NGSS science and engineering standards were coded separately.

Lessons were also coded for the presence of an engineering design challenge that required understanding of scientific concepts. Two sets of codes were used. The first identified whether the design challenge was open- or closed-ended (A2, Part 1). Open-ended solutions are considered defining characteristics of engineering problems (Cunningham & Carlsen, 2014). Lessons with a design challenge were coded further to document whether science content was noted explicitly as part of the design challenge (A2, Part 2) (Brophy et al., 2008; Hmelo, Holton, & Kolodner, 2000; Mehalik et al., 2008). Next, the materials were coded to document explicit connections between engineering concepts and science learning that were scaffolded across the curriculum (Crismond, 2001; Householder & Hailey, 2012). See A3 for the range of codes used. A final set of content-based codes focused on whether lesson materials included a student assessment explicitly targeting understanding of both science and engineering

Table 1. The Engineering-Infused Lesson Rubric.

A1. This lesson is: (check all that apply)

❒ Standards-based with NGSS high school science standards. Standards-based lessons describe the content of the lesson explicitly in relation to at least one NGSS performance expectation.

❒ Standards-aligned with NGSS high school science standards. Standards-aligned lessons were those that listed relevant standards but did not provide an explanation for how the content of the lesson connected to the content of the standard.

❒ Standards-based with NGSS high school engineering standards. Standards-based defined above.

❒ Standards-aligned with NGSS high school engineering standards. Standards-aligned defined above.

❒ References other high school science or engineering standards.

A2, Part 1: Describe the design challenge included in this lesson:

❒ Included, and has at least one open-ended component (continue to A2, part 2)

❒ Included, but has closed-ended components only (skip to A3)

❒ Included in extension/associated/assessment activities only (skip to A3)

❒ Not included, but has science lab/experiment (skip to A3)

❒ Not included (skip to A3)

A2, Part 2: Science concepts featured in the open-ended design challenge:

❒ Stated in the procedure for the open-ended portion of the design challenge

❒ Stated in the lesson objectives/summary only

❒ Science content not required to solve the design challenge

A3: Explicit connections between science and engineering content should be present in the procedures of the lesson and/or in the student materials. Connections must be present in the materials themselves, and not only on the introductory/summary page of a lesson:

❒ Explicit connections between engineering and science content

❒ Include engineering content, but connection to science learning is not explicit

❒ Include engineering content, but presented in total isolation from science content

❒ Does not include engineering content, but descries the kinds of work that engineers do to solve scientific problems

❒ No engineering content

A4, Part 1: Assessment:

❒ Focuses on both science and engineering outcomes (continue to A4, part 2)

❒ Focuses on science content outcomes (continue to A4, part 2)

❒ Focuses on engineering content outcomes (continue to A4, part 2)

❒ No assessments included (skip to next section)

A4, Part 2: Authentic Assessment: (check all that apply)

❒ Are an extension of the scientific, team, or design process included in the curriculum materials

❒ Are not included; traditional assessments only

A4, Part 3: Outcomes are standards-based: (check all that apply)

❒ Labeled explicitly in relation to the NGSS science standards featured in the lesson

❒ Labeled explicitly in relation to the NGSS engineering standards featured in the lesson

❒ Not labeled explicitly in relation to NGSS standards

B. Design-Centered (code only if Design Challenge was 'included' according to A2)

B1, Part 1: Students work in teams of two or more during at least one component of the lesson.

❒ Yes (if not checked, skip to B2)

B1, Part 2: The team work included in the curriculum materials featured: (check all that apply)

❒ A hands-on activity during which teams manipulate materials.

❒ A pencil-paper activity in which teams work together to complete a worksheet or create a product such as a brochures or PPT.

❒ A discussion in which the team's primary activity is a group conversation (such as a brainstorming or debrief session). Presentations to the entire class do not count as discussion.

❒ Checks and balances are explicit in the lesson plan and describe a team structure that ensures that all students participate. Examples include assigning individual students to play specific roles during the design challenge, including a peer rating system in students' report-out and/or grade, and/or requiring each student to report out on results.

B2: Unique solution

❒ A unique solution is probable. The lessons plan explicitly states that a unique solution is either desirable or required.

❒ A unique solution is possible. The lesson plan may or may not include general language about unique designs. The constraints of the design challenge do not promote or support unique design.

