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Visualizing Arguments to Scaffold Graduate Writing in Engineering Education

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Abstract
Many graduate students come to engineering education research with technical backgrounds in engineering. This can present a challenge for them in learning to write social science research, with new expectations around the structure of academic arguments for the field of engineering education research. Existing research suggests that even graduate students familiar with writing strategies struggle when entering new communities of practice and disciplines. Although some scholarship has focused on writing, minimal strategies for encouraging argumentation through a rhetorical approach have been developed for graduate students. Unlike a focus on written product, which privileges sentence-level concerns, a focus on rhetoric functions on a more abstract level, helping students to understand the structure and purpose of arguments as part of the writing process. Our research addresses the struggle many graduate students in engineering education experience as they work to develop rhetorical argumentation skills and presents a rhetorical approach to supporting graduate student writing that focuses on visualizing arguments using page forms. This paper provides both the foundational theories required to understand a visual rhetoric approach, and preliminary data that suggests its impact on graduate students in a doctoral-level engineering education program.

Keywords
Visual page forms (VPF), visual metaphor, engineering education, visualizing arguments, rhetoric, writing, graduate students

Why visualize arguments?

Across graduate education in engineering, the importance of communication, particularly writing, has received increasing attention and for good reason [1]–[4]: communication skills are essential for success in engineering practice, engineering education, and across the academy. For graduate students entering engineering education, the literacy and communication practices required of them can be daunting, in part because their previous discourse communities (usually in engineering) had different norms for writing, speaking, and developing articles than engineering education research, and in part because the development of new knowledge often results in a regression of otherwise effective communication skills [5].

In engineering education, faculty instructors face a particular challenge of teaching graduate students completely new discourse practices, including reading social science and philosophy articles, learning to communicate using non-technical language, and reading and constructing complex arguments that respond to engineering education challenges. This last challenge—reading and constructing arguments—is the focus of this article and the intervention we discuss below. Casey and Alice, two scholars in chemical education and engineering education respectively, teamed up with Kristen and Erica, two rhetorical scholars who focus on STEM communication, to engage students in visualizing arguments as a way of building students' skills in moving into a new discourse community. In this paper, we present a sample teaching case to

illustrate how visualizing arguments might be integrated into other engineering education graduate curricula.

In the case we present here, most graduate students enrolled in Alice's classes were new to the field of social science writing and to the world of academic writing. They were typically in their first semester of graduate school in engineering education, and many of them had been steeped in years of engineering coursework and some had additional years of enculturation working as engineers in industry. Participation in engineering coursework and additional years of enculturation working as engineers in industry can be detrimental to students' graduate writing practice, as writing is not often seen as part of the work of 'real' engineering [6].

Our experience, presented through this sample teaching case, suggests that visualizing arguments (rather than writing arguments) provides students with an approach to understanding arguments outside of the linearity of the linguistic form. This visual approach provides new graduate students in engineering education with an opportunity to engage with ideas more flexibly and challenges them to think more expansively about the ideas they read, synthesize, and develop. In short, visualizing arguments provides students with a strategy for thinking rhetorically about their work and others, and making better arguments in the process.

Writing, communication, and rhetoric in engineering education

Our research and intervention extends from an explicit need: to shift engineering education graduate students from a writing framework to a rhetoric framework. The literature illustrates this need by noting : 1) that undergraduate engineering writing is often (though not always) approached through an a-rhetorical framework [6-10], 2) that crafting arguments (rhetoric) demands different skills than simply writing correct sentences [11-17], and 3) that in engineering education, communication has been acknowledged as an important skill but few scholars have clearly differentiated between the development of writing skills and argumentation skills [18-22].

Undergraduate engineering writing

Graduate students in engineering education programs have typically been trained through ABET-accredited engineering programs. Despite ABET's communication requirement, engineering undergraduate students have limited opportunities to learn to write in their discipline [7]. Often, explicit writing instruction is limited to two courses: one in first-year writing, and one that focuses on engineering writing. The other writing engineering students do is integrated implicitly in design and laboratory coursework. In these contexts, writing practices are often rendered invisible as students are asked to fill forms, draw sketches, and incorporate appropriate equations into reports rather than write essays or reflections [6]. Instructors do not emphasize writing processes, and students do not often receive feedback or formative assessment on earlier stages of their writing. Grades tend to focus on propositional, technical knowledge not writing. [7]. These experiences often leave students untrained in thinking about the rhetorical nature of writing tasks within engineering contexts. Additionally students have limited understanding of the rhetorical nature of engineering writing compared to engineers in the field, suggesting that engineering students lack opportunities to engage in writing meaningfully as a situational and responsive activity [8].

Though writing is often relegated to writing-focused courses or integrated implicitly in course assignments, some researchers have intentionally integrated writing into core engineering coursework. When one instructor added writing for conceptual understanding into undergraduate engineering coursework in a statics class, assignments which had students explain their problem-solving approach to statics problems resulted in improved conceptual knowledge for students and provided them with better learning of the material [9]. Others who integrated team research writing into a core physiology course for biomedical engineers found that students struggled with integrating figures with text to explain ideas, synthesizing ideas from research papers, and structuring papers using headings and designed apprenticeship-based learning accordingly to model appropriate argumentation practices in research writing and communication [10]. Unfortunately, these experiences are rare in the undergraduate engineering curriculum and though they engage students in writing, they reinforce writing as an accessory to arrive at a product.

As a result of their sparse writing education, engineering students often approach writing as a product-driven activity, rather than engaging in the rhetorical processes necessary to develop sophisticated argumentation processes. Genre-driven approaches to writing focus on putting engineering content in the right section of a form, allowing the genre organization to drive the argument and causing the rhetorical work of argumentation to disappear into the genre. The pragmatic framework that engineering students are conditioned to work in presents the issue of students not wanting to make time to think in terms of rhetoric if the end product would need to be presented as linear. Thus, writing is typically abstracted from making sense of engineering, in that students see it as separate from the technical content, calculations, or their identities as engineers [7].

