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A Systematic Review of Argument-assessment Frameworks in Engineering Education

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ABSTRACT:
Argumentation, the process in which students construct spoken or written arguments to articulate and justify claims or explanations, has been well-studied in the context of mathematics and science education. Engineering has not received the same treatment, as very few studies assess the quality and nature of arguments in engineering education. While it was non-existent a decade ago, there has been a shift towards understanding and usage of argumentation frameworks in engineering. The development of frameworks that can be used to assess the quality of student generated arguments is a foundational step in the adoption of argumentation in the field and researchers need access to and awareness about framework to gauge engineering arguments systematically.

In order to better understand the adoption of argumentation in engineering education, our research team conducted a systematic literature review. Systematic reviews can provide comprehensive summaries of previously conducted research, assessing both the general understanding of and the gaps within the literature of focus. In this review, a comprehensive collection of relevant publications was compiled by identifying appropriate search terms, databases and inclusion criteria. An initial search identified 478 results. Once 223 duplicates were removed, the titles and abstracts of the remaining 255 publications were screened and 201 records were removed because of their irrelevance to the topic of interest. Finally, the full-texts of 54 articles were assessed for eligibility and articles were excluded based on (1) lacked a framework (n = 25); (2) irrelevance to engineering in higher education (n = 15); and (3) examined the process of argumentation, rather than a produced argument (n = 2).

The full texts of the 11 qualifying studies were then examined and coded to reveal trends within the existing body of knowledge. Analysis revealed that only two types of analytic frameworks were used to examine the quality of student arguments in engineering education; both rely heavily on structural elements of arguments. These frameworks, which can clearly demarcate the structure of an argument, provide replicable templates for instruction and analysis that can be applied in a variety of contexts and compared between disciplines. However, literature in science and math education point to more nuanced approaches to assessing the nature and/or quality of arguments than by simply identifying structural components and assigning an arbitrary value assessment to them. Implications and future research are discussed.

INTRODUCTION:

Argumentation has been a focus of science and mathematics education research over the past few decades. Engineering education has recently started to incorporate argumentation into learning experiences as a way to analyze student arguments and inform teaching practices, however little research currently exists. This review aims to understand the utilization and progression of argumentation theory in the field of engineering over the last two decades. Specifically, we examine engineering education research for usage of argumentation frameworks for student response assessment. As a part of this review, we highlight the affordances and constraints of each category of frameworks with a sample student response. This article also discusses trends within categories, observations about student learning, and the implications for future research.

Arguments and Argumentation

The basis of argumentation lies in the study of arguments. An *argument* is the artifact created by students to specify and justify a claim. *Argumentation* is the process of generating and evaluating these artifacts. In other terms, argument is the product generated by the process of argumentation. These definitions are based on the traditional differentiation in these terms according to science education research (Sampson and Clark, 2008). Students use arguments to propose, support, and challenge claims, assertions or ideas. Analytical frameworks serve one or more of three main purposes: 1) understand the structure or complexity of an argument, 2) judge the accuracy and adequacy of the content in an argument, and 3) understand the nature of justification. For instance, a seminal study by Toulmin (1958) in the field of argumentation provides a structural model for an argument that is used by many education researchers. Analytical frameworks assess arguments on a qualitative or quantitative scale, assigning levels to the argument quality based on the presence of components and/or quality of components and help provide insight about students' understanding of educational content, their reasoning, communication, justification and epistemological understanding.

The Role of Arguments and Argumentation in Professional Engineering

Engineering design requires interaction with a diverse set of people, namely, fellow engineers, management and executives, financiers, government officials, various stakeholders and the general public. Starting from problem definition and task formulation, progressing through conceptualization, design embodiment and design detail, culminating in a solution, each step of the engineering design process (Haik et al., 2018) requires argumentation. For example, designing a water bottle involves decisions about material, ergonomics, color, production method, bottle cap safety, environmental impact and cost. Comparison of competing designs, material selection, aesthetic choices, safety concerns, and every other engineering design component can be envisioned as the result of argumentation.