❒ A unique design is not possible in that the design challenge in structures such that all end up with one solution OR one of a few possible solutions.

B3: Lesson includes specific coaching strategies for teachers to use to guide students through the activity.
Coaching strategies could provide hints to teachers about either content-based challenges that students often face and/or pedagogical suggestions for directing learning. Procedural instructions that are part of the step-by-step lessons for teachers are not counted as coaching.

❒ Yes ρ No

B4, Part 1. The design challenge includes at least one form of iteration, either through a conceptual redesign, rebuilding, and/or testing that is informed by data and/or knowledge. Iterations created as part of an initial brainstorming session are not coded here. Doing multiple tests alone does not count as iterations. Iteration requires a plan that will guide the redesign, rebuild, and/or test.
❒ Iteration is included in the primary lesson plan.
❒ Iteration in included as an extension activity, but not part of the primary lesson plan.
❒ Iteration is not included. (skip to B5)

B4, Part 2. Type of iteration included in the design challenge:
❒ Students rebuild their product and do a second test. The redesign of their product includes a justification for changes in design decision.
❒ Students rebuild their product but do not do additional testing. The redesign of their product includes a justification for changes in design decision.
❒ Students do a conceptual redesign of their product only. The redesign includes a justification for changes in design decision.

B5. Students express rationale behind design decisions through activities that require them to reflect on or articulate explicitly the scientific basis for design decisions.
❒ Lesson includes specific questions about the scientific rationale for design decisions
❒ Lesson includes generic 'why' questions as part of student activity that may or may not be answered by providing the scientific basis for design decisions
❒ Lesson includes specific questions asking students to explain design decisions, but not in reference to science specifically.
❒ None of these is true.

C. Engagement with Engineering Concepts

C1. Engineering terminology includes the use of terms such as constraints, requirements, parameters, and prototype. Note that this list is not exhaustive, but just includes commonly-used terms. Eligible terms must be in the material delivered to students, and not only in the summary materials that are provided for the teacher at the beginning of a lesson. Analysis, models, and systems can also be considered terminology if they are used in an engineering rather than science context. Note that the terms 'design' or 'engineering design process' on their own are insufficient to be considered terminology. Choose the top-level code that applies.

Engineering terminology is:
❒ Taught to students as part of the lesson.
❒ Included in the lesson content, but not the focus of instruction.
❒ Not included.

C2, Part 1. Lesson uses real-world examples to frame learning.
❒ Yes ρ No (skip to end)

C2, Part 2. The real-world example:
❒ Is an authentic problem/phenomenon of interest to scientists and/or engineers
❒ Is a contrived problem/phenomenon created for the purpose of the lesson only

C2, Part 3. The real world example provides the rationale for science learning
❒ Yes ρ No

C3, Part 4. The real-world example is introduced to students
❒ At the beginning of the lesson to set the stage for learning
❒ At the end of the lesson as part of the wrap up

concepts in an authentic context (A4, Part 1), the presence of both authentic and traditional assessments (A4, Part 2), and assessments that targeted outcomes related to the NGSS science and/or engineering standards (A4, Part 3). Assessments were coded only if they were labelled as such in the materials.

Design-centred teaching practices

The second section of the protocol identified pedagogical practices for implementing design challenges with students (Crismond, 2001; Fortus et al., 2004, 2005; Householder & Hailey, 2012; Mehalik et al., 2008; Sadler et al., 2000). The codes in this section were only assigned to lessons that included a design challenge according to A2.

A number of codes were used to document whether and how students worked as teams during the design challenge. Working in groups enables students 'to learn not only from their own designs, but also to work in groups and to learn from the efforts of others'

(Cunningham & Carlsen, 2014, p. 206). Code B1, Part 1 identifies lessons that included teamwork. Specific types of teamwork were then coded in B1, Part 2.

Ideal design challenges include at least one form of iteration that is data-driven and based upon mathematical and/or scientific analyses (Crismond & Adams, 2012; Householder & Hailey, 2012). They require students to express the rationale behind their decisions throughout the design process as they work to solve design problems are ill-structured, complex, and have the potential for multiple viable solutions (Brophy et al., 2008). Lessons were coded to indicate whether iteration was included in the lesson's design (B4 Part 1), the type of iteration included (B4, Part 2), whether students were required to provide a rationale for their decisions (B5), and the type of solution expected (B2).