The role of rhetoric in writing

Across rhetoric and writing studies, scholars agree that the effectiveness of any piece of writing depends upon the rhetorical situation: a lab report's effectiveness, for example, can never be determined without assessing who the report is for (audience), what the report is about (purpose), and/or who the author is (context). In engineering, rhetorical effectiveness is sometimes replace with task completion, masking the reflective, knowledge-making affordances of writing. While experienced writers recognize that complex documents are built iteratively and in non-linear fashion [11], many new engineering graduate students tend to think that producing scholarly work is similar to the act of reading it; that is, writing a paper proceeds from introduction through conclusion. Engineering graduate students understand the role of writing in knowledge transformation, and yet they struggle to construct arguments [4]: they struggle to determie what the building blocks of their argument would look like, to determine the order in which to place them, and to filter which details would be useful to their argument from those that are not.

Historically, engineers have often considered writing as purely technical and neutral; however, in recent years, engineering writing scholars have articulated the rhetorical role of writing [12]. Winsor's landmark book, *Writing Like an Engineer: A Rhetorical Study*, presented a longitudinal study of engineering students' writing practices in co-op programs, which revealed that students came to realize through their writing experiences that power relationships and persuasion were important to writing in the field [13]. More recently, Berdanier explored the impact of engineering graduate students' attitudes on the rhetorical strategies they employed in grant

applications and found that students with strong writing attitudes were able to construct arguments in a variety of ways in research proposals [14]. Similarly, an engineering graduate course in publication writing showed that students who participated in the course came to a heightened rhetorical awareness, namely they realized that relationships between the writer, audience, and purpose were important in the construction of texts [15]. These research studies suggest that engineering writing work is rhetorical, contextual, and deeply complex and, as such, rhetoric (in addition to writing) is important not just for student knowledge of writing processes, but also for student understanding of the material.

Rhetorical thinking and argumentation do not occur in a linear fashion: contexts of building arguments and communicating are complicated and difficult to capture. Research on mechanical engineering graduate student writing has analyzed the rhetorical moves that students make in constructing literature reviews to aid in teaching students to incorporate different rhetorical moves in constructing research gaps [16]. Research in disciplinary writing education shows that analysis of discipline-specific texts is an ideal starting point for writing instruction so that students may move to critique disciplinary conventions and draw these practices into their own writing [17]. Graduate engineering students who completed an assignment in a rhetorical analysis of an article published in the field in which they intended to publish found that this rhetorical analysis helped them to better understand the importance of writing for an audience and the expectations of constructing claims in an argument [15]. A rhetorical approach to communication acknowledges the ecosystem of writing contexts; this approach is necessary in all communication—even professional engineering context. Yet, as we discuss in the next section, the contexts of writing for graduate students in engineering education are novel, and the communications practices required for success in graduate-level engineering education makes the need to consider rhetoric an important part of graduate education in engineering education.

Engineering education writing concerns

Engineering education students need to cultivate academic writing skills as a part of their educational experiences, but few programs in engineering education provide formal training to transition from engineering writing to engineering education's more social science literacy practices. Researchers of academic literacies suggest that effective writing instruction ought to include more than just technical writing skills; instead, they advocate training students to consider rhetorical skills beyond the text, such as the power relations that affect student writing, the ideological conventions of writing, and the contrast between disciplinary and general academic practices [18].

When students transition from engineering to engineering education, they are faced with an ontology problem that often shows up as a writing problem. In engineering, reality is taken as objective and knowable through closely controlled measurement), and therefore writing should function like a window pane: a clear plane through which the reader can see the world [19]. As a social science, engineering education research assumes that reality is socially constructed and therefore requires crafting arguments based on researchers' assumptions about reality and how to know that reality. One way this distinction shows up in writing practice is in the use of passive voice. Scientific discourse and academic tone often prioritize passive voice, divorcing the author from the content [20]. For example, quantitative analyses may rely on a third person voice to

preserve an epistemology of an objective and knowable measurable reality. But social scientists and particularly qualitative researchers (like those of us writing) engage with writing differently. When qualitative analyses require researchers to account for subjective reality located from their positionality, they may need to use a first-person voice.

The use of visual representations in engineering education writing also differs from engineering. Students may not have had to explain visuals within texts in their engineering coursework since technical writing in engineering often prioritizes the importance of the visual over that of the written. In engineering education writing, one must also interpret and design different types of graphical representations from what a practicing engineer might. Depending on the sort of inquiry that students will prepare themselves to do, they might need to design and interpret abstract ideas, such as in qualitative work. Conceptualizing metaphors in writing requires that engineering education students, previously trained to think of drawings as illustrations that match up in some way or another to a knowable empirical reality, shift to making use of drawings to represent abstract ideas. To meet the challenge of representing abstract ideas, some research has advocated for the use of mind maps in aiding students in constructing writing. While mind maps can be a useful tool in keeping track of complex writing projects and for getting started with a writing project [20], they do not necessarily have an argument ingrained within them, and are different from the tool of a visual page form which illustrates the rhetoric of a text through shapes [21], [22].

Visualizing arguments and sketchnoting with visual page forms

In rhetoric and writing studies, the importance of including non-linguistic modes in writing instruction has been well-established [23]; students' literacy skills are not (and should not be) limited to linguistic modes because, simply put, rhetorical situations often call for non-linguistic or multimodal responses. In technical writing, this is particularly true: visual and information design are a foundation of effective report writing, professional genres, and data communication [24], [25]. Sketching and drawing as they occur in visual page forms are not merely visual—they are multimodal, often requiring a kinesthetic engagement as well as linguistic modes of communication. This multimodal engagement is also low-tech, freeing students from the kinds of technological constraints that often weigh down visual thinking and communication [21].