Engineers rely heavily on argumentation skills to converse with and persuade others of their design choices, often balancing a variety of concerns such as political issues, economic constraints, technological limitations and environmental concerns. This involves justifying tradeoffs and prioritizing different aspects, a hallmark of argumentation. In addition, engineering research requires significant evidence-based argumentation for new designs to be accepted and for the adoption of innovative practices. As such, argumentation is deeply embedded into the informal and formal practices of professional engineers.

The Role of Arguments and Argumentation in Engineering Education

Argumentation theory has been used in science and mathematics education research over the past few decades but has been largely underexplored in engineering education; very few studies assess the quality and/or nature of arguments made by engineering students. This review will thoroughly explore those few that do exist in detail. Despite a lack of extant research, threads of argumentation are already being incorporated into students' learning experiences. For instance, the process of engaging in critique and evaluation are found in persuasive presentations, formal report writing etc.

Moreover, the parallels between argumentation theory and the engineering design methodology are noteworthy. Both argumentation and the engineering design methodology hope to develop students' abilities to evaluate claims, to consider alternatives, and to support their own ideas. Understanding and applying the design process is a core element of nearly every undergraduate engineering students' education. Students will learn how to generate solutions that meet a customer's stated constraints and criteria; how students support their design choices through argument is a fundamental aspect of the design process, and subsequently, engineering education.

In their book outlining practices and core ideas in K-12 Science education, the National Research Council (2012) outlines eight practices essential to learning engineering, including defining problems, analyzing and interpreting data, designing solutions, and engaging in argument from evidence (NAP citation). Similarly, ABET, the Accreditation Board for Engineering and Technology, coordinates a list of skills they believe each engineering undergraduate degree program should be able to cultivate in their students, including: (a) an ability to apply knowledge of mathematics, science and engineering, (b) an ability to design and conduct experiments, as well as to analyze and interpret data, (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability, (e) an ability to identify, formulate, and solve engineering problems, and (g) an ability to communicate effectively (ABET Criterion 3. Student Outcomes (a-k)). We argue that all of these skills are essential components of the argumentation process, and thus, that argumentation provides ample opportunity for developing the professional skills of undergraduate engineering students.

As such, we have outlined the many parallels between professional engineering skills and the skills that argumentation can help students develop. Moreover, we have emphasized the value of adopting research-backed frameworks that provide insight about students' understanding of educational content, their reasoning, communication, justification and epistemological understanding. Given the importance of these skills to the field of engineering, understanding the adoption, or lack thereof, of frameworks to evaluate students' argumentation in engineering education is essential. To do so, our research team conducted a systematic literature review.

METHODOLOGY:

Systematic reviews can provide comprehensive examinations of extant research, assessing both the general understanding of and the gaps within the literature of focus. By synthesizing the existing body of knowledge, these reviews provide access to the literature and serve as foundations for future work. Systematic reviews are guided by the following procedure: (1) identification of research questions and eligibility criteria; (2) a systematic search and screening of existing literature; (3) assessment and coding of selected publications; (4) synthesis and dissemination of results (Borrego, Foster, & Froyd, 2014).

Screening Process

A comprehensive collection of relevant publications was compiled by identifying appropriate databases, search terms, and inclusion criteria. Ebscohost was used to search the following databases simultaneously: Academic Search, Education Source, ERIC, PsycINFO, Science & TechnologyCollection, and SocINDEX with full text. These databases were selected due to their relevance to the topic of interest and the disciplines of focus. Conducting the searches simultaneously through Ebscohost allowed the authors to quickly identify and remove duplicates across databases.

In order to capture all publications that discussed arguments and argumentation, we included "argument*" as the first line of our search. Next, we limited search results to publications that addressed engineering in education spaces, rather than in professional settings. Our search string, (argument*) AND (engineering education OR engineering instruction OR engineering teaching), was used across all databases searched. The search was performed in September 2019.