A final best practice for design challenges is to include specific coaching strategies for teachers to use to guide students through the activity (see B3) (Cunningham & Carlsen, 2014; Householder & Hailey, 2012).

Engaging with engineering concepts

The third section of the EIL Rubric focuses on the use of engineering terminology and connections to real-world engineering applications. The use of terminology is a best practice that makes engineering concepts explicit to students during the implementation of the lesson (Custer, Daugherty, & Meyer, 2010; Rossouw, Hacker, & de Vries, 2011). See C1 for examples of terminology and the codes used.

The EIL Rubric made the distinction between real-world examples or scenarios that were authentic or contrived (C2, Part 1 and Part 2; Sadler et al., 2000), those that provided the rationale for science learning (C2, Part 2), and when in the lesson the example was presented to students (C2, Part 3).

Coding

The EIL Rubric was used to code all student background materials, activities, and assessments for each lesson in the sample. Teacher background materials and extension activities were considered supplementary and were noted in the coding, but not eligible to receive the highest level of a code given that teachers might or might not use the materials with their students.

NVivo 11 was used to code and analyse the lessons. Comprehensive PDF versions of each lesson were created by combining all relevant files into one PDF document (e.g. lesson plans, PowerPoint presentations, student worksheets, etc.). Codes were assigned to document the highest level code found for each EIL Rubric characteristic. The first instance of each characteristic was coded; additional instances and evidence of lesser codes were not recorded.

Inter-rater reliability was established by a team of three researchers who each coded 20% of the sample lessons ($n = 16$). The first eight biology and eight physics lessons from the random number list were used. Krippendorff's alpha (K alpha) was used as the reliability statistic. K alpha is ideal for this study because it can be used with teams of more than two researches and for codes that are dichotomous (Hayes & Krippendorff, 2007). K alpha for the rubric was .74, indicating an acceptable level of reliability across the three coders. The remaining 64 lessons were coded by two researchers; each coded approximately half of the remaining biology and physics lessons.

Four summary scores were created to describe each lesson. A Curriculum Materials score was created using eight best practices from Section A of the rubric: NGSS science-based, NGSS engineering-based, open-ended design challenge, explicit connections between science and engineering content, assessment of both science and engineering content, authentic assessments, assessments with explicit links to NGSS science, and assessments with explicit links to NGSS engineering. One point was given for the presence of each best practice. Strengths were then defined as best practices that were found for at least half of the sample. Best practices used by less than half of the sample were considered missed opportunities. The same procedure was used to create scores for the design-centred and engaging concepts components of the EIL Rubric. Design-centred scores were created by assigning one point for the presence of four team activities: hands-on, pencil-paper, discussion, and checks and balances. The remaining design-centred points were awarded for unique solutions probable, iteration that included a redesign and second test, providing the scientific rationale for decisions, and the inclusion of coaching tips for the teacher. The total possible score for design-centred was eight.

A total of three points were possible for engaging concepts scores, based on the presence of teaching engineering terminology, the use of authentic real-world examples, and introducing those concepts at the beginning of the lesson. The fourth score was the total score, calculated by summing the scores from each component of the protocol.

Results

Lessons were identified by student age, scientific discipline, and length. Half of the lessons in the sample were targeted towards 17-year-old students. Most lessons could be completed in two traditional class periods or one 90-min block period. This pattern of results was similar for biology and physics lessons (see Table 2).

RQ1: What are the strengths in how online biology and physics lessons infuse engineering best practices, according to the EIL Rubric? What are the missed opportunities?

Analyses were conducted at two levels to answer this question. First, descriptive analyses were used to document the average score for each section of the EIL Rubric. The total score possible for each component, and the mean and range of scores, are presented in Table 3. Though average scores were low for two of the three components, the wide range of scores across all components indicates that the EIL Rubric was successful at documenting variability in the level of engineering infusion found in online lessons.

Table 2. Lesson sample.

	All ($n = 80$)	Biology ($n = 40$)	Physics ($n = 37$)	Both ($n = 3$)
Student age				
15-year-olds	19%	20%	19%	–
16-year-olds	15%	13%	19%	–
17-year-olds	55%	55%	57%	33%
18-year-olds	8%	5%	5%	67%
15–18-year-olds, general	3%	7%	–	–
Lesson length				
<90 min	66%	64%	67%	67%
91+ min	34%	36%	33%	33%

Table 3. Mean and range scores for EIL Rubric components.