Outside of rhetoric and writing, sketching and drawing have been adopted as strategies for collaboration and leadership [26], [27], and sketchnotes, specifically, have also been used as a listening and notetaking strategy [28]. Drawing activities provide the basis for design work [29], [30], user experience journey mapping [31], [32] and the development of syllabi [33], [34]. In a workshop at the Association of Computer Machining's Special Interest Group on the Design of Communication, Kristen (along with co-facilitators), synthesized rhetorical studies' approaches to visual communication and these other interdisciplinary approaches to sketching and drawing, arguing that drawing provides affordances for teaching students to listen, collaborate, and communicate in dynamic and sophisticated ways. These affordances do not require (or teach) advanced drawing skills; instead, the affordances are rhetorical and epistemological: drawing can help us think across purposes and make new knowledge about concepts as we learn them.

About the case: Integrating visual arguments into engineering education courses

In order to explore the role visuals might play in assimilating graduate students into the rhetorical writing practices of engineering education, the authors of this article integrated explicit training on drawing and visual page forms into a graduate level engineering education course. Our focus is on a first-year graduate course for the PhD program in engineering education at Casey and Alice's university; we first explain how the authors entered into the case.

Alice and Casey's narrative

Most students come to the course with at least one degree in engineering, and many come with professional engineering experience, whether in the US or abroad. A key learning objective is to help students with engineering training and experience start to learn the genre of academic writing in the field of engineering education research, both as readers of writing, and as writers themselves. Historically, students have struggled with the ontological and communication shift we describe earlier, as the course seeks to initiate students into a reflective culture that acknowledges and appreciates the ways knowledge has been socially and historically constructed [35]. The course is designed to help students meet 4 competencies in our graduate program: Synthesize knowledge, Communicate knowledge, Think critically and reflectively, and Participate actively in a professional community.

In previous years, instructors including Alice have organized the writing in the class into reflective writing and argumentative writing. For many years until 2019, students wrote reflective posts on a discussion board to help them prepare for in-class discussion, and then a series of 10 page (or so) essays answering the questions, what is education? What is engineering? And what is engineering education? The pedagogical reasoning behind this assignment organization was that their early papers would be revised with the submission of the next essay– but it was clear that students also struggled with how to revise their arguments rather than beginning again from scratch.

In Fall 2017, Alice shifted to a different model. She wanted students to see long-form academic argumentation in the form of books, and so asked students to choose a book on engineering or engineering education scholarship, and then integrate it with the shorter readings throughout the semester in a longer essay submitted by the end of the term. Alice also incorporated more peer review and drafting into the process of writing that single longer essay, and tried to revise how she gave feedback, taking cues from Haswell's "minimal marking' paper [36].

In Spring 2019, Alice learned about Kristen's work on visualizing arguments. Simultaneously, Alice was revising the course to be able to be presented online pre-COVID (although with synchronous components). Alice and Kristen worked together over spring 2019 to incorporate some of the ideas Kristen had been developing into the course. Kristen advised on a structure to introduce the content, suggested papers, modeled graphical page forms on papers my students were reading, and Kristen's graduate student, Kehinde, produced 4 introductory videos for Alice's students to watch.

Casey, as a scholar in chemistry education, took a different course with Alice on race, class and gender in engineering education. They enjoyed working together, and Alice invited Casey to serve as a faculty apprentice in the course analysed in this case. Casey, being from a disciplinary education area, had recently traversed the path from a scientific discipline to the social science

domain of disciplinary education research that first year engineering education students were traveling in the course.

Erica and Kristen's narrative

In order to support engineering education graduate students' development of rhetorical reading and writing skills, we (Kristen and Erica, with Kehinde's help) developed videos with content that introduced key concepts on sketchnoting and a workshop to introduce students to how we have used drawing in our own work. In the videos, we offered students instructions on seed shapes (see Figure 1) and sample page forms (see Figure 2) that allowed them to begin thinking non-linearly about the content of the course. These scaffolded videos aimed to offer students the basic building blocks visualizing arguments and provided some early rhetorical training. In Table 1, we provide an overview of the key topics and takeaways from each of the videos.

These building blocks were the foundation for teaching students to think about visual metaphors. Page forms do more than simply organize ideas: they create visual metaphors for exploring the relationships among ideas in an argument. The page forms we used with students allowed them to play with the relationships among ideas and explore the rhetorical ideas in their own and others' articles.