The search results from each database were then examined using the following inclusion criteria:

1) Published as a report, article, conference paper, or dissertation in English since 1990
2) Uses a clearly defined framework to assess products of engineering-based argumentation

Table 1 details the exclusion criteria used to evaluate the full-text of articles for eligibility after an initial screening of abstracts and an example of a study eliminated by each criterion. Publications were excluded if they did not clearly define the framework by which they evaluated arguments. For instance, some authors simply assigned a rating to the product without an accompanying rubric that detailed how that rating was assigned. This evaluation was considered to be subjective and irreplaceable, and as such was not deemed to be a clear framework. Articles were then screened by their area of focus. This review sought to synthesize the adoption of argument assessment frameworks in engineering education specifically, and as such, articles which did not focus on engineering were irrelevant to our search. Finally, publications were removed if they examined the process of argumentation rather than the products of argumentation.

Table 1: Exclusion Criteria

Exclusion Criteria	Description	Example Citation
Lack of Framework	Articles which did not provide an explicit framework with which they evaluated arguments.	Gainsburg, Fox, and Solan (2016) analyze the presence of evidence-based reasoning in engineering, law, and medicine. They do not provide any specific frameworks to evaluate the arguments, just focusing on the presence or lack thereof.
Irrelevance to Engineering	Articles which did not focus on undergraduate engineering students or undergraduate engineering subject matter.	McConnell and Dickerson (2017) consider student arguments about the function of external structures on animals for survival. The subjects are fourth-grade students.
Examine Process rather than Product	Articles which examined the process of argumentation, rather than the products of argumentation (e.g. a writing sample) produced by subjects.	Purzer (2011) studied student arguments, self-efficacy and individual student achievements. The discourse argument motives were categorized and contrasted with achievement scores.

Search Results:

An initial search identified 478 results. Once 223 duplicates were removed, the titles and abstracts of the remaining 255 publications were screened and 201 records were removed because of their irrelevance to the topic of interest. Finally, the full-texts of 54 articles were assessed for eligibility and articles were excluded based on (1) lack of framework (n = 25); (2) irrelevance to engineering (n = 15); and (3) examination of the process of argumentation rather than a produced argument (n = 2).

Figure 2 shows the inclusion and exclusion flowchart in the form of a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) checklist (Moher, Liberati, Tetzlaff, & Altman, 2009). This checklist is widely used to ensure both the replicability of studies and their quality level.

