Research Article

Teaching Stasis Theory as a Critical Thinking, Reading, and Writing Tool in Engineering Subjects

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As a discipline, engineering has no shortage of critical thinking tools and approaches, from problem-solving algorithms and design thinking to George Heilmeier's "catechism," a series of questions to be asked and answered about any engineering project (Madhaven, 2015). These tools help to structure the complex and messy problems engineers encounter and provide sequential steps to help ensure a rigorous, rather than haphazard, approach to solving these problems. Applying these tools helps engineers to develop engineering judgment, which is a goal of the Accreditation Board for Engineering and Technology (ABET). Its Criterion 3 for student outcomes states as the sixth outcome "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions" (ABET, 2021, Criterion 3 section). ABET uses "engineering judgment" in its traditional sense, as related to the mathematical and scientific principles within each engineering field and the ability to apply them to real-world problems. While each of the above critical thinking tools is useful to the development of engineering judgment, they collectively tend to simplify and abstract content; indeed, simplification and abstraction are two key maneuvers that allow engineers to mathematically model complex phenomena. But engineers work at the intersection of the natural and social worlds and need critical thinking tools for argumentation, negotiation, and collaboration, as well as for modeling and analyzing physical forces. Research has shown that engineering students often see engineering communication as arhetorical, focusing on data rather than persuasion (Beaufort, 2007; Leydens, 2008; Mathison, 2019; Winsor, 1996), and that the type of problems student engineers learn to solve in problem sets doesn't prepare them for the ill-structured workplace problems that involve collaboration, persuasion, and trade-offs in values (Jonassen et al., 2006). More recent research has explored the relation between engineering communication and the development of engineering judgment (Francis et al., 2021). As Scott Weedon (2019) has recently argued, engineers need tools from the field of rhetoric in order to develop sound engineering judgment. He usefully redefined engineering judgment as "a capacity of participants to rhetorically establish common cause to interrogate and reflect on the relations between technical data and situations" (p. 165).

One powerful rhetorical tool—stasis theory—can augment the existing critical thinking tools in engineering and help engineers develop rhetorically robust engineering judgment as they learn to analyze audiences, develop and critique arguments, identify areas of uncertainty and the need for further research, and promote effective collaboration and sound design choices. Here, I will overview and refine stasis theory; show that, as a tool for reasoning and argumentation, it has features that align with many different theoretical approaches to critical thinking; and apply it to specific tasks and problems that engineering students are likely to face.

Overview of Stasis Theory

Stasis theory has a long history, dating back to classical Greek and Roman rhetoric, and has been modernized for American academic contexts by Michael Carter (1988), Jeanne Fahnestock and Marie Secor (1988), Sharon Crowley and Deborah Hawhee (1994), Davida Charney et al. (2004), and Martin Camper (2017), among others. The updated version perhaps most commonly taught in composition and argumentation textbooks is, on the surface, quite simple; five stases locate the issues that may be open or contested on any topic or project: questions of fact, definition, causation, evaluation, or policy. As Fahnestock and Secor (1988) have noted, stasis theory is descriptive in the sense that it names types of argument that occur in real-world settings and reveals existing conceptual relationships between these types of arguments, but it is also a tool for analyzing and generating arguments. Stases are "open" with respect to a specific audience if the author and audience don't agree on a claim, and thus the author would need to engage in reasoning with evidence to persuade the audience of the claim. Considered another way, stases are "open" if we collectively don't have certainty about a claim or don't have a convincing answer for a specific question, in which case we likely need to engage in research and reasoning about evidence to close the stasis. Thus, stases are rhetorical, in that they are always focused on a specific audience and situation, but they also function for knowledge production, and not simply targeted persuasion, when they address open (as yet unresolved) questions in a field or in a particular situation.

For example, a relatively straightforward question in the stasis of fact—"How many people in the United States were infected with the COVID-19 virus on March 5, 2020?"—can be difficult to answer with certainty, or may generate many plausible answers, due to differences in how we count. We might, for instance, include only those who have tested positive and whose test results have been certified by the Centers for Disease Control and Prevention (CDC), or we may include "clinical diagnoses" or believe that an estimate achieved through careful statistical modeling is more accurate due to limitations in testing protocol or availability. In other words, even in the stasis of fact, we may very well have legitimate debate or disagreement, and stasis theory can help us identify and isolate where open questions or differing claims exist with respect to our audience. Stasis theory also helps us to then identify stronger and weaker reasoning and thus judge competing claims in an open stasis, reducing uncertainty and/or achieving consensus to "close" the stasis.

Importantly, these stases are not just five separate categories of issues but instead are ordered and interconnected (Fahnestock & Secor, 1988). In Greek and Roman forensic rhetoric—that is, rhetoric applied in a legal context to address issues of guilt and innocence—the stases were addressed in a fixed sequence, from fact to policy/procedure (Fahnestock & Secor, 1988). In updating the theory for modern academic argumentation, Fahnestock and Secor also emphasized their interconnectedness and conceptual order, with the stasis of fact as foundational to "higher" stases. At the same time, they noted that in common contemporary usage, stases aren't necessarily addressed in a fixed order, as "a question about any issue can interrupt the discussion of any other, sending the whole procedure" into a revised process of addressing and confirming all of the stases (Fahnestock & Secor, 1985, p. 218). Uncertainty or disagreement in one stasis (in our example, the stasis of fact) can propagate through the linked stases—the interconnected issues that we need to consider in any situation. If we believe the number of people infected by COVID-19 is quite low—for instance, if we take only the cases that were tested and confirmed by the CDC—we might then define our situation as in an early stage of outbreak—the "containment" stage—and that would prompt certain kinds of evaluation and action. If, however, we have reason to believe the "true" number of infected is quite different but don't have agreement on a good alternative measure, then we have a large uncertainty in the stasis of fact, which could easily make us also uncertain about how to categorize the situation, how to evaluate it, and what to do in response (for instance, designing at-home testing kits or repurposing manufacturing facilities to produce ventilators).