	Total score possible	Mean	Range
Curriculum materials ($N = 80$)	8	2.31	0–5
Design-centred ($N = 21$)	8	3.95	2–7
Engaging concepts ($N = 80$)	3	2.05	0–3

Next, scores were compared across discipline. It has been speculated that life science teachers might have a particularly difficult time finding meaningful ways to integrate engineering into their classrooms as they adopt the NGSS (Bybee, 2012). A series of independent-samples *t*-test were conducted to determine if the quality of lessons available to life science teachers was lower than those available to physical science teachers. No differences were found in the scores of biology and physics lessons across any of the three categories (curriculum materials, $t(75) = -1.32$, $p = .19$; design-centred, $t(18) = 0.52$, $p = .61$; engage concepts, $t(75) = 1.61$, $p = .11$), indicating parity in the quality of life science and physical science lessons in the sample. Given that life and physical science lessons appear to be of similar overall quality, the remaining findings are presented in aggregate rather than by discipline.

The remaining results in this section are presented in tables that summarise the results for each section of the EIL Rubric. The ideal practice listed first and in bold, followed by alternate practices that were also coded.

Curriculum materials

Scores for the 'Curriculum materials' section ranged from 0 to 5, with an average of 2.31 best practices included across lessons. The eight best practices related to curriculum materials are presented in Table 4. The results showed that best practices were found in the minority of lessons in the sample, indicating a range of missed opportunities.

Standards

Lessons were coded for evidence of being NGSS-based or NGSS-aligned to both science and engineering standards. Just under half of the lessons (43%) were NGSS science-based. With regard to Life Science, the disciplinary core ideas From Molecules to Organisms (LS-1) and Ecosystems (LS-2) were featured most often (in 10 out of 11 cases). This commonality seems to reflect both a strength of online lesson content in relation to these two standards, and missed opportunities with regard to other high school standards in the life sciences. With the Physical Sciences, all four disciplinary core ideas were included, indicating strengths in the full range of content featured in these NGSS-based lessons. Most were based on Motion and Stability (PS-2) and Energy (PS-3); 10 out of 11 lessons were based on standards from these content areas, respectively. Five lessons were based on Earth Science standards: all focused on the disciplinary core idea Earth and Human Activity (ESS-3).

An additional 24% of lessons were considered NGSS science-aligned. For Life Science, the pattern of disciplinary core ideas was similar to those for lessons that were standards-based; all instances of alignment were related to LS-1 or LS-2. The distribution of alignment to the Physical Science standards was relatively even, with three or four instances of alignment to each core idea. One lesson was aligned to ESS-3.

Table 4. Best practices in curriculum materials across the sample.

	All ($n = 80$)
NGSS science-based	**43%**
NGSS science-aligned	24%
No reference to NGSS science	23%
NGSS engineering-based	–
NGSS engineering-aligned	43%
No reference to NGSS engineering	57%
Open-ended design challenge in lesson	**23%**
Closed-ended design challenge in lesson	4%
Design challenge in extension activities only	15%
No design challenge, but lab or experiment	40%
No design challenge, lab, or experiment	18%
Explicit connections science and engineering content assessments	**55%**
Science content and engineering careers	21%
Engineering included, but no connection to science content only	10%
No engineering content	13%
Science and engineering assessments	**45%**
Science assessments only	51%
Engineering assessments only	3%
No assessment included	1%
Assessments linked to NGSS science	**21%**
Not linked to NGSS science	79%
Assessments linked to NGSS engineering	–
Not linked to NGSS engineering	100%
Authentic assessments	**39%**
Traditional assessments only	60%
No assessments included	1%

None of the lessons in the sample were considered NGSS engineering-based (i.e. they were not described explicitly in relation to a NGSS standard). A subset of lessons were coded as aligned to NGSS engineering, such that the lesson provided a general list of relevant engineering standards; 43% of lessons were coded as NGSS engineering-aligned. Ten lessons in this group were also considered either NGSS science-based or science-aligned. The remaining 22 lessons focused on Engineering Design (ETS-1) alone. Both the lack of standards-based lessons and the fact that standards-aligned lessons did not integrate both science and engineering standards were missed opportunities.