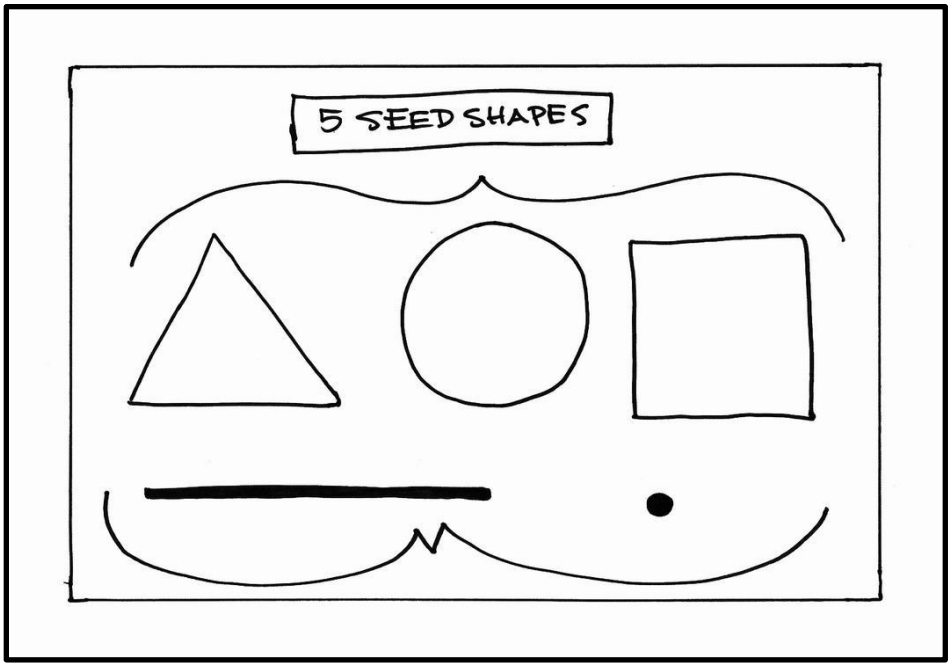

Figure 1: Drawing of 5 Basic Seed Shapes from Kristen's Workshop Videos
[Alt text: A hand drawing containing a heading at the top that says "5 Seed Shapes" inside of a rectangular container. Representational shapes include an equilateral triangle, a circle, a square, a straight line, and a dot.]

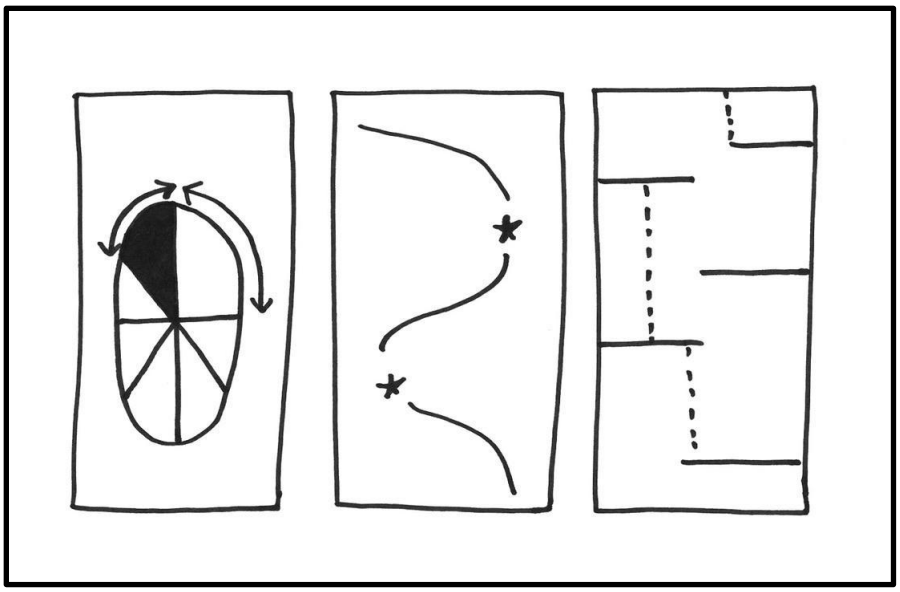

Figure 2: Sample Page Forms
[Alt text: A hand drawing containing relational shapes made from the 5 basic seed shapes in Figure 1. Page Forms to show metaphorical and conceptual relationships (e.g., a pie chart with arrows, a curved line broken up by stars; a metaphorical brick wall created from solid lines and dotted lines.]

Table 1: Overview of Video Topics and Key Takeaways

Video Topic	Key Takeaways
Drawing the 5 Seed Shapes	a) You don't have to be good at drawing to do this; b) You can draw anything with the 5 seed shapes
Understanding Relational Drawing	a) We can create new meaning when we draw relationships b) Relational drawing requires visual metaphors.
Page Forms, Containers, and Connectors	a) Page forms begin to structure visual metaphors and relationships b) Two key tools in articulating or discovering relationships are containers (what belongs together?) and connectors (how are these ideas related?)
Drawing Other People's Ideas	a) Page forms can help us understand other authors' arguments and discover gaps or tensions we experience; b) VPFs can be combined and recombined to show the relationships among particular article/argument sections

As an example of the way page forms work, we provide two drawn versions of this paper: a) the relationship among key ideas in the above review of literature and b) the key structure of the argument. Figure 3, for example, illustrates the way a common visual page form, the upside down triangle, can illustrate the relationships among rhetoric, writing, and grammar. Simple additions to that triangle help to articulate where our paper topic. In Figure 4, a different page

form is used to explain the structure of the argument. Both examples rely on seed shapes to explore the paper you're reading.

One of the key benefits of visualizing arguments as opposed to reading and writing them is that students can get "unstuck" from the linearity that texts impose on ideas and learn to read arguments more dynamically. To demonstrate this point, Kristen and Erica attended Casey and Alice's class and facilitated a workshop that supported students' development of skills.

During the workshop, Kristen and Erica illustrated their uses of drawing and sketchnotes and offered an opportunity for students to discuss the process of drawing. As one of Kristen's former students, Erica had both learned to draw from taking courses with Kristen's and also over time have adopted the practice of drawing as well. Working together, we offered students a glimpse into the messy and sometimes ugly work of drawing.

We demonstrated three ways that we use drawing in our own work: listening (Figure 3), reading (Figure 4), and ideating (Figure 5). In addition to providing an opportunity for students to hear how others used visual page forms, the workshop helped to solidify how visualizing arguments provides a way to think non-linearly about an argument's anatomy. Additionally, our workshops provided an opportunity for engineering education students to see how VPFs 1) get better with practice, and 2) provide an alternative way to deconstruct, and in some cases reconstruct, complex arguments and disciplinary concepts.