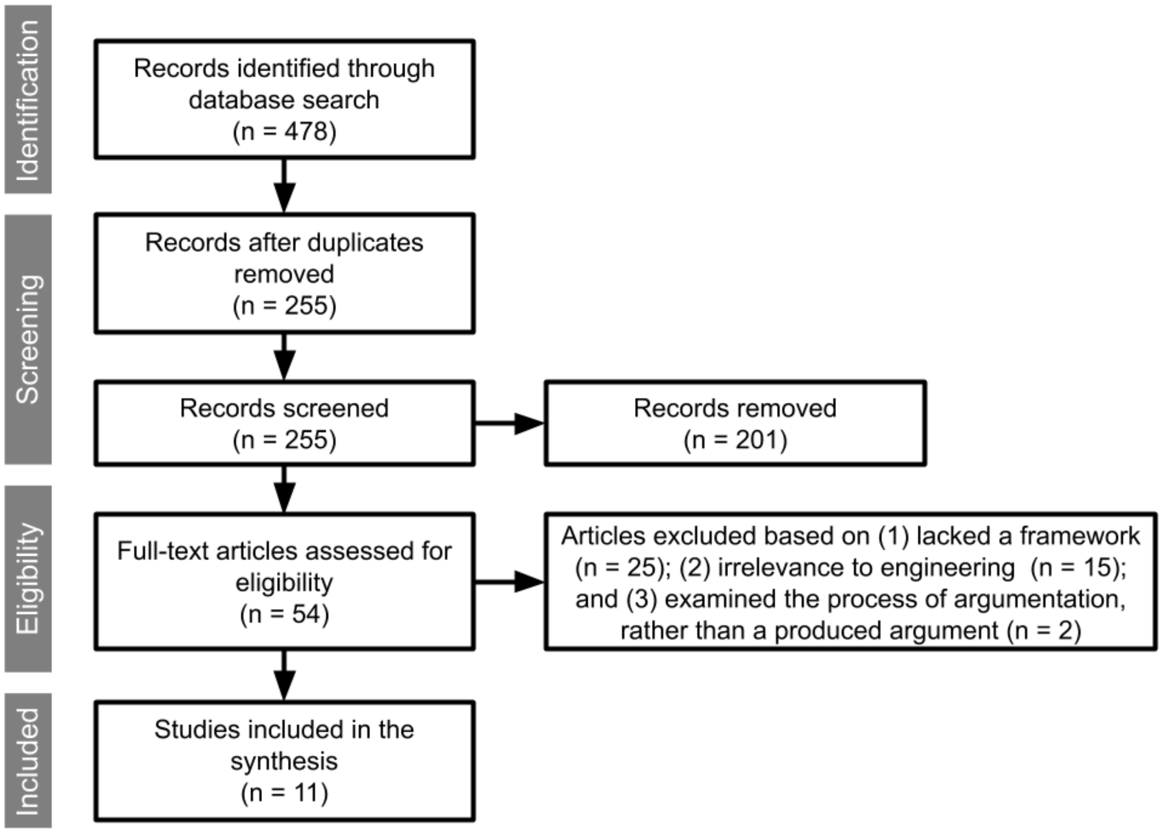

Figure 2: PRISMA diagram of the screening process.

Coding Process:

The full texts of these 11 qualifying studies were then coded to reveal patterns across publications and trends in the literature. Researchers coded each study by publication type, publication source, sample size, participant characteristics, and type of framework used. The first four metrics were gathered from directly the full-text of each publication. The type of framework was evaluated qualitatively and grouped into two categories. Following the lead of Sampson and Clark (2008), we then use a sample argument to help articulate the ways these frameworks define and evaluate arguments. This coding was done only for one exemplar of each framework type to illustrate similarities and differences between framework categories, not as a systematic process.

FINDINGS:

The 11 qualifying articles were first reviewed to identify general characteristics of our sample. Table 2 provides an overview of these characteristics, organized by publication source. The eleven articles were published across seven journals, with the highest representation in Journal of Engineering Education and the Journal of Science Education & Technology. The sample sizes ranged from n=10 to n=226, representing a mixture of undergraduate classifications and engineering disciplines. In two cases, engineering instructors were the focal subjects. All studies were peer-reviewed and framed as research studies, rather than as practitioner papers, and published from 2007-2018.

Table 2: Summary of Qualifying Studies

Journal	Article Title	Sample Size	Subjects	Division
European Journal of Engineering Education	A Place for Arguing in Engineering Education: A Study on Students' Assessments.	226	Mixed Undergraduates	Mix of Majors
International Journal of Science and Mathematics	Analysis of Arguments Constructed by First-Year Engineering Students Addressing Electromagnetic Induction Problems	142	Freshman Only	Mix of Majors
Written Communication	Argumentation Across the Curriculum	173	Lower Division	Mix of Majors
Computer Applications in Engineering Education	Automatic Argument: Assessment of Final Project Reports of Computer Engineering Students.	30	Mixed Undergraduates	Computer Engineering
Journal of Engineering Education	Engaging and Supporting Problem Solving in Engineering Ethics.	116	Freshman Only	Mix of Majors
	Fostering Argumentation While Solving Engineering Ethics Problems	50	Mixed Undergraduates	Mix of Majors
	Promoting Advanced Writing Skills in an Upper-Level Engineering Class.	10	Upper Division	Biomedical Engineering
Journal of Science Education & Technology	Examining Science Teachers' Argumentation in a Teacher Workshop on Earthquake Engineering	10	Instructors	Earthquake Engineering
	Exploring Simulator Use in the Preparation of Chemical Engineers	41	Instructors & Students	Chemical Engineering
	Exploring Students' Experimentation Strategies in Engineering Design Using an Educational CAD Tool	10	Mixed Undergraduates	Information Technology
Education Sciences	Incorporating Sustainability into Engineering and Chemical Education Using E-Learning.	26	Seniors Only	Mix of Majors

For the qualitative analysis of these 11 articles, we investigated the frameworks each article used to evaluate student product. We then grouped the frameworks into categories based on commonalities between articles. Further, we use a sample argument to articulate the ways these frameworks define and evaluate arguments.