Open-ended design challenge

Lessons were coded for the inclusion of an open-ended design challenge comprised of at least one component that allowed students to make their own design decisions. Approximately one-quarter (23%) included this best practice, indicating that this is an area of missed opportunity. The examples found challenged students to design a range of products, such as heart valves, sunscreen, eco-friendly villages, rocket launchers, and water treatment devices. Another 15% of lessons included a design challenge as an optional extension activity. These included a one or two sentence description of how to add a design challenge and no procedural description for students. It was most common for lessons to include a science lab or science experiment, rather than a design challenge (40% of the lessons coded).

Explicit focus on science and engineering concepts

Approximately half of sample (55%) provided explicit connections between science and engineering concepts to help students understand how the disciplines relate to and support one another. This category was greatest strength among the range of codes used to characterise curricular materials. The interplay between scientific concepts and design decisions was a key feature of lessons using these connections in the introductory text to provide context for learning. Questions such as, *How do engineers exploit periodic motion?* (https://www.teachengineering.org/lessons/view/uno_swing_lesson01) and *Why do biomedical engineers care so much about the materials they use in their designs for replacement body parts?* (https://www.teachengineering.org/lessons/view/van_floppy_lesson02) were used to help students make their own explicit connections between science and engineering. Students were challenged to make explicit connections during activities as well, via prompts such as, *Have students complete the research component of the project, which includes researching both the physics of aerodynamics as well as the components of gliders that take advantage of that science* (https://www.teachengineering..org/activities/view/uconn_gliders_activity1).

An additional 21% of lessons discussed engineering careers or the kinds of work that engineers do to apply science concepts. These lessons named 'engineers' or 'engineering' generally, and in relation to a science concept (e.g. harmonic movement, the Bernoulli equation, biomimicry, energy, etc.). Chemical and biomedical engineering careers were each mentioned in several lessons, while careers related to aerospace, automotive, environmental, mechanical, and nautical engineering were included in one lesson each.

Assessment

Several categories related to the types of assessment included in the lessons. Almost all lessons in the sample (99%) included at least one assessment. Even so, a minority included best practices from engineering education in the design of the assessment, indicating a range of missed opportunities. Just under half (45%) included assessments of both science and engineering concepts. These included those with an individual assessment consisting of content from both disciplines, as well as lessons that included multiple discipline-specific assessments. It was rare for assessments to be linked directly to the NGSS standards addressed; 21% referenced an NGSS science standard and none referenced an NGSS engineering standard.

Almost all lessons (95%) included traditional assessments such as quizzes and worksheets, including 60% that included only traditional assessment options. Authentic assessments that used elements or products from the scientific and/or design process were included in 39% of the lessons. The examples coded took advantage of steps in the engineering design process to create authentic assessments of student progress. Brainstorming notes, proposal plans, design sketches, milestones, and final product and analysis presentations were all used as authentic assessment measures.

Design-centred teacher practices

A total of 21 lessons (out of 80) included a design challenge and thus qualified for the codes related to design-centred teacher practices. Design-centred scores ranged from 2 to 7 out of the 8 best practices coded, with an average score of 3.95 across lessons. The results for specific teacher practices are presented in Table 5. The findings indicate that teamwork was a strength of the design challenges included in the sample. The remaining

Table 5. Best practices in design-based teacher practices across the sample.

	Lessons with a design challenge ($n = 21$)
Teamwork included	**100%**
Pencil-paper	95%
Hands-on	81%
Discussion	67%
Checks and balances	24%
Iteration includes rebuild and second test	**24%**
Iteration includes a rebuild only	10%
Iteration is conceptual	19%
No iteration included	47%
Scientific rationale for design decisions required	**24%**
General why questions for design decisions	28%
Decisions explained, but not with relation to science	10%
No rationale required for design decisions	38%
Unique solution probable	**10%**
Unique solution possible	81%
No unique solution possible	9%
Coaching strategies for teachers	**52%**
No coaching strategies included	48%

teacher practices were present in a small portion of the lessons, and thus missed opportunities.