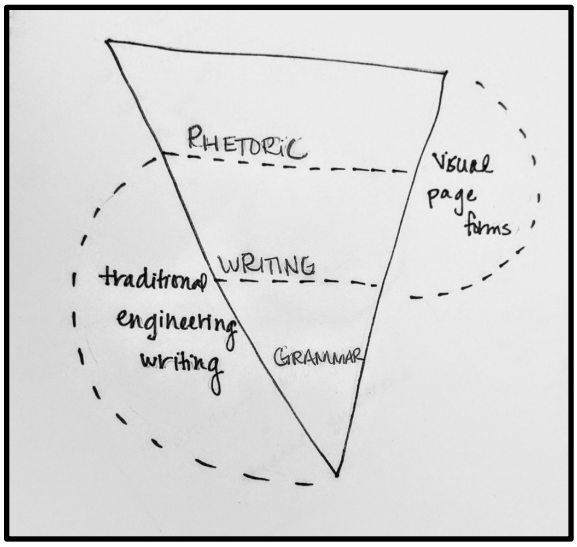

Figure 3: A hand drawn example of how one page form can be used to explain the relationships among key ideas in this paper.
[Alt text: Upside down triangle split into 3 sections labeled: rhetoric, writing, grammar. On the left side, a bracket appears with the words "traditional engineering writing." On

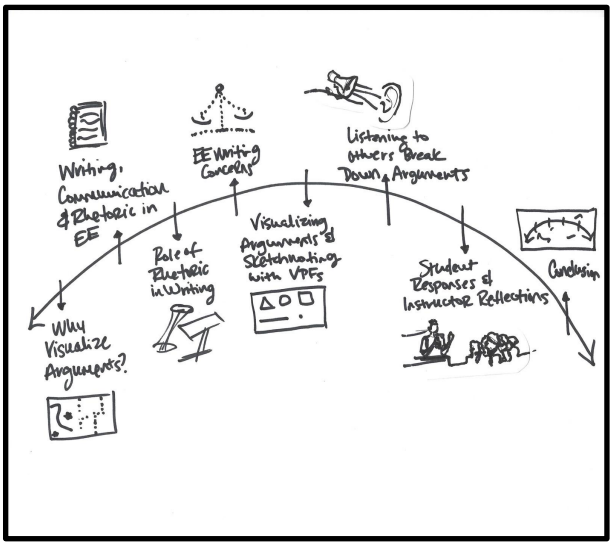

Figure 4: A hand drawn example of how one page form reveals the structure of this paper's argument.
[Alt text: A journey arch that maps the phases of our own writing process for this paper. Each tick mark on the timeline is labeled to match the section titles and smaller VPF drawings that represent each phase appear above them.]

the right side, a bracket contains the words "visual page forms."]

Table 2: Workshop Demonstrations and Takeaways

Workshop Topic	Key Takeaways
1. Listening to others using VPFs	Kristen and Erica demonstrate how working with VPFs as a listening tool gave Erica the opportunity to play and practice with the page.
2. Reading and interpreting others' work	Kristen and Erica demonstrate how VPFs provide a foundation for understanding complex texts.
3. Ideating using VPFs	Erica demonstrates how VPFs allowed them to ideate during her dissertation-writing process.

Workshop demonstration 1: Listening to others break down arguments using VPFs
The content of the vidoes and the workshop extended from Erica's experience during a graduate course in 2016, Kristen drew this image (see Figure 5) during a class meeting to show her graduate students how to visualize other scholars' arguments using VPFs. As a new graduate student, Erica found the experience of watching someone else draw a set of arguments and discuss the drawing process in real-time to be an important step in using VPFs as both visual and conceptual metaphors.