As the above example suggests, one reason to use the stases systematically is to identify and isolate the "open" questions or disagreements that prevent resolution in other stases, thereby letting us focus our efforts. The stases can be understood as nodes in a complex information network and should be understood as a tool for systems thinking and engineering judgment (and again, one that can explicitly unite mechanistic and rhetorical thinking). Almost like a circuit with many switches, a network of stases can provide the reasoning, certainty, and consensus to power decisions and collective action if all of the stases can be closed. The goal is to be able to move through the stases, not to be in a standstill of uncertainty or disagreement, and applying stasis theory as a framework of critical analysis can help to turn a host of conflicting claims and multiple uncertainties into an ordered process of problem solving.

To fully understand this argument that the stases can be used as a tool for systems thinking and engineering judgment, we need to address a limitation in the way that stases have often been used. While Fahnestock and Secor (1985, 1988) offered nuanced and complex arguments about the stases as a robust and flexible system, they also tended to simplify this system in their examples and analysis of disciplinary texts. They argued explicitly for recursiveness and that this iterative process of moving through the stases "evokes more refined questions at the same stasis and counter-argument at every stage . . . . Any adaptation of the stases should take account of and even value this complexity, for it means that the stases can lead the rhetor to an enriched invention strategy" (Fahnestock & Secor, 1985, p. 218). However, they seem to have viewed this recursiveness as primarily occurring *prior to composition*, with the finished texts being a relatively orderly progression through the stases in support of the "main," or open, stasis. In "The Stases in Scientific and Literary Argument," they (1988) argued that specific, individual literary arguments address primarily the stasis of value and that research articles in literature *in general* do that. In other words, they identified a major open stasis for a discipline as a whole. According to their analysis, "arguments in disciplinary contexts often stay in one stasis" because "scholars usually focus on well-defined issues for limited audiences" (p. 430). Scientists, they argued, address the lower stases of fact, definition, and cause, and they read the separate articles in one issue of *Science* as each addressing one of these stases. While they also noted that no argument in any stasis can stand without at least implicitly addressing a question of the argument's value or significance, they see these questions of value as addressing the article's major claim. Their textbook, and another that uses the stases as a framework, approaches the production of argument in a similar way, offering specific chapters on each stasis, with assignments asking students to produce an argument of fact, definition, causation, value, or policy (Charney et al., 2004; Fahnestock & Secor, 1996).

I would, instead, like to revise that view in line with their own theoretical claims about complexity and recursiveness. Fahenstock and Secor (1988) argued that the stases sit between Toulmin's model of the structure of an argument, in which each claim is related to data, warrant, backing, qualification, and rebuttal—a general model—and the specific warrants of any individual issue. I agree. However, it is important to recognize that Toulmin's structure applies to what he called "micro-arguments," which are data-claim structures on the order of a simple sentence, such as "Harry is a British citizen," not on the order of a text such as a research article (Toulmin, 1994). Many interconnected micro-arguments form chains of evidence and reasoning in any complex text, and these chains branch and interconnect in multiple ways. Each micro-argument might be in any of the stases, and while a text's main goal may be to ultimately settle a question in one stasis, there are usually multiple open questions in different stases that need to be addressed along the way, and not in a simple, linear sequence but instead with a multiply branched structure arising from different, but interconnected, threads in the reasoning.

Kanoksilipatham's (2015) recent analysis of engineering research articles has shown just such a complex structure of claims, with many claims of existence, definition, causation, value, and sometimes policy interconnected through the articles. Consider, for example, a research article that argues for an improvement that can be made to a synthesis of chemicals that produces a desirable product and an undesirable byproduct; this improvement involves a novel catalyst (of a certain class, discovered through reasoning by analogy to similar catalysts) that supports a more efficient reaction, and the authors claim the improved process reduces energy consumption and overall cost; improves the purity of the desirable product; and produces a different byproduct that can be sold for other purposes, further reducing cost. The open stases, in relation to the audience, begin with fact (the existence of this novel catalyst); link to definition (Does this classification and reasoning by analogy make sense?); branch into two different causal questions (How is the catalyst made? What effect does the catalyst have on the reaction?); and branches back to two questions of fact (How much of each product and byproduct are made?), each with its own questions of quality (How pure and valuable are the product and byproduct?). Separately, branching from the causal node of what effect the catalyst has on the reaction is a line leading to questions of fact (How much energy is used? How much does it cost?) that then lead to questions of value (How much money is saved? How significant is that amount?), which, when linked back to the other value claims about the products, lead to an implicit policy claim: adopt this novel catalyst and new process. It is difficult to say what the "central" open stasis of such a network is; however, it is easy to see that failure to close any of the multiple open stases in this complex network limits the ability to close others.

