Diagrams as an Instructional and Communicative Medium for Engineering Students

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Over the past three decades, writings studies scholars have had a spate of interest in the literate lives of engineers and scientists. Several scholars have researched the role that texts play in the communication process for engineers and students. Dorothy A. Winsor explains the role of writing in providing communal knowledge for engineering work (*Invention* 247) and she reveals the importance of writing in communicating to managers and peers in an engineering center (*Writing* 87). Mya Poe, Neal Lerner, and Jennifer Craig discuss the role that writing plays in crafting professional identities for engineers (48). Christopher R. Wolfe explains how argumentation is heavily used by engineers to communicate with clients and mangers and the role that written communication plays (208). Additionally, the role that texts play in learning and report writing for scientists and engineers has been researched by Catherine Prendergast and Winsor. Prendergast found that, instead of being the main focus, writing is merely one of the many activities that plays a role in lab-related learning (16) and Winsor found that technical writing is not only essential to completing reports, but it is essential to completing the work that precedes the report (*Invention* 247). Diagrams present an expansion to traditional views of literacy within the engineering student discourse community.

While these existing studies have emphasized the role that literate activity plays in communicating and learning information through traditional text, they have either not addressed or have underestimated the role that diagrams play in these same activities. Diagrams allow introductory engineering students to learn complex information quicker and more effectively as well as allowing these students to communicate complex information faster and more effectively. In addition, these processes are interdependent because the process of composing and inscribing a diagram allows it to become a channel of communication, and the process of interpreting a diagram represents an understanding of that channel of communication and illustrates a successful diagram inscription.

Diagrams are more relevant to traditional notions of writing, composing, and inscribing writing-to-learn (WTL) literacy practices than has been previously discussed, and the view of writing in the scientific community should be broadened to incorporate previously overlooked texts, such as diagrams. Other scholars have also agreed that "we do not yet know enough about writing in the sciences," especially when referring to the traditional WTL literacy practices (Prendergast 2). The creation and utilization of diagrams represents a learning process that rivals academic paper writing as demonstrated in WTL literacy activities, so much so, in fact, that many professors of science-related fields often forgo academic paper writing in favor of lab work (Prendergast 3). This lab work involves interpreting and creating diagrams as a part of the learning process for the students involved, therefore demonstrating the relevance of diagrams to learning and communication.

The utilization of diagrams in the lab setting brings up another important concept: the idea that objects and data can be represented as visual text. Transforming objects into visual texts and communicating the information present in those texts becomes an interesting concept when applied to the creation and interpretation of diagrams. The process of "inventing" content for traditional writing draws parallels to lab work, as well as the process of collecting data for a diagram. This technical inventiveness is often referenced as the process prior to inscribing the material for members of the scientific and engineering community (Winsor, *Invention* 228). This reveals that student learning, whether it stems from an experiment or a professor, ends up being processed into an articulated text. The process of inventing and writing content is revealed to be mutually dependent (Winsor, *Invention* 229) in the same way that interpreting diagrams and creating diagrams are mutually dependent. This demonstrates the vast amount of information and learning that can be incorporated into diagrams, and why it is such a critical skill for introductory engineering students to develop. The ability to create a diagram is not limited to transferring an object or concept into text; it also involves the ability to effectively communicate that information through the visual medium of a diagram.

Diagrams are more relevant to traditional notions of "inventiveness" and WTL literacy practices than has been previously discussed.

My inquiry was guided by these key research questions:

> *Research Question 1:* How do engineering students' use of diagrams facilitate their learning of complex concepts and information?
>
> *Research Question 2:* How do engineering students communicate complex information through diagrams, and what skills do they use to collect and format that information?
>
> *Research Question 3:* How do engineers use technology and physical mediums to create diagrams?
>
> *Research Question 4:* How and where do engineering students learn the skills required to interpret and create diagrams effectively?

Overall, the answers to these questions suggest a much more involved role played by diagrams in the literacy lives of engineering students. Therefore, diagrams are more relevant to traditional notions of "inventiveness" and WTL literacy practices than has been previously discussed, and the view of writing in the scientific and engineering community should be broadened to incorporate previously overlooked texts, including diagrams.

This article will be structured as follows. I will begin with the methods I utilized during this study, move on to a case study with a specific point for each of my two participants, and finish with conclusions and implications for this study and future research.

Methods

In this section I will address multiple facets of the methods that I employed, including the participants, setting, data collection, interviews, and analysis of the interviews and texts collected.