ASSESSING THE NATURE OR QUALITY OF ARGUMENTS IN THE CONTEXT OF ENGINEERING EDUCATION:

Our analyses revealed that only two types of analytic framework were used in studies that examine the quality of student arguments in engineering education. We describe these frameworks as *Structural Only* and *Structural Plus*. *Structural Only* frameworks examine the structural components of an argument (e.g. the presence or absence of a claim, data and a warrant). *Structural Plus* frameworks noted which elements were present, but also included an assessment of the quality of the argument as a whole and/or the quality of its components. Of the 11 articles, six used a *Structural Only* framework and five used a *Structural Plus* framework.

To help illustrate the nature of these analytical frameworks, we will use both of them to code a sample argument. We will then highlight the affordances and constraints of using each one. Imagine students were asked to respond to the following design prompt:

TASK: You are working with a team of engineers from an environmental engineering company that specializes in water treatment. Your team's customer requires a filtration system that will reduce particulate matter by 45% and can process 10 million gallons a day. The customer would like it if the system was blue and could process 20 million gallons a day, as they expect growth in the next few years. The customer has a total budget of $18,000 for purchasing and installation. Your team must choose from the following three designs.

	System A	System B	System C
System Cost	$12,000	$15,000	$20,000
Installation Cost	$5,000	$4,000	$7,500
System Size	10' x 15'	12' x 12'	15' x 15'
Particulate Matter Reduction	55%	30%	45%
Processing Capacity	10 million gallons	15 million gallons	20 million gallons
System Color	Yellow	Blue	Red

Student Response:

System B is the best system for this customer because it can treat 15 million gallons of water per day, which is well above the constraint stated by the customer. It also requires the lowest square footage and is blue, which was another constraint outlined by the customer.

Figure 3: Design Prompt & Sample Argument

The student response will serve as our sample argument:

> "System B is the best system for this customer because it can treat 15 million gallons of water per day, which is well above the constraint stated by the customer. It also requires the lowest square footage and is blue, which was another constraint outlined by the customer."

This argument, however, is flawed. The student is conflating constraints and criteria, and mistakenly thinking that it is required for the system to be blue. Moreover, the system does not meet the necessary percentage of particulate matter reduction and the total cost exceeds the customers budget. In actuality, System A would be the best fit for the customer in question.

Structural Only Frameworks:

The first grouping of frameworks is *Structural Only.* These frameworks note only the presence of structural components of the argument and assign a level to the argument dependent on their presence. The common structural elements are claims and data (defined below in Table 3), while other elements such as warrants, backing, interpretation, presence of alternate viewpoints are framework specific. The Toulmin (1958) framework is an influence for multiple studied frameworks. Here, we examine a modified version of the framework developed by Venville and Dawson (2010), as listed in Table 4. This framework was also used in Yerrick, Lund, and Lee (2013).

Mechanics of the Framework

The Venville and Dawson (2010) framework relies on identification of five main structural elements: claim, data/warrant, backing and qualifier. These structural components are based on Toulmin's (1958) description of arguments and are detailed below in Table 3. Presence of a *claim* is a necessary component of any argument. The *claim* is supported by information in the form of *data*, and a *warrant* ties the *data* and the *claim* together. The strength of the *warrant* is indicated by the inclusion of a *qualifier*. *Backing* provides the assumptions to support the *warrant*. The last component, the *rebuttal*, considers counter-arguments and puts them in context with the current claim. According to Toulmin, construction of a scientific argument is a process of using data, warrants, and backings to convince others of the validity of a claim.

Table 3: Components of an argument (Venville & Dawson, 2010)

Component	*Description*
Claim	Statement, conclusion, proposition only
Data	Evidence supporting the claim
Warrant	Relationship between claim and data
Backing	Assumptions to support warrant
Qualifier	Conditions under which claims are true

In this framework, a claim is the necessary component to generate an argument and is included at each level; as such, a level 1 argument consists just a claim. Providing data or the warrant improves upon the claim by allowing the reader to make connections or to know how the claim may be scaffolded. The next level includes a claim and data, in addition to either a backing, an assumption to support the warrant, or a qualifier, the conditions under which claims are true. A level 4 argument would include all four of these components.