Consequently, the image of a complex network of stasis nodes represents the recursivity of the thinking process, as well as the structure of texts, better than does a linear representation of the five stases. This network view retains the original meaning of stasis, which arises from the Greek word for "to stand," and indicates a "standstill," or stoppage, which of course only takes on its full meaning in relation to the assumption of movement. We are in an open stasis if we have a stoppage—this is where agreement or certainty breaks down, and we need to stop to resolve this open stasis before we can travel elsewhere in the network. We can only resolve the disagreement if we achieve "clash"—that is, if we don't talk past each other but isolate specific claims and counterclaims (Crowley & Hawhee, 1994). While we can isolate a claim or question in any stasis for analysis or discussion, we cannot ultimately separate our understanding of the claim from its function in the overall network in which we find (or place) it. Thus, engineers can think of stasis theory as similar to modular systems thinking—we can break apart the larger system of an argument into its stases (modules), but we must always also view each stasis and the relationships between them in terms of the overall system and the effect the argument as a whole is meant to have on its audience.

In an engineering context, because the stases are inherently social and dialogic, they can therefore function to keep a team aligned in effectively targeting their collective action. As we'll see in some examples later, much important work in research projects occurs in the act of identifying specific sources of uncertainty (and debate) and ruling out options. These might be disagreements in measurement, instrumentation, or methodology or trade-offs, such as valuing efficiency over robustness in design. Identifying the specific micro-claims and counterclaims and their respective stases can narrow disagreements and offer specific means of addressing the conflict. Should these open questions be not only disagreements between team members but currently open questions in a discipline, identifying them could help guide new research. One of the catechism questions from Heilmeier addresses this goal broadly; for any engineering objective, one would need to ask: "How is it done today, and what are the limits of current practice?" (Madhavan, 2015, p. 24). Stasis theory is a fine-grained tool to identify "current practice," "state of the art," or a "knowledge gap" within a field. During a literature review (or even a team meeting), the stases can be used to track unanswered questions, alternative viewpoints or approaches, and unresolved disagreements. Once again, the recursive nature of stasis theory can guide students to a nuanced set of interconnected, local claims and questions. For such investigation, having a structured tool that links decisions about technical content to social and ethical reasoning helps students develop the habits that lead to effective engineering judgment.

Stasis Theory as a Critical Thinking Tool for Developing Engineering Judgment

As I hope the above discussion of stasis theory shows, the stases are a relatively simple taxonomy and heuristic and, at the same time, a robust tool for making and analyzing arguments and, consequently, for critical thinking. Indeed, most scholars who have modernized stasis theory for academic contexts have already made a claim of this sort (Brizee, 2008; Fahnestock & Secor, 1985). I see stasis theory as aligning to some extent with a variety of definitions of critical thinking and propose that as a tool, it can help to navigate some of the differences in how we approach critical thinking because, though simple, it is both a general heuristic and one that can illuminate disciplinary and situation-specific reasoning, combining elements of both formal logic and social consensus.

Others in this journal and elsewhere have offered careful analyses and critiques of theoretical approaches to critical thinking. My purpose here is not to position myself within that theoretical debate but instead to show how stasis theory might be a useful framework from any of these perspectives and, consequently, might enrich the discussion and teaching of critical thinking, especially in its relationship to writing. Therefore, I will work with a range of representative approaches to and positions on critical thinking rather than attempt to specifically situate stasis theory in relationship to a wide variety of theoretical texts.

One common approach, that of considering critical thinking primarily as the ability to form and analyze logical arguments through critical attention to the reasoned relationships between claims and evidence, aligns directly with stasis theory's emphasis on claims within specific stases and their relationship with each other. Textbook approaches (e.g., Fahnestock & Secor, 2004; Charney et al., 2005) to stasis theory provide frameworks for making and analyzing arguments in each stasis and offer useful heuristics for identifying the stasis of each claim and for considering both the features of evidence and reasoning necessary to close a stasis. For instance, in the stasis of causation, students would learn that a successful argument would need to identify a correlation, a sequence in time, a necessary and sufficient factor (or agent), and, if necessary, the conditions or context in which the causation can occur (Charney et al, 2005, pp. 54–57). For most students, learning how these types of evidence and reasoning interact within this stasis is more useful than learning that correlation is not causation or that *post hoc ergo propter hoc* is a logical fallacy.

Working with stasis theory, students also learn the various forms of reasoning that occur in each stasis. In the stasis of definition, for instance, one can obviously name, classify, or categorize, but one can also compare and contrast, include or exclude, exemplify, move up or down the ladder of abstraction (e.g., from genus to species), and, importantly, reason by analogy (Charney et al, 2005, pp. 37–42). In the stasis of evaluation, similarly, one can evaluate or judge quality (Is it good or bad?), argue for significance or insignificance (Does it matter?), argue for trade-offs between criteria, make ratings on a scale, or even argue for a different scale or criteria (Charney et al, 2005, p. 43–51). Thus, students learn not only to identify the stasis of a particular claim but also to consider the claim's function within a framework that allows them to consider whether alternative functions would be more useful, or perhaps also necessary, to explore an open question or persuade an audience.

Stasis theory's detailed approach to identifying open questions and showing what kinds of evidence and reasoning are necessary to close them aligns it with other approaches to critical thinking that emphasize systematic questioning and logical analysis of argumentation. Stasis theory's combination of coherence, flexibility, and robustness as a reasoning tool usefully augments some approaches that teach argument analysis through a more limited claim-evidence framework or that teach students lists of logical fallacies without teaching a vigorous invention and production framework for generating strong arguments.