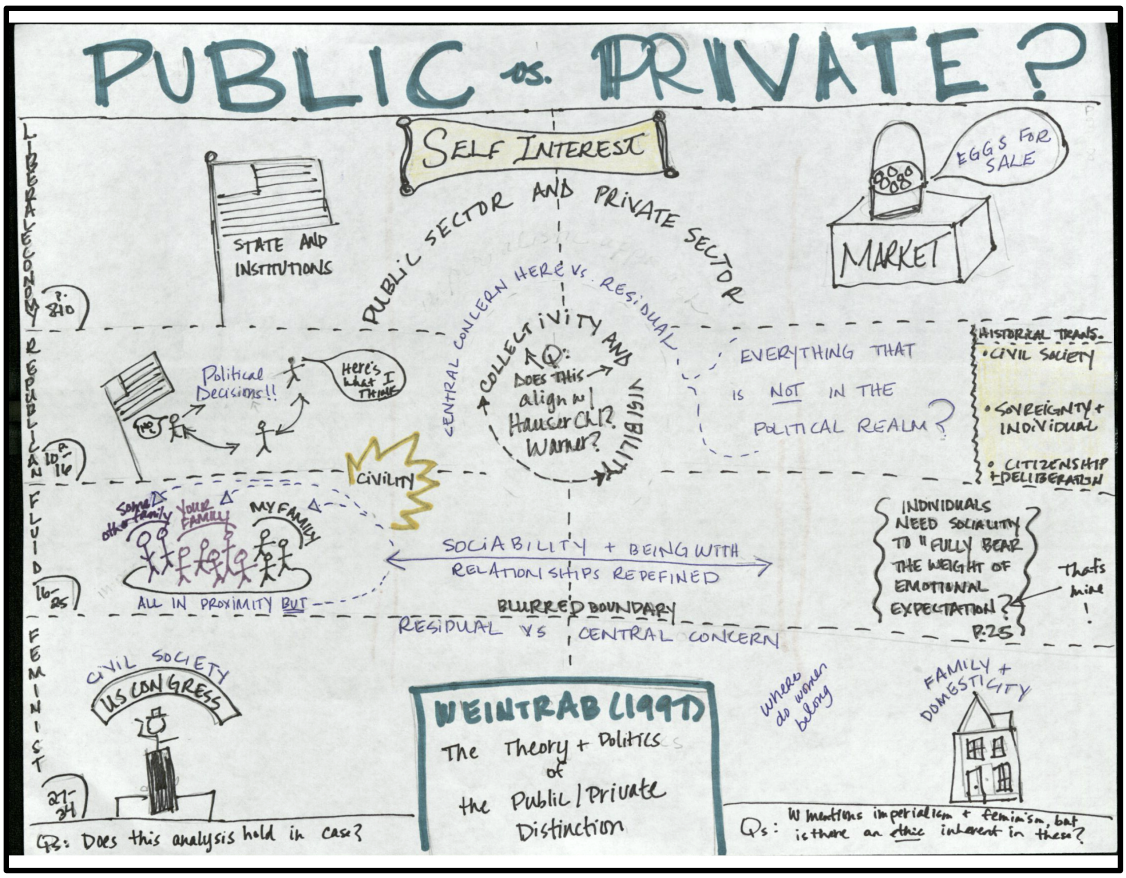

Figure 5: Drawing of Weintrab's (1997) Theory of Politics and the Public/Private Distinction [Alt text: A hand drawing containing words and images that depict the salient arguments from Weintrab's article. Representational images include an American flag, a group of people, and a house. Relational seed shapes and page forms include dotted lines, squares, and circles.]

Workshop demonstration 2: Reading and interpreting other scholars' arguments using VPFs
After watching Kristen draw others' arguments, Erica began to draw their own experiences reading and interpreting other scholars' arguments. As a new VPF user, they had a difficult time understanding how to draw conceptual metaphors. To start, they tried to represent visual metaphors in existing objects. For example, instead of using the seed shapes or VPFs shown in Figures 1 and 2, they relied on existing ecological metaphors, like a flower, to describe their reading experience and interpretations of Hart & Conklin's description of qualitative and quantitative methods in technical communication [37].

Because the U.S. education system introduces metaphors within the context of figurative language, we often drop metaphors from our proverbial "toolbox" when we move into technical spaces like engineering or technical communication. But metaphors aren't just tools for comparison; they're also thinking tools and conceptualization tools. When moving from metaphor as a representational comparison tool to a conceptualization tool, it's often tempting to use existing metaphors, like a flower (see Figure 6), that feel easily drawable.

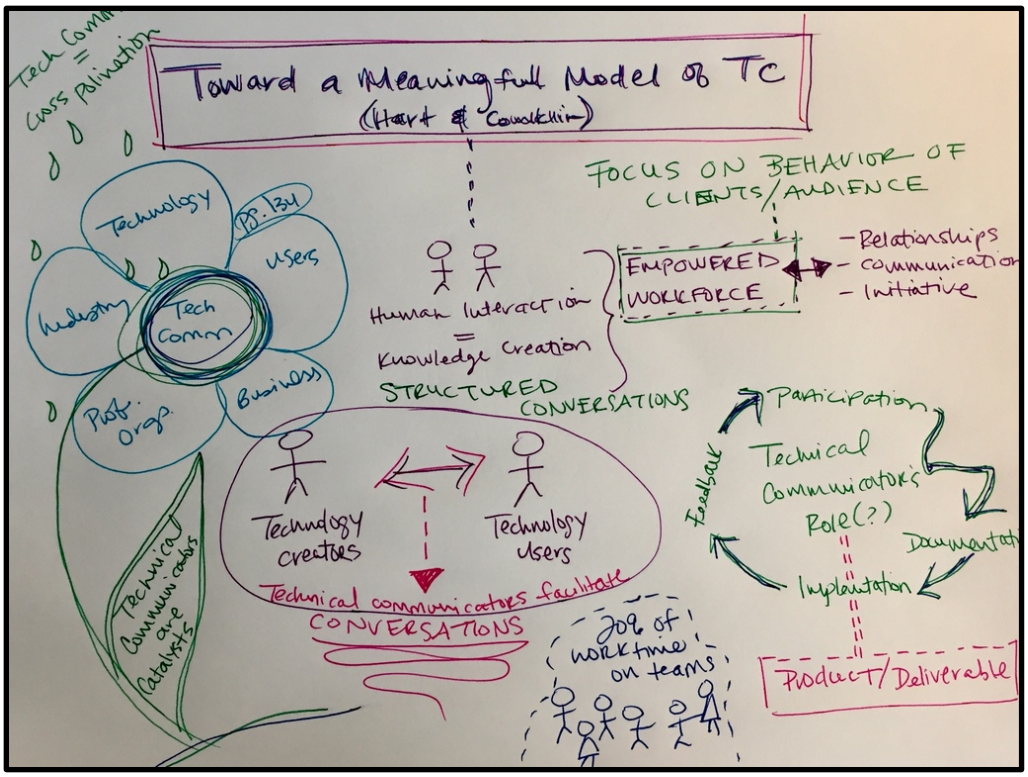

Figure 6: Drawing of Hart & Conklin's (2011) Toward a Meaningful Model of Tech Comm [Alt text: A hand drawing containing words and images that depict the salient arguments from Hart & Conklin's article. Representational images include a flower, raindrops, and people in conversation. Relational seed shapes and page forms include dotted lines, squares, and circles.]

Workshop demonstration 3: Ideating arguments using VPFs

When beginning my dissertation in 2018, I (Erica) began to use VPFs to ideate my own arguments and dissertation plans (see Figure 7). As mentioned in our Visualizing Arguments and Sketchnotes section, the affordances of VPFs are both rhetorical and epistemological; they help new scholars, like myself, think across purposes and make new knowledge and develop concepts.

When drawing visual metaphors or using VPFs to ideate their own arguments for the first time, students face two particular struggles: 1) thinking with the page as the metaphorical plane; and 2) failing to move from representational images as metaphors (e.g., flowers, raindrops) to relational page forms and seed shapes (e.g, dotted line, arrows) as visual metaphors. The literal and dismissive treatment of metaphor in most higher education spaces and academics' inability to work abstractly in visual spaces is the cause of this disconnect. We understand graphics and visual representation very well, but we don't understand how to think in metaphors as if they are similes on the page. VPFs help us engage in this kind of conceptual, relational thinking.