Table 4: Level of arguments based on components (Venville & Dawson, 2010)

Level	Description
1	Claim
2	Claim, data and/or warrant
3	Claim, data/warrant, backing or qualifier
4	Claim, data/warrant, backing and qualifier

Table 5 shows our analysis of the sample argument. Please note the framework provides no guidance about the scope of the individual component. For this example, we have chosen to delineate components at an idea level, rather than at a sentence or paragraph level. As such, this sample argument has a claim, three data points and two backing statements. Given the presence of three of four structural components, this argument is coded as a level 3 argument.

Table 5: Application of the Sample Argument

Portion of the Argument	Component	Level of Argument
System B is the best system for this customer	Claim	
it can treat 15 million gallons of water per day	Data	
which is well above the constraint stated by the customer	Backing	
It also requires the lowest square footage	Data	3
and is blue	Data	
which was another constraint outlined by the customer	Backing	

The framework does not reward the presence of multiple components of the same kind, instead favoring the existence of different components. As such, our decision to code the product at the component, rather than sentence level, is not impactful in this specific framework; however, a different framework may take it into account, which would change the quality of the argument. Additionally, the framework fails to consider the quality of the structural components. An argument is considered better if it has a variety of structural components, failing to account for their quality or quantity.

The framework does not account for the accuracy of any component of the argument. In this example, the chosen system does not meet the particulate matter reduction constraint. However, the argument is coded to be a level 3 argument because it contains three of the four structural components. Moreover, the student misidentifies the customer's preference for the color as a criterion, rather than a constraint. The sample argument states that the system being blue is a constraint by the customer, when it is merely a preference.

Structural Plus Frameworks:

We next consider the second grouping of frameworks, *Structural Plus*. As previously stated, these frameworks included an assessment of the quality of the argument as a whole and/or the quality of its components, in addition to noting which elements were present, as done in *Structural Only*. Some assess the quality of the argument as a whole, and others evaluate the quality of the individual components. Here, we illustrate this type of framework using a modified version of a set of rubrics developed by Ferretti, MacArthur, and Dowdy (2000) that is listed in Table 6 & 7, and cited in two of our 11 qualifying studies (Jonassen & Cho, 2011; Jonassen et al., 2009).

Mechanics of the Framework

Like the other frameworks in this grouping, the Jonassen framework first requires the identification of the structural elements of the argument. A student product is examined to determine which of the following components it contains: solution, counterclaim, rebuttal, supporting reason, perspective, theory and canon. The definitions of each of these elements are expanded upon in Table 6, as provided by Jonassen and Cho (2011).

Table 6: Argument Components

Component	Definition
Solution	An opinion or conclusion that an author supports to solve an engineering ethics problem
Counterclaim	A claim that refutes the solution
Rebuttal	A claim that refutes the counterclaim
Supporting Reason	A warrant or evidence that supports a solution, counterclaim, or a rebuttal
Perspective	A supporting reason based on the perspective of a stakeholder
Theory	A supporting reason based on ethical theory
Canon	A supporting reason based on an NSPE ethical canon

Subsequently, student products are evaluated for overall quality on a 6-point scale. Ranging from 0-5, the rubric scores a product based on both the components identified and the quality of these components. A student product is then designated as: response to the topic, undeveloped opinion, minimally developed, partially developed, well developed, or fully developed. This is a rubric, detailed in Table 7, was first reported by Ferretti, MacArthur, and Dowdy (2000), and later modified by Jonassen et al., 2009. This rubric emphasizes support for the claim, the identification and rebuttal of counterclaims, and the overall clarity and organization of the argument.

Table 7: Argument Level

Level	Description
0. Response to topic	Essay does not provide a clear claim.
1. Undeveloped opinion	Essay states a clear claim but no reason is given to support the claim, or the reason given is unrelated to the claim.
2. Minimally develop	Essay provides a clear claim and reasons supporting the claim, but the reasons are not well explained or elaborate.
3. Partially developed	Essay provides a clear claim and substantial reasons that are well explained and elaborated, but no counterclaim is addressed.
4. Well developed	Essay provides a clear claim and counterclaim and rebuts the counterclaim, but some reasons supporting the claim or rebutting the counterclaim are not well explained or elaborated.
5. Fully developed	Essay provides a clear claim and a plausible counterclaim, and they are supported by substantial reasons that are well explained and elaborated. The essay effectively rebuts the counterclaim with substantial reasons and/or proposes a valid alternative solution that addresses counterclaim concerns.