Many approaches to critical thinking emphasize "habits of mind" rather than focus primarily on elements of formal logic or argument analysis. Such habits of mind might include a critical stance towards sources, the consideration of counterarguments or alternative perspectives, or the recognition and analysis of one's own or others' unstated assumptions. Again, I believe that central elements of stasis theory align with and promote these habits of mind. Because stasis theory is inherently situational and dialogic, the consideration of counterarguments and alternative perspectives is central to its application. One cannot determine whether a stasis is "open" or "closed" in relation to one's audience without actively seeking to identify and consider the audience's potential alternative perspectives. Nor could one proceed to close an open stasis without exploring the counterarguments that exist in relation to the specific claim and achieving "clash." As Jonassen et al. (2006) showed through interviews of professional engineers, engineers learn and practice engineering judgement situationally, drawing from previous examples and solving ill-structured workplace problems in collaboration with teams of experts, clients, and others. As a tool for identifying points of consensus and dissent in such rhetorical situations, stasis theory can aid engineers in solving problems and making decisions in a structured and reasoned fashion.

Stasis theory can also be useful in identifying unstated assumptions—in my experience, an otherwise difficult process to teach, as it requires students to analyze not only texts (theirs or others') but also what is not explicitly stated in the text. Here, it is useful to note how the stases shape and structure texts. Essentially, if we believe that a stasis is open with respect to our audience, we will rhetorically amplify our claim, evidence, and reasoning, giving important textual space to developing our position as well as rebutting potential counterarguments. However, if we believe that a stasis is closed, that our audience is in agreement on that particular claim and shares our understanding of the evidence and warrant, then we use the rhetorical shortcut of *enthymemes* in which we offer the claim only, leaving the warrant, backing, and often the evidence implicit. As we analyze texts, or our own arguments, the categorization of stases as open or closed can be a useful tool for identifying unstated assumptions; essentially, identifying closed stases allows us to pinpoint segments of text that are the likely locus of various kinds of assumptions.

In addition to bridging the divide between critical thinking approaches more aligned with formalist logic or more aligned with cognitive habits or dispositions, modern stasis theory can, I believe, bridge the divide between theories of critical thinking that view it as a general skill (following Ennis [1989]) and those that see it as situated and shaped by specific disciplines (following McPeck [1990]). Fahnestock and Secor (1988) argued that the stases rest "between the general outline of an argument, applicable to all arguments regardless of field, described by the Toulmin model, and the very specific lines of argument engendered by the special topoi preferred by specific disciplines" (p. 429). As a generic framework, the stases can be taught in general education or first-year writing courses and applied to a wide array of assignments, arguments, and readings. Indeed, we now have decades of just such instruction in certain university programs, perhaps most notably the University of Maryland's writing curriculum, overseen for decades by Jeanne Fahnestock. Yet, while certain modernizations of the stases emphasize specific and disciplinary stases for legal and textual argumentation (Camper, 2017; Hoppmann, 2014), the basic stases of fact, definition, causation, evaluation, and policy can be applied in any field, and when they are, they can facilitate learning the discipline-specific warrants and topoi. Causal arguments in political science, for instance, and those in brain sciences will use vastly different evidence, with discipline-specific methods of gathering and analyzing that evidence, but in each case the causal argument can be assessed on whether, and how well, it identifies a sequence, a correlation, an agent, and any necessary conditions for change.

The fact that stasis theory not only aligns with different theories of critical thinking but can also bridge them should lead to a much wider emphasis on teaching the stases at all levels of the curriculum and in all disciplines. Indeed, I and others at my university teach it in many classes, from first-year composition, through advanced rhetoric, to capstone classes in many engineering disciplines and even to graduate engineering students. Due to the collaborative nature of work in engineering, and the fact that engineering projects and research straddle the technical and social spheres, and are often multidisciplinary, we believe that stasis theory is a particularly useful rhetorical and critical thinking tool in engineering contexts for the development of engineering judgment. In the remainder of this article, I present the stases as a tool for reading engineering journal articles, for performing literature reviews, for engaging in collaborative design projects, and for writing and presenting complex research.

The Stases as a Tool for Reading Engineering Journal Articles

In my experience, engineering curricula emphasize problem-solving, mathematical, and technical skills, with comparatively less emphasis on reading and analyzing published literature in the field. Since this published literature is the repository of disciplinary knowledge and the state of the art, students' limited access to it can in turn limit their professionalization and understanding of research, as well as the development of their engineering judgment. At the same time, engineering journal articles can be difficult to learn to read and analyze carefully, and even graduate students can struggle with this task. At MIT, we teach both undergraduate and graduate engineering students how to read texts in their field through the lens of stasis theory.

Let's take as an example a research article, "Free Surface Electrospinning from a Wire Electrode," by Keith Forward and Gregory Rutledge (2011), which we use as a sample text in a chemical engineering capstone course. We ask students to analyze texts with us, in class, cold, when we first demonstrate the method. After a presentation of the stases and discussion of what it means for a stasis to be open or closed in an argument, we ask students to go sentence by sentence, naming the stases for each claim and identifying whether it is open. We often ask students the secondary question—Do the authors expect we'll accept this claim, or do they show that they know they will need to convince us of it? To demonstrate the method we teach, I'll analyze the first few paragraphs. Let's look at the first sentence of the article to see how this works:

> Electrostatic fiber formation, or "electrospinning" has attracted much attention over the past decade as an effective technique for producing submicron fibers and non-woven mats with remarkable properties. (p. 492)

This first sentence links claims in a number of stases, beginning with definition (the naming of a category called "electrospinning," which students note may be open; even though not much space is given to convincing us here, the quotation marks signal that the authors perceived "electrospinning" to be a new term). "Effective technique for producing submicron fibers and non-woven mats" combines factual, causal, and evaluative claims, which the text treats as closed (though we could easily question: How effective? Compared to what other methods? Do we have evidence that the fibers are submicron? etc.). The sentence ends with a different evaluative claim, that these fibers and mats have "remarkable properties"—certainly one that we would want to question. Thus, we see, in just one sentence, a network of interconnected stases already set up and branching.