Teamwork

Four types of teamwork were coded for design challenges. All lessons with a design challenge (100%) included at least one form of teamwork, with 2.9 types of teamwork included on average. Both of these findings confirm that teamwork is a strength of existing online lessons. Pencil-paper activities were those found most often (95%), and typically consisted of worksheets for the team to complete. Many design challenges (81%) also included hands-on activities. Most (67%) also included team discussions, consisting of activities such as brainstorming design ideas at the beginning of a design challenge and/or team debrief discussions of the results of product testing. Approximately one-quarter (24%) included checks and balances to ensure that all students participated in the activity. These included assigning each team member to a specific role for the project, requiring all students to present results to the class, peer review of team member's performance, and coaching strategies for teachers to use when monitoring student teams.

Iteration

Approximately half of the design challenges included iteration as a primary component of the design challenge. Of these, 24% included components that required students to both re-design and re-test their product. It was less common (10%) for lessons to include a second build of the product without a re-testing requirement. Approximately one in five (19%) included a conceptual re-design only. Conceptual re-designs were created by answering questions about what the students would do differently or what they would do next, and by drawing the next iteration of their product.

Rationale for design decisions

A minority of design challenges required students to share the rationale for their design decisions. Approximately one-quarter (24%) were required to use scientific concepts to explain their design decisions. These included specific questions such as *Why is IR light better than visible light for your design?* (https://www.teachengineering.org/lessons/view/mis_sensor_lesson01*)*, and general prompts that asked about the science concepts related to design choices.

A similar portion (28%) required students to answer general questions about why they made design decisions, such as *Why did you choose that design?* An additional 10% included specific questions that did not focus students' attention on the science in their decision-making. These instances focused on the trade-offs of design decisions or whether new designs worked.

Unique solutions

Though most of the design challenges in the sample included open-ended components, few (10%) included requirements or constraints that made unique design solutions probable indicating that this was a missed opportunity in most instances. These included instructions for teachers such as, *The idea for the valve project is to provide an assortment of materials, but not direct groups towards any single solution* and an activity that gave each design team a different materials list. Most design challenges in the sample (81%) could have resulted in unique solutions, but did not provide instruction or requirements to encourage unique solutions. Few design challenges (9%) were organised such that students would have the same or one of a few common designs.

Coaching strategies for teachers

The high demands of design challenges on students necessitates coaching on the part of teachers. Approximately half of the design challenges (52%) included tips and strategies to help students navigate the demands of completing a design challenge. As such, coaching tips were a strength of the lessons coded. The most comprehensive example of coaching read as follows:

> Students may struggle with this activity because it is different from the more commonly experienced science labs in which students follow a set protocol to generate a series of data that is likely expected by the teacher (if not also students). Even in open-ended labs, students are rarely asked to evaluate the data from their first tries and redesign their protocols to get better results. In this activity, the instructor asks students to use their own research to identify materials to use in their models, test them, make decisions based on their results, design and construct prototype models, and test them. Once they test their models, they will likely need to redesign them and test further to ensure they are the best possible solutions to meet the challenge. Encourage students, without giving them answers, since part of the strength of activities that employ the engineering design process lies in the fact that students are thinking critically to design, evaluate and redesign their solutions. (https://www.teachengineering.org/activities/view/van_floppy_lesson02_activity1)

Engagement with engineering concepts

Three best practices were coded in relation to engaging concepts; lesson scores for this component ranged from 0 to 3 with an average of 2.05 components included in lessons across the sample. The results related to specific practices are presented in Table 6, and demonstrates that the use of authentic and real-world examples was a clear strength of lessons in the sample.

Table 6. Best practices in engaging with engineering concepts across the sample.

	All ($N = 80$)
Teaching engineering terminology	**21%**
Including engineering technology, not taught	49%
No engineering terminology	30%
Authentic real-world example as context for learning	**93%**
Contrived real-world example as context for learning	2%
No real world example as context for learning	5%
Real-world example introduces the lesson	**91%**
Real world example concludes the lesson	5%
No real world example included	4%

Use of engineering terminology

The majority of lessons included the use of engineering terminology (70%). These terms were the focus of instruction for 21% of lessons. In some instances, the lesson taught students the engineering design process. In other cases, engineering terms were included as part of the lesson's vocabulary list (e.g. model, prototype, constraint). Engineering terminology was mentioned, but not taught, in 49% of the lessons coded. Looking across lessons, terms were found in both the background materials and student instructions. Depending on the learning that preceded these lessons, students may or may not have an understanding of these terms. Given this ambiguity it is difficult to determine whether the use of engineering terminology is a strength or missed opportunity in the lessons coded.