To demonstrate the application of this framework, we have coded our sample argument following these guidelines. Following the same procedure used to code the argument with a *Structural Only* framework, the sample argument was broken down into portions by the content of the phrase, rather than grouping by sentence. In this case, the argument contains one solution, two perspectives and one supporting reason. The argument as a whole, then, is partially developed.

Table 8: Application of the Sample Argument

Portion of the Argument	Component	Level
System B is the best system for this customer	Solution	Partially Developed
because it can treat 15 million gallons of water per day, which is well above the constraint stated by the customer	Perspective	
It also requires the lowest square footage	Supporting Reason	
and is blue, which was another constraint outlined by the customer	Perspective	

Like the *Structural Only* frameworks, frameworks in the *Structural Plus* category first evaluate an argument by the presence or lack of components; the frequency of these components are again, irrelevant, and priority is placed on the quantity of components, rather than their quality. One can note that again, the framework fails to identify both that the solution the student offers (System B is the best system for the customer) is incorrect and that the student is misconstruing the constraints and criteria proposed by the prompt.

Unlike *Structural Only* frameworks, this framework also applies a quality rating to the student product. In this case, the argument is partially developed because it provides a clear claim and substantial reasons that are well explained and elaborated, but it does not address any counterclaims. These level classifications however, are rather subjective. The rubric does not articulate what defines as well-supported or well-elaborated reason, making it impossible to replicate assessments of the same student product. Moreover, not justification is provided for the number of levels included in the rubric.

CONCLUSIONS

There has been relatively little research that has examined how students craft arguments in the field of engineering education over the last three decades. As a result, there are few analytical frameworks that have been developed and used to determine how well students support their ideas. Our systematic review of the literature suggests that there are two main types: we describe these frameworks as *Structural Only* and *Structural Plus*. In the paragraphs that follow, we provide a brief summary of the frameworks, highlight some affordances and limitations associated with each, and discuss what they can help us learn about student thinking.

Framework Types

There are two main types of frameworks used to examine the quality of student arguments in engineering education. *Structural Only* frameworks consider the presence of structural components of an argument (e.g. *claim*, *warrant*, etc.) Many of these frameworks are inspired by Toulmin's (1958) argument pattern and assign points based on the presence of one or more of Toulmin's structural elements (e.g. Venville and Dawson (2010), Ferretti et al. (2000). *Structural Only* frameworks inherently imply that the presence of a variety of structural components is the singular mark of a stronger argument. These frameworks can be easily adapted into tools for instruction and quantitative analysis of student products in a variety of contexts and disciplines. However, they do not account for the quality or accuracy of the structural components, nor do they provide direction for the assessment of the repeated presence of one component type. In short, these frameworks reduce both simple and complex arguments to a quantitative rating and, as such, have limited applications.

In addition to noting which components are present, the *Structural Plus* frameworks also include an assessment of the quality of either the components or the argument as a whole. Like *Structural Only* frameworks, *Structural Plus* frameworks do not account for the accuracy of the argument and nor the quantity of the individual structural components. By contrast, the quality assessment allows for a more nuanced classification of an argument, offering a clear advantage over a *Structural Only* approach. The frameworks, however, do not offer guidance for assigning a quality rating, which may introduce subjectivity raise issues of reliability in replication.

Trends Across Frameworks

The *Structural Only* frameworks examined either use a claim-data-warrant-backing-qualifier notation or a claim-evidence-rationale-counterpoint notation. The *Structural Plus* frameworks all assign a quality rating to either a claim-data-warrant-backing-qualifier notation, a conclusion-relevance-evidence-sufficiency notation, or a claim-evidence-rationale-counterpoint notation. While these frameworks can assess a student's ability to evaluate and support, not all frameworks assess their ability to justify or critique. Additionally, while arguments cannot always be reduced to either correct or wrong, none of the adopted frameworks assess accuracy or the level of accuracy of the content of the argument in question.