> However, one of the perceived drawbacks of the method for industrial purposes is its low production rate. A typical production rate from a single spinneret is 0.1–1 g of fiber per hour, depending on the solution properties and operating parameters; in general, the smallest fibers are fabricated by reducing the solids content of the spin dope or by reducing the flow rate to the spinneret, both of which lead to lower productivity [1]. (p. 492)

That the method has "the drawback" of "low production rates" is clearly a claim of evaluation, which is then linked to the reasoning chain of claims that support this evaluation, including claims of fact (a single spinneret produces 0.1–1 g/h) and of complex causation (reducing solids content and reducing flow rate both create smaller fibers, but also "lead to lower productivity"). Here, the space and detail allotted to the reasoning chain and evidence signal that the claim of "low production rates" is not one that the authors assumed the audience already knows and accepts. If one is tracing which claims are made in which stases, it becomes clear that the initial evaluative claim that electrospinning is “effective” may be in tension with the claim that it has low productivity.

> Several attempts have been made to use an array of spinnerets to increase productivity [2,3]. These studies are typically characterized by careful attention to the spacing and geometric arrangement of the spinnerets and/or the use of auxiliary electrodes to modify the inter-jet electrical field interactions. For a typical spacing of 1–3 nozzles/cm^2, a production rate of 1 kg/h can be realized, in principle, with a multi-nozzle design on the order of 1 m^2 in area. However, these configurations often lead to non-uniform electric fields, resulting in discontinuous operation and poor quality nonwoven mats [4–8]. Operational and quality control issues such as nozzle clogging and spatial variation of the jets from nozzle to nozzle are often cited as problems encountered by these approaches. (p. 492)

Here, claims of fact (“several attempts have been made,” “spacing of 1–3 nozzles/cm^2”), definition (the classifying of these attempts as having the common features of geometric spacing and/or auxiliary electrodes), causation (both that these arrangements can achieve 1 kg/h of production “in principle,” and that, in practice, they produce clogged nozzles and poor mats), and evaluation (“poor,” “non-uniform,” “discontinuous,” “clogging”) form a complex and tightly interconnected network. All of these claims are initially open but closed by the support of references 2–8.

Discussion with students at this point—the end of the first paragraph—elicits not only the recognition of how tightly packed the claims are, or which stases they are in, or the understanding that the value claims may seem subjective without clear criteria for what constitutes “poor quality” or “remarkable properties” or a sufficient production rate, but also the clear implication that with existing approaches having been judged insufficient, claims in the policy stasis are necessary—that we collectively need a new, and better, approach to electrospinning.

While this kind of detailed close reading of the arguments of engineering texts may seem unusual, to say the least, our students find the process intriguing and very helpful. Science and engineering students initially tend to see technical texts as flat strings of information rather than as multidimensional argument structures; without a framework for analyzing arguments, their interaction with these texts initially tends to focus on surface-level understanding and the collection of facts. Not only does such a fact-focused approach make it difficult for them to read critically and evaluate the work (thus building their engineering judgment), but it also often makes understanding the knowledge structure itself more difficult.

Moving on to the second paragraph of this work will help to illuminate the complex structuring of information occurring here. The authors continue:

> A remarkable feature of the electrospinning process is that jets can be launched, in principle, from any liquid surface [9]. Thus, a variety of configurations have been reported that produce jets from free liquid surfaces, without the use of a spinneret. These include the use of a magnetic liquid in

> which "spikes" can be formed to concentrate field lines at points on a liquid surface [10], liquid-filled trenches [9], wetted spheres [11], cylinders [12–14] and disks [14], conical wires [15,16], rotating beaded wires [17] and gas bubbles rising through the liquid surface [18,19]. In the case involving the use of a magnetic liquid, a jet density as high as 26 jets/cm2 was reported [10]. Such methods have several potential benefits, including simplicity of design, robustness against clogging of a spinneret, and increased productivity though the simultaneous operation of numerous jets. All of these methods share the feature that liquid jets are launched from a free liquid surface, often with the aid of a device or disturbance that introduces curvature to the liquid interface. We refer to these processes collectively as "free surface electrospinning", although some have been previously described as "needleless electrospinning" [9–16], or "bubble electrospinning" [18,19], for example. (p. 492)

In this paragraph, the primary open stasis is definition. Forward and Rutledge (2012) categorized a wide, seemingly disparate array of approaches as similar because they all "produce jets from free liquid surfaces" rather than funnel the liquid through a spinneret. While noting the differences in approach to producing the jets—all variation in the stasis of causation—they also made the value claim that the same "potential benefits" exist for the entire group. By renaming the collective set of approaches "free surface electrospinning," they both dissociated these from the spinneret approach that didn't live up to the "remarkable" potential (thus reclaiming that potential) and created a new category that emphasizes the similarity between what was formerly seen as separate: "needleless electrospinning" and "bubble electrospinning." This brief paragraph performs a complex information restructuring of this small subfield of electrospinning as it unites claims in the stases of definition, causation, and evaluation, once again implying the need for a policy claim—that we (researchers) should do something in particular in response to this restructured knowledge.