Real-world examples

Four codes were used to characterise the kinds of real-world examples in the sample, and each indicated that the use of real-world examples is a strength of online lessons. Real-world examples were used to contextualise learning in most cases (95%), and almost all examples were authentic engineering challenges (93%), such as how airplanes fly, repairing broken bones, nanotechnology applications, the Tacoma Narrows Bridge collapse, and a TED talk by Janine Beynus about recent discoveries in biomimicry. The two contrived examples included scenarios that were also likely to be engaging for students: a zombie apocalypse and a scenario in which students were asked to imagine that their school had been contaminated. In most cases, the real-world example was presented at the beginning of the lesson (91%), though a few presented real-world connections as part of the lesson wrap-up only.

RQ2. Which EIL Rubric components are most commonly associated with engineering-infused lessons?

Overall scores on the EIL Rubric were used to identify and isolate the lessons that received the highest scores, and to explore those lessons further to determine if any particular characteristics set them apart. Total scores ranged from 1 to 13 out of 19 possible points, with an average score of 5.4. Lessons with total scores of at least one standard deviation above the mean were grouped into a High Score group. Fifteen lessons were isolated into the High Score group using this method.

Chi-square analyses were calculated to determine whether the high score lessons differed significantly in their inclusion of each best practice, when compared to the rest of the sample. High score lessons were elevated in their use of five best practices at a statistically significant level. These included four best practices related to curriculum materials, and one best practice for engaging engineering concepts. The percentage of lessons that included these characteristics is presented in Table 7, along with the chi-square statistic and significance level.

The sample size for lessons with design challenges was too small to calculate reliable chi-square statistics. Of the 21 lessons that included a design challenge, 15 were in the high score group and 6 were not. Descriptive statistics were used to denote best practices that seemed to differentiate high score lessons. Percentage differences at or above 20% are presented in Table 8. In each instance, high score lessons were more likely to include the best practice compared with the remaining lessons that included a design challenge.

Discussion

This study focused on 80 lessons, randomly selected from three online repositories, and coded with the EIL Rubric to identify the extent to which they were infused with best practices from engineering education. Scores were created to document the average level of alignment to best practices as a way to document the starting point that lessons provide to teachers who are interested in infusing engineering into their science teaching. Rubric scores indicated that most existing lessons included few best practices from engineering education in the design of curriculum materials. These missed opportunities in lesson design offer ideal points for modification as teachers enhance materials for use with their students in the classroom. Moderate scores were found for engineering infusion related to design-centred teacher practices and engaging with engineering concepts, indicating that these were relative strengths of online engineering lessons. The range of scores captured across each of the categories indicates that the EIL Rubric was effective at identifying variability in the level of engineering infusion included in online lessons.

The EIL Rubric was also successful at documenting both specific strengths and areas for improvement. The strengths of the coded lessons included their focus on NGSS science, and the use of authentic real-world problems to frame learning for students. When design challenges were included, the level of teamwork in those challenges was high,

Table 7. Differential use of best practices by high score lessons.

	% High score lessons ($n = 15$)	% Remaining lessons ($n = 65$)	Pearson χ^2	p-Value
NGSS engineering-aligned	74%	28%	7.18	<.01
Open-ended design challenge included	86%	8%	43.59	<.001
Science and engineering assessments	73%	39%	5.99	<.05
Authentic assessments	80%	29%	13.24	<.001
Teaching engineering terminology	67%	11%	22.76	<.001

Table 8. Differential use of design challenge pedagogy by high scores lessons.

	% High score lessons ($n = 15$)	% Remaining lessons ($n = 6$)
Hands-on teamwork	87%	67%
Discussion teamwork	73%	50%
Iteration included in primary lesson plan	67%	33%
Scientific rationale for design decisions required	33%	–

consisting of the full range of best practices. This corresponds with much of the literature on engineering education at the primary, secondary, and post-secondary levels that emphasises the importance of collaborative, group-based activities (Cunningham & Carlsen, 2014; Smith, Sheppard, Johnson, & Johnson, 2005).