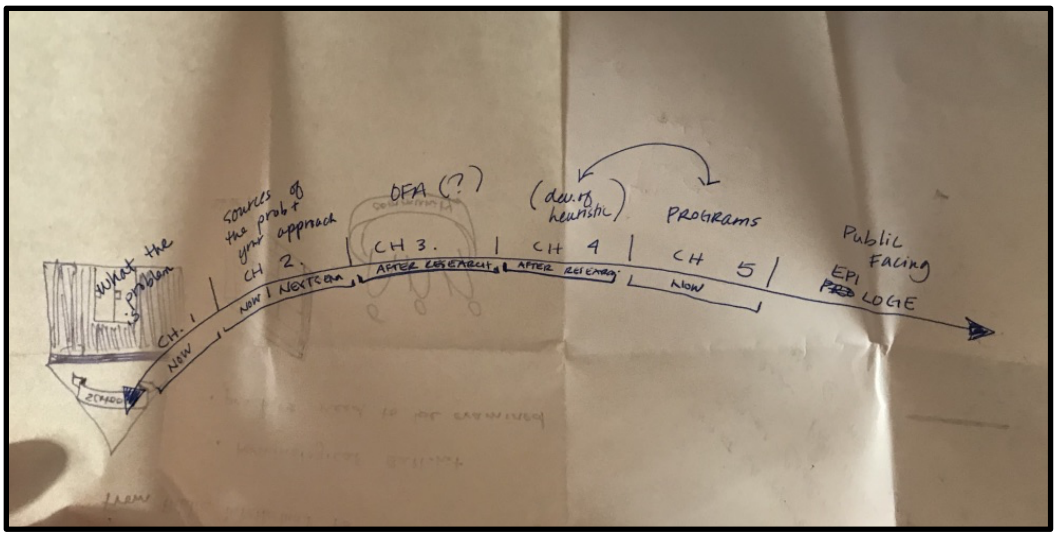

Figure 7: Drawing of Erica's dissertation plan as of March 2018
[Alt text: A hand drawing of a dissertation plan and organization using an arrow and journey page pattern.]

Student responses and instructor reflections
In order to understand how and if these approaches worked for students in the graduate engineering education course described earlier, we collected both informal data, including anecdotes from students and TAs, reflections from student drawings, and more formal data, including student evaluations and semi-structured interviews. Although the purpose of this article is not to focus on the interviews as a study, we include the interview questions and other study details in Appendix A.

Visual metaphors and conceptual thinking
One of the key concepts at the center of this instructional approach was visual metaphor: VPFs allowed for the structure of arguments to take shape in new ways. As introduced in the videos, this page form presents a visual metaphor, or set of relationships among ideas on the page. However, students struggled to shift from conceptual metaphors to visual metaphors, and this struggle is particularly clear in the way students used icebergs, for example, as metaphors in the course.

The iceberg metaphor is useful for many concepts because it prompts us to consider what might be hidden from our view. For example, a number of memes employ the visual of the iceberg to demonstrate the way much white supremacist and racist ideology is invisible. Throughout the classes, students relied on the iceberg metaphor (among other known metaphors like a flower or bridges over rivers or across oceans, plants growing, magnifying glasses, running tracks with hurdles on them, paths through a forest) to conceptualize and visualize specific ideas (such as connecting theoretical frameworks from different disciplines, developing one's understanding of a particular topic, using a new theory on an old problem, conceptualizing of why engineering remains largely demographically homogeneous, describing an educational journey). Students relied on conceptual metaphors that they could capably draw such as icebergs, umbrellas and rainstorms, rather than visual metaphors, such as circles drawn overlapping, or concentric circles that would have allowed them to discover new relationships or structure arguments in new ways.

Part of the issue with conceptualizing metaphors was that engineering students are trained to think of drawings as illustrations that match up in some way or another to a knowable empirical reality. When using the term "metaphor," the transition from conceptual to visual metaphor challenges students; instruction in visual metaphor can draw on known conceptual metaphors in order to aid students in this transition. Additionally, explicit clarification of terms (as shown in Table 3) can aid students in differentiating among the related, but different terms.

Table 3. An overview of key terms for students.

Term	Definition	Example
Metaphor	A figurative language strategy where the meanings of one term are applied to another.	White supremacy is like an iceberg.
Visual metaphor	A communication strategy where the graphical image meanings are applied to a concept or term; or, any time a visual stands in for one of the comparisons in a metaphor.	Figures 5 and 6, or drawing a picture of an iceberg to explain white supremacy, or drawing concentric circles to explain the relationship between white supremacy, patriarchy, and heteronormativity
Representational Images as Conceptual Metaphor	A type of visual metaphor where a representational image is applied to a concept or idea;	Drawing a flower to demonstrate ideas or arguments (as in Figure 6), or drawing a picture of an iceberg to explain white supremacy
VPFs as Metaphors	A type of visual metaphor where an abstract page form or layout is applied to a concept or idea.	Figure 3, or drawing concentric circles to explain the relationship between white supremacy, patriarchy, and heteronormativity

The differentiation between visual and conceptual proved difficult for students in Alice's engineering education course as it did for students like Erica in Kristen's courses. The struggles relate to three historical and cultural tendencies in higher education: 1) we have historically dismissed the page and drawing as a meaningful and sophisticated epistemological tool: serious thinking happens in words, and if it happens visually, it happens with data; 2) the use of metaphor as a sophisticated tool rarely ports into technical spaces, and 3) students rarely have an opportunity to think in graphical planes.