Indeed, in the next paragraph (the final paragraph of the introduction), Forward and Rutledge (2012) explained the type of free surface electrospinning that they were researching, in which rotating wires dip into a liquid surface, picking up (entraining) and then releasing (dewetting) the liquid in jets as the wires spin. Their explanation is a causal claim about how the process works, and their main argument rests in the stases of causation and value: "Here we examine how the liquid properties (i.e. surface tension, viscosity, density and concentration) and the operating parameters of applied electric potential and spindle rotation rate (or wire velocity) affect the productivity of the process, in terms of the sequential steps of entrainment, de-wetting, and jetting" (p. 493). This statement, which ends the introduction, seems straightforward. To foster critical thinking, we ask students at this point in the analysis of the article what they expect to find in the results, discussion, and conclusion. Students typically predict that the article will show how each property and parameter affect the productivity, with causation claims broken down and detailed by stage of the process, and they further expect that the results of each of these more local causation claims will lead to a final explicit value claim about whether this method produces significant or disappointing productivity in relation to the other methods named in the introduction. Some suggest that the article will show how to optimize productivity through this process.

Some also suggest that the article will support an implicit policy claim in the conclusion—that this approach to free surface electrospinning will yield positive mat qualities with comparatively high production rates *and thus should be adopted or further researched*.

With multiple related but not identical predictions about which stases will be closed, and which will be most emphasized, students approach the rest of the article critically, assessing claims and evidence in relation to their predictions, not all of which are accurate. For instance, the article does not explicitly state a productivity rate for this approach. Instead, the article models the geometry of the process; defines which parameters are dominant and how parameters relate to each other; and derives operation equations that make the process predictable and thus controllable, allowing them to predict where future research can further optimize the process. The students are surprised not only that the article does not state a calculated productivity rate but by other features of the text as well, and the ensuing discussion focuses on which students are convinced by which claims, and why—in other words, it focuses on how well each stasis is closed and how we, as engineers, can assess the credibility of research claims, a key element of developing engineering judgment.

As this example shows, having students analyze engineering literature through the lens of stasis theory helps them to understand not just the information but also the knowledge structuring that the authors perform. By asking explicitly of each claim and statement "What stasis is this in?" and "Does the author assume I already know this or will agree, or does the author assume I will need to be convinced of it?" students learn to see themselves in dialogue with the authors rather than as passive receivers of information. This example also shows that these texts form complex networks of micro-claims, with some strings of claims working in parallel and others serially, to build argument (and knowledge) architectures that students need to be able to assess at many discrete but interconnected critical points.

In addition to aiding students in reading individual articles, stasis theory can be a very useful framework for reading and analyzing across a body of articles focused on similar research and thus as a tool to aid in both experimental design and the writing of a background section or literature review. At the beginning of a new project, such as those common in capstone, project-based classes, students (often in teams) need to come up to speed quickly on possible approaches and identify what has been done before and what is most promising. The first time they do this, students find the process daunting and often have difficulty shifting from consumers of knowledge to active producers. They might, for instance, spin their wheels, not knowing how to proceed; expect to be carefully guided to the "right" choice from a few curated options; or make decisions based on limited understanding of alternatives. Stasis theory can be taught as a tool for identifying consensus and disagreement in the literature and has significant advantages as a structure for managing information. First, the stases offer a pre-existing and generic, yet powerful, system of classifying the claims in different articles. Students (or teams) can construct a literature review chart with their list of articles in the left-hand column and another column for each of the five stases, as shown in Figure 1. As they read each article, they can record the claims in the stases of fact, definition, causation, value, and policy, noting which stases are closed by each article and which remain open. Because this structure can exist before any articles have been read, it ensures consistent notetaking across different articles (i.e., whether the article is read early or later in the process) and is also, therefore, an effective structure that ensures consistency should a team take a "divide-and-conquer" approach to reading the literature.

Article information	Fact	Definition	Causation	Value	Policy
Article 1					
Article 2					
Article n					

Figure 1. Example of a stasis-based literature review chart.

Moreover, once the chart is completed, the stasis structure allows students to easily see areas of consensus and disagreement in the field. In our experience, students can usually recognize disagreements of fact and differences in methods, or results, without using a stasis theory chart. However, while they may recognize these differences, they often don't fully understand *why* these differences exist—to return to the previous article as an example, had students read the variety of electrospinning articles that Forward and Rutledge (2012) summarized in their introduction, they likely would have simply seen an array of options, without understanding the reasoning that could be done to categorize options together. In addition, they likely would have seen a variety of parameters that could be manipulated and studied, without understanding their relationships, and thus without a useful framework for turning that variety into a clear experimental design. Additionally, they would likely struggle with understanding what criteria they should prioritize—productivity rate? Properties of the mats? Ease of process? Or ability to predict and control the outcome? These challenges occur because differences and disagreements in the stases of definition and value are much more challenging for most readers—especially novices in the field—to identify without specifically tracking them. And without understanding—or noticing—the conceptual structuring that each article performs in the stasis of definition or value, readers are left understanding isolated claims but less able to critique the strength of the networked claims—the knowledge architecture—that is constructed, either in each individual article or by the collection of articles or the field as a whole.

It's worth pausing here to delve a bit more deeply into the conceptual work performed in the stasis of definition to fully understand why missing these—possibly brief—micro-arguments can be so limiting to a critical understanding of a text or field and also why they are so easy to miss or dismiss. At its heart, the stasis of definition is about categorization, and consequently, it performs the work of including or excluding facts from consideration because *these facts* have an important similarity and *those facts* have an important difference. This stasis, therefore, is also where the concrete and physical reality of chemicals, currents, materials, etc. with which engineers work are linked to the abstract concepts (enthalpy, inertia, turbulence, etc.) of theory. Moving up and down this ladder of abstraction is common in research, as are the inclusion and exclusion moves of categorization. Inattention to the constraints or affordances of these moves (and the possibility of introducing uncertainty or error in such a move, which can propagate through the network of claims) limits reading to the level of facts, not of knowledge—and indeed, makes it very difficult to evaluate those facts and develop engineering judgment.