Missed opportunities centred on a need for content and teaching practices to make explicit connections between science and engineering. This trend was found across the three components of the protocol. For example, only half of the lessons made explicit connections between science and engineering concepts featured in the lesson. Similarly, it was rare for design challenges to include requirements for students to state the scientific rationale for their decision decisions, and engineering terminology was rarely taught to students. These outcomes reiterate those from Welty et al. (2008), and suggest that work remains to be done to help teachers and students understand the areas of overlap between science and engineering.

Highlighting engineering careers has also been cited as an important aspect of primary and secondary education, improving the 'pipeline' of future engineering talent (Reynolds, Mehalik, Lovell, & Schunn, 2009). The complex interaction between scientists and engineers reflects how they collaborate in the real world (Gott & Duggan, 1996). Indeed, some lessons in the sample provided explicit connections for students by noting the scientific principles that are commonly used by particular engineering disciplines. Using careers to demonstrate the interplay between science and engineering was a strength of these lessons, and seems a viable strategy.

Given the number of missed opportunities identified, significant work remains to develop comprehensive engineering-based materials for use in science classrooms. This is not surprising, given that engineering concepts and practices are new to the science standards. The implementation of standards requires significant effort and includes curriculum development, programme reform, and teacher professional development that often takes as much as a decade to accomplish (Loucks-Horsley & Bybee, 1998). Teachers who are interested in infusing engineering into their science teaching will need to enhance existing lessons in several ways before implementing them with students. Lessons with the highest EIL Rubric scores had common strengths. They were aligned to the NGSS engineering standards, and included an open-ended design challenge, instruction on engineering terminology, authentic assessments, and/or assessments focused on both science and engineering. These individual characteristics might serve to help teachers, researchers, and curriculum developers identify science lessons that also offer the highest levels of infusion overall. For teachers, these lessons would require fewer modifications before being implemented with students

Bybee (2012) speculated that life science teachers might have a difficult time finding meaningful ways to integrate engineering into their classrooms. Indeed, there were more than twice as many physics as biology lessons eligible for this study. The results from the EIL Rubric, however, indicated similar overall scores for the biology and physics lessons coded. Thus, while the prevalence of physics lessons online is greater than that for biology, the level of engineering infusion is similar. It is also possible that the method used to select the lessons for this study inflated the extent to which engineering appears to be infused in science lessons from both disciplines. Alignment with the NGSS was used as a criterion for the study sample because we believe teachers will use this search criterion most often to find materials that include both science and engineering. The results from this study must be interpreted with the sampling criteria in mind; they reflect the level of engineering infusion for a specific subset of lessons and not for science lessons overall. Though the results cannot be generalised to all science lessons, the findings do demonstrate the potential for applying engineering across a range of science disciplines (biology, earth science, and physics).

It is important to note that the data set for this study consisted of individual lessons rather than units or curricular materials. As educators consider the ways to leverage engineering design within the context of science classrooms, it will be important to incorporate engineering practices and concepts in a comprehensive way through fully developed curriculum materials that allow students to experience the engineering design process it its entirety. This requires a thoughtful approach to ensure that science learning supports (and is not sacrificed to) engineering activities. The EIL Rubric serves as an example of how to use educational research to guide this process. Educators can use the EIL Rubric, for example, to gain insight into the kinds of materials and pedagogical techniques that would provide meaningful additions to existing online lessons. This application of the tool is most aligned with research evidence-informed practice (Miller et al., 2008). The EIL Rubric can be used as a measure of 'research evidence-based practice' for those adopting the NGSS, by considering the characteristics on the rubric to reflect specific recommendations related to the engineering standard.

Educators and curriculum developers who want to harness the meaningful connections embedded in engineering face a number of challenges. They must identify and develop curricular materials that make explicit connections between science and engineering throughout, help students recognise the kinds of careers that are available (and the global challenges that can be resolved as the result of those careers), and include open-ended design challenges that allow students to apply their science knowledge to solve engineering problems. The EIL Rubric represents one strategy to bridge educational practices across disciplines. We anticipate that the EIL Rubric will continue to prove a useful tool for the continued study of science materials that are created and implemented to align with the NGSS specifically. We also hope that the rubric serves as a demonstration of how to apply research to practice, by providing teachers and curriculum developers with research evidence that can be used in their everyday decisions about meaningful ways to enhance lessons before they are implemented in science classrooms.

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