By graduate school, students remember metaphors as simple, rudimentary similes rather than metaphors that allow us to do complex and sophisticated intellectual work. In introducing "visual metaphors," we confused students in the course. They heard metaphor and thought, "Oh, what can I draw that represents this idea?" The answer: a flower (see Erica's example above)! Or an iceberg! Or a donut! The move from representational drawing to relational drawing can only be accomplished when we break away from representational shapes and move to non-representational and relational seed shapes, page forms, and more abstract, metaphorical (not

simile) thinking. This struggle is not to suggest that students were doing it wrong; rather, students taught us that we as instructors were teaching it wrong. In future iterations, we will introduce metaphors more slowly: from conceptual metaphor to drawing conceptual metaphors to drawing visual (relational) metaphors.

Collaborative drawing and group work with drawing

Throughout the semester, students were asked to work in groups to visualize arguments that they'd read or were developing as a part of their own writing process. The collaborative drawing proved difficult but rewarding for students. One student discussed the difficulty in this way:

> "[P]eople were imagining different metaphors...so then, then combining people's metaphors [was hard] because I mean, obviously all the ideas are great, but then you can only have like one drawing...I think it was harder to do it with maybe like, you know, having more voices and knowing how to incorporate everyone's ideas."

The difficulty of drawing collaboratively wasn't something we authors discussed ahead of time, and students struggled to draw in ways that could accommodate all of the ideas brought to the discussion. Yet, showing different drawings provided an opportunity for students to think about the content in a number of ways.

Collaborative and group work were an essential part of learning to think with the page. As we continue to teach with visual metaphors, the scaffolding we describe earlier can focus group drawing and collaborative visual thinking in a number of ways. We can first focus on the drawing activities: students can be assigned specific conceptual and visual metaphors to work with, such as "use a flower this time, then use these visual page forms and seed shapes." Then, students will have a shared visual language before exploring with the page forms and engaging with visual metaphors.

The new scaffolded approach to visual metaphor should also help students as they move from reading others' ideas to thinking about their own ideas through visuals. Throughout the course, students were routinely asked to draw authors' arguments; they were also asked to read literature and visualize the arguments within. These tasks were challenging for the students because students had to focus on both the content and the structure of the argument. Both in groups and individually, the shift from understanding the ideas to seeing the structure was difficult but the process was aided by the act of visualizing. One participant called this a "mental shift," suggesting that by the end of the semester, they'd accomplished the shift. It wasn't until they began ideating and drawing their own ideas that the shift was really clear. An increased attention to non-representational drawing should aid students as they make this shift.

Nevertheless, we are encouraged by the results of our early instantiations of teaching visual arguments. By the end of the semester, participants shared that they'd begun using drawing both in their own writing and in data analysis, even outside of class. For example, one participant used page forms and visual arguments in their work with an NGO; another participant began using visualization to develop new coding structures for their data. This suggests that by the time students began writing with visuals, the visual instruction had provided the foundation needed to transfer the content into other contexts.

Conclusion

This demonstration case found that visualization and page forms can provide an intermediate step for novice engineering education graduate students making the transition from engineering writing to social science writing. It emphasizes that the process of writing is not linear and gives students additional strategies for composing effective arguments. Visualizing arguments prompted students to think about rhetorical arguments and structure in ways that they had not historically done.

After several semesters of implementing this strategy, we have made some changes based upon students' feedback, including moving the workshop earlier in the semester, and emphasizing openness and invention during the drawing phase (rather than correctness of the use of page forms). Students' feedback will continue shaping our process as we continue the use of visual page forms. While this paper provides only limited empirical evidence of the effectiveness of this approach, we plan to continue research on the impact of visual page forms on engineering education graduate students' writing practices. While this work is early, it provides an instructional intervention that supports the disciplinary border crossing required in the education of disciplinary education researchers.

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Appendix A: Methods & Interview Questions

The purpose of this qualitative analysis is to understand how students in an engineering education course learned to use visual page forms in their development as writers. Specifically, we sought to understand students' perception of the visual work as relevant to their reading and writing practices and to probe students' reactions to integrating visual work into their coursework. As noted within the article, we did not view the interviews and their associated data as a complete study, but rather an opportunity for qualitative feedback on the graduate students' experiences with visual page forms. In this appendix, we offer our guiding questions, a brief summary of our methods, and a copy of the interview questions.

Guiding Questions

1. After completing the course, do students find visual page forms useful and/or relevant to their understanding of course content and their own writing and reading practices?
2. After completing the course, do students characterize visual work as a positive part of their learning experience? If so, in what ways did the visual work create a positive learning opportunity? If not, why not?
3. How do students understand the connection between visual page forms and other forms of written discourse?

Methods Summary

In order to understand student experiences with learning visual page forms, we developed a(n IRB-approved #FWA00008824) qualitative, semi-structured interview protocol (see below) to learn from students who were enrolled in the engineering education courses where our workshops took place. At the time of this writing, only two interviews have been completed and analyzed. In order to protect the identity of the current participants, we omit most details about the participants and their identities.

Interview Questions

WARM-UP

Tell me a bit about yourself as a scholar--background, how long you've been enrolled., etc. What motivated you to enter the field of engineering education?

RECALL

As you know, this study seeks to understand how the work with visual page forms worked for you as a student. Can you describe how visual page forms were integrated into your ENE 502 course? How did you/the class use/integrate visual page forms throughout your semester?

PERSONAL STORY

Can you describe any moments when visual page forms helped you understand your own thoughts or someone else's more effectively?

CONTEXT FOR INVENTION

Tell me about the process of developing one of your page forms--what tools do you use [the stuff of writing?]

Do you think you'll use visual page forms in the future? What aspects do you think you would need more about, or practice would you need to be able to use them effectively in your research work (or elsewhere)?

Do you have any suggestions for improving the use of visual page forms in the future? (Follow-up: how could we have used VPFs differently? What additional information/[or something else] would you like to have had?