In an example from later in the Forward and Rutledge (2012) article, after characterizing the processes of entrainment, dewetting, and jetting through modeling and experimentation, they spend another paragraph entirely in the stasis of definition in order to explain the differences between what they observe at rotation rates under versus over 7.1 rpm. At the slower rotation rates, the amount of liquid on the wire determines the productivity of the process (which they name the "entrainment-limited regime"), while for rotation rates over 7.1 rpm, in what they name the "field-limited regime," it is the electric field on the wire that limits productivity. The two different regimes are governed by different variables and parameters and not only have different causation but also need to be evaluated somewhat differently. Consequently, understanding how this argument in the stasis of definition functions to link facts to causation and value is necessary to understand the complex challenge of further increasing productivity.

These examples show how the stases are a useful framework for analyzing engineering research articles and allowing students to more quickly learn necessary critical thinking skills in relation to the range of current approaches to solving specific engineering problems. I hope they also show how micro-claims in different stases form complex chains that can be difficult to fully analyze without a recognition of the different stases and the type of conceptual work that each performs as well as a method of tracking and analyzing the network of claims overall.

Stasis Theory as a Tool for Collaboration

Of course, once students have analyzed the relevant literature as background for their project, they will need to collectively decide on a number of features of their project and coordinate work—often reconsidering and making changes in design as they progress. Here, stasis theory can again be a useful tool to aid analysis of options and careful decision-making, which are core aspects of critical thinking. Brizee (2008) has argued that stasis theory is useful in team situations and decision-making processes in workplaces; I would like to build on his argument to show how stasis theory can function specifically in engineering project team contexts and as an aid not only to collaborating but also to developing engineering judgment.

Consider as an example the situation of a mechanical engineering student team designing a small robotic boat, the project in a capstone design class at MIT. Teams begin with a boat kit for the hull but need to make many design decisions, ranging from the purpose of the boat to its propulsion, navigation, and sensor systems, and of course none of these decisions is entirely isolated but will have implications for decisions about other systems. Often, these teams are interdisciplinary, and even if not, students' expertise can be comparatively specialized, with some students more expert in coding Arduinos and others stronger in circuits or fluid mechanics or mechanical design and construction. Consequently, a framework for structured communication and decision-making is central to their ability to successfully complete the project.

Because stasis theory centers on the work of identifying areas of current consensus and disagreement, as well as certainty and uncertainty (uncertainty and disagreement being often aligned), and provides both a sequential process for addressing disagreement as well as criteria for how to reduce uncertainty in each stasis and come to consensus, the theory offers teams a robust method for structuring the communal work of design decisions. All of the design decisions are essentially policy decisions, but disagreements in the stasis of policy are in actuality usually due to disagreements or uncertainty in lower stases propagating through the network. If students use a chart (on paper or on a whiteboard) of the stases for each decision (such as the example in Figure 2), they can easily identify unknowns or disagreement and focus their attention there. Such a chart also serves as a record of both decisions and the reasoning that led to them, ensuring that all members of the team are on the same page moving forward. In our experience, without such a shared, structured framework, students often believe they are in consensus when, in fact, they have quite different understandings of the project.

	Propulsion Option A	Propulsion Option B	Navigation Option A	Navigation Option B
Policy (choice)				
Value (What are the criteria? Which criteria matter more?)				
Causation (What effect does each feature have?)				
Definition (What class or category is each item?)				
Fact (For each option, what are the measurable features—dimensions, cost, power, accuracy, etc.?)				

Figure 2. Example of a design-decision stasis chart. Student teams can fill in each stasis with information they have or agreements they reach; open stases reveal where they need new information or have not yet agreed.

Perhaps as importantly, such a structured record ensures that if circumstances change, such as a part needed for a chosen design not being available, students can easily see whether a simple shift to an analogous part is feasible or where in the stases they need to reopen the discussion—for instance, do they need to reopen the stasis of definition and look at parts from another category of device (GPS rather than sonar?), rethink causation (Will this heavier-than-planned device shift the boat's moment of inertia and thus call for a physical redesign?), or renegotiate trade-offs in the stasis of value (e.g., speed versus maneuverability)?

When consensus is reached at each stasis through shared criteria, and clearly recorded to enable collaborative decision-making to quickly account for changed information or circumstance, the possibility for two major potential problems in collaborative engineering projects are greatly reduced. First, with a structured system for identifying open questions and a method for resolving them, there is less likelihood that disagreements will lead to interpersonal conflict and consequently poor team dynamics and weak decision-making. Second, a clear record of the chain of reasoning that led to each choice reduces the possibility that as circumstances on the ground change throughout the project, revisions to the original plans will be made in a piecemeal and arbitrary fashion within each system, without regard to how local changes affect the system as a whole. Recognizing the potential unintended consequences of design changes is central to engineering judgment, and stasis theory can be a valuable tool for showing these relationships.