These frameworks demonstrate that students often provide a single claim to support their argument, and do not distinguish between multiple claims of varying importance. It can be seen in Jonassen et al. (2009) that students have trouble with synthesis and evaluation, which resulted in being unable to differentiate between the importance of different theories. From studies focusing on the entirety of an argument, it is observed that students have issues linking prior knowledge and ideas with data and claims. For example, Almudi and Ceberio (2015) found that students only used Faraday's law to analyze EMI phenomenon, while ignoring Lorentz's law which would be applicable in multiple instances. This is also affected by question design, as noted by Jonassen et al. (2009), where question design prompted a notable difference in identification of different perspectives and application of prior knowledge. Framework types also show that student justification is seen either via the lens of structural component presence/absence or via their thought process (content, discursiveness and reflectivity). This leads to the observation that students focus on articulating the claim rather than justification of the claim. Seah and Magana (2019) note that student arguments were not supported by sufficient or quality evidence to justify their design choices in Information Technology.

IMPLICATIONS

These findings have implications for future research, for the development of instructional materials for engineering classrooms, and for undergraduate engineering degree programs. As engineering educators and researchers begin to explore this topic, they have many lessons to learn from the extant research in science and math education. Opportunities to participate in argumentation and its analysis could become an essential component of learning and mastering the engineering design process. Moreover, integrating argumentation into engineering degree programs has clear advantages for producing desired student outcomes, such as the ability to design a system with respect to relevant constraints and criteria. These assertions are explored in detail below.

Future Research

As stated, there is currently little research around arguments and argumentation in engineering spaces; our systematic review identified only 11 peer-reviewed articles that use a clearly defined framework to assess products of engineering-based argumentation. Those that exist put forth, or borrow from, frameworks that examine only a few dimensions of arguments. These approaches, which can clearly demarcate the structure of an argument, provide replicable templates for instruction and analysis that can be applied in a variety of contexts and compared between disciplines. However, literature in science and math education point to more nuanced approaches to assessing the nature and/or quality of arguments than by simply identifying structural components and assigning an arbitrary value assessment to them (cite cite cite). Moving forward, structural frameworks will need to address both the connections between components and the relevance, sufficiency and accuracy of their content (Sampson & Clark, 2008). Our use of a sample argument demonstrated the inability of the extant frameworks to address these concerns. We argue that as educators embark on the process of integrating argumentation into engineering classrooms, they would do well to borrow from the lessons learned in science and math education over the last few decades.

Development of Instructional Materials

Understanding and applying the design process a core element of nearly every undergraduate engineering students' education. Throughout their coursework, students will make countless design decisions and subsequently assert the superiority of one particular solution over the others. How they support their claims through argument is a fundamental aspect of the design process, and subsequently, engineering education. However, without a clear or common way to evaluate these student arguments, comparisons between designs, degree programs, and studies on improving the design process becomes challenging. Argumentation frameworks offer the potential to structure instructional materials about the design process and corresponding student assessments to include how to effectively state and justify a design choice. Moreover, an analytical framework for assessing the nature of quality of generated arguments enables curriculum designers or faculty to be clear about what counts as a strong argument in this context. This clarity enables instructors to design lessons and assessments that will elicit student understandings of the course content and the engineering design process as a whole.

Engineering Degree Programs

Undergraduate engineering degree programs aim to graduate students with a specific range of skills essential to be a professional engineer; some of these skills are even formally detailed as a part of the ABET accreditation process (ABET Criterion 3. Student Outcomes (a-k)). Integrating argumentation into engineering degree programs is one possible way to produce these desired student outcomes. Developing students' abilities to evaluate claims, to consider alternatives, and to support their own ideas could move engineering curriculum away from the plug-and-chug coursework it often relies on. These skills are essential for comparing between designs and solutions, and necessary for work as a professional engineer. Incorporating argumentation into engineering education may provide an opportunity to focus not only on the quality of designs generated by students, but also on the quality of the arguments students make to support their design decisions. This may subsequently shift the way engineering content is taught/learned and the structure of the curriculum. Moreover, consistent use of an analytical framework would enable longitudinal analysis of student growth within and between subjects, in addition to throughout their time in their undergraduate major. As such, comparisons between subjects and time points are not often available to evaluate student growth.

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Appendix A

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