Stasis Theory as a Framework for Composing Engineering Texts

As both a rhetorical and critical thinking framework, stasis theory can provide a variety of benefits for students learning to compose engineering texts. Just as students often miss the argument structure of published texts, and initially read primarily for information, they also often write proposals and reports as if they are simply reporting decisions and actions, without linking them into a meaning-making structure. Sometimes they recognize the need to make an argument in the discussion section without recognizing that other sections require clear reasoning structures and that some claims in those sections might be new to the audience or require justification. Stasis theory helps students focus on *convincing an audience* rather than on reporting information. It also helps them link local claims to the larger reasoning structure, understand what evidence is necessary to support claims in each stasis, recognize when to link their claims to those of their sources, decide which claims will require the most space in their text, and structure the internal logic of sections. Finally, if they are writing collaboratively, the various stasis charts they have made during the literature review and project planning stages can help them to divide the writing tasks logically and enhance coherence across separately written sections.

For all writers, composing in genres that are unfamiliar, especially if those genres are also complex, is a very challenging task. As noted above, engineering classes rarely spend much time teaching students to closely read and analyze literature in the field, nor do they assign such reading as a common practice. Consequently, students usually have neither passive nor active familiarity with the kinds of texts they are asked to compose in capstone classes (Conrad, 2017). The very close examination of the argumentative structure of even just one or two published (or model) texts that was illustrated earlier helps students not only to parse the engineering reasoning of relevant sources, as preparation for their own decision-making in project design, but also to build a detailed familiarity with the genre, particularly in terms of how argumentation works in their discipline.

Because “audience” is one of stasis theory’s formative concepts—because it foregrounds meaning-making as not only logical but also dialogical—thinking in terms of stases also means composing with the audience in mind, and increasing students’ audience awareness has long been shown to improve students’ persuasive writing ability (Berkenkotter, 1981; Flower & Hayes, 1980). To determine which stases are open, and thus should be expanded in the text, and which are closed, and thus can be summarized and streamlined, students have to ask of each claim, “Does my audience already know this?” “Does my audience share my view of this?” and “Will my audience be convinced of this, and if so, how?” To gauge their audience’s knowledge, beliefs, and credulousness or skepticism, they can refer back to their own experience of reading the journal articles, as well as that of their team or classmates. What type of claim did they readily accept? Where did they require lengthier explanations? What types of evidence and reasoning (and likely visuals) did they need in order to both understand and be convinced? By triangulating between their position of skeptical reader of disciplinary texts, their position of researcher predicting and confirming—or perhaps disconfirming or being surprised by—the work of their project, and their position of author convincing an audience in their field, students learn early in the research project not only to develop the ability to compose coherent, convincing texts but also to internalize the audience and what it will take to convince them. Importantly, through these movements, because the claims, evidence, and audience are discipline-specific, they also learn to use this general critical-thinking framework in a uniquely disciplinary way.

As will be readily apparent, having stasis-based literature review charts and decision charts created during the work in progress are great aids to composing proposals and technical reports. At the most basic level, drafting from detailed notes is far easier than composing without them. But these charts are in addition already organized in relation to reasoning and argumentation. The stasis structure in the literature review charts reveals where consensus, disagreement, and uncertainty reside in the existing literature, and thus aids the process of summarizing the state of the art and the research gap in an introduction, as well as organizing and synthesizing sources for the background section, justifying methodology and design choices, and comparing results to that of published literature. Similarly, the stasis decision charts created during the design process (whether of a design project or an experimental research project) provide detailed notes of the reasoning that can be expanded into the experimental design and methodology sections of a research paper, or into the subsections of a design report. Here too, the charts not only record information but also structure it in a way that supports an emphasis on the reasoning process, and not just on what was done.

Importantly, not only do these charts enable strong collaboration as a process during the design or lab work, but they also scaffold a collaborative writing process. If teams are jointly writing proposals and reports, as is common not only in capstone project classes but also in academic labs and in industry, shared, coherent documentation of processes, sources, and decision-making are crucial to creating coherent texts. With literature review and design decision charts collaboratively created and shared, writers of each section of a shared document can work independently while confident that their memory and understanding of both sources and the work of the project are consistent with that of their teammates.

Conclusion

As I have shown, the benefits of teaching stasis theory to engineering students are extensive. It can be an aid across the entire spectrum of a project, from analyzing literature to collaboratively designing experiments and projects to composing proposals and reports. When learning to read for micro-claims, their stases, and their relation to other claims in a complex network in which some claims are open and some closed, students are better able to critically assess published research in their field and use it to foster their own approach to research and design projects. For team collaboration, stasis theory offers a systematic process of identifying open questions and charting the reasoning that leads to agreement in design decisions, in such a way that revisions to a design mid-project can be addressed systematically, linking the original reasoning to the new situation and isolating exactly what claims and agreements, in the chain of reasoning, need to be reopened. As an aid in composing texts, stasis theory helps students to focus on convincing an audience rather than simply reporting work.

I have also shown that, as a critical thinking framework, stasis theory is general enough to be taught in a variety of contexts and flexible enough to support rigorous analysis and argumentation in specific fields, such as a variety of engineering disciplines. The stases isolate particular kinds of arguments, teaching students both the conceptual work each kind of argument performs and also what is required to reduce uncertainty or disagreement for claims in each stasis. The stases also show the relationship between claims in a network or knowledge structure and help students understand how local weakness or disagreement can propagate through a complex system of claims. Thus, teaching stasis theory achieves the ends of helping them understand and analyze formal logic and promoting habits of mind conducive to critical thinking. Moreover, because stasis theory promotes both logical and dialogical thinking, it is especially useful for engineers, as it can unite mechanistic and social conceptual realms. Stasis theory is a practical tool for helping students to develop engineering judgment in both the traditional sense and in an expanded sense that recognizes the situational and rhetorical nature of engineering practice.

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