Setting

Since my study involves the use of diagrams by introductory engineering students, the participants I selected are all freshman within the engineering program at the University of Central

Florida (UCF). These participants were all enrolled in the Introduction to the Engineering Profession (EGS) course at the time of the study. This course has a lecture and a lab component, each with different goals. The lecture component introduces guest speakers with presentations to assist these introductory students with declaring a major and getting involved in organizations, and includes a companion text called *The Engineering Survival Guide*. The lab component introduces the students to the process of engineering and familiarizes students with group cooperation and tactile lab work. The lab component introduces these skills through a small robotics kit called the Boe-Bot robotics kit. This kit comes with an accompanying online manual called *Robotics with the Boe-Bot* that details the process to construct and perform the activities associated with the Boe-Bot.

Participants

I interviewed and collected data from two specific introductory engineering students: Timmy and Kenneth. I must disclose that I am an introductory engineering student, and that both of my interview participants are high school acquaintances of mine. Both participants have had prior experience with engineering through a high school engineering magnet program called Global Technologies, and have had limited experience with an engineering program called Project Lead the Way. The significance of this is that my participants have experience with the 3D modeling program SolidWorks and creating novice engineering notebooks. Since these experiences were in high school and not every engineering student gets to have them, I made my inquiry specific to their experiences utilizing diagrams within the introductory EGS course. In addition, the data I collected also represents core concepts from the EGS course that each engineering student has to learn. These two factors allow my inquiry to become a better generalization of the importance of diagrams within the entire population of introductory engineering students at UCF.

Data Collection

In order to collect the data for my inquiry, I conducted two interviews with each of the participants and collected verbal accounts of the types of diagrams that they utilized. I also collected samples of the types of diagrams and noted things like the format and medium that they used for each diagram. The interviews consisted of questions that inquired about the student's major, the types of diagrams they used, the medium they utilized, the situations or classes in which they utilize diagrams the most, the purpose of their diagrams, and where they learned to use diagrams. Each of these questions helped me collect data that provides a better understanding of their interaction with diagrams.

Timmy

In this section, I will explain how Timmy communicates information quicker and more effectively through the diagrams that he creates. Before I begin my case study, I want to give some background on Timmy. Timmy is a 19-year-old introductory engineering student at UCF. His major is currently declared as mechanical engineering, and he is currently taking several classes on the track towards his major including Principles of Chemistry, Calculus I, and the Introduction to the Engineering Profession course. I will specifically be looking at Timmy's interaction with diagrams with respect to the Introduction to the Engineering Profession (EGS) course because this course is aimed at getting students acclimated to the kinds of work engineering entails.

Timmy creates a multitude of diagrams for his EGS course and many of these diagrams have to do with a robotics kit called the Boe-Bot. The kit involves constructing and coding a small robot that has several abilities such as locomotion, sound creation, tactile sensation, light sensation, and infrared sensation. Figure 1 is an example of a diagram that Timmy has created to compare the code values for pulses of electricity to a servo and the resulting speed of that servo.

	B	C	D
1			
2			
3	Pulsout Duration	Rotational Velocity (RPM)	Pulse Width (ms)
4			
5	650	50	1,400
6	655	45	1,410
7	660	45	1,420
8	665	45	1,430
9	670	45	1,440
10	675	45	1,450
11	680	45	1,460
12	685	45	1,470
13	690	50	1,480
14	695	50	1,490

Figure 1: Timmy's EGS diagram.

This excerpt of a diagram was created as part of an assignment given to Timmy by the teacher of his EGS lab. It was assigned and completed on September 25, 2015 and was completed in a spreadsheet program called Microsoft Excel. The purpose of the assignment was to assign code values to servo speeds in order to optimize the Boe-Bot's motion. The Pulsout Duration column values represent the code values, the Pulse Width represents the number of pulses per millisecond, and the Rotational Velocity represents the servo speed. Timmy had to test each value through observation and record his results in this diagram to reveal the optimum values to use for each velocity. He used this to understand the relationship between the code values and the speed of the wheel. Timmy received an A for his work on this assignment.

Timmy's creation of this diagram not only helps him complete the assignment and optimize the use of his Boe-Bot, but it also creates a channel for communicating the information about his Boe-Bot.

First, Timmy uses qualitative analysis to represent his Boe-Bot as a text. By experimenting with his Boe-Bot and recording the data that he receives, Timmy is able to compile a resource that allows him to utilize qualitative analysis. After analyzing the data, Timmy is able to gain an understanding of the speed of his servos in relation to the code he uses to operate the servo. This is also where Timmy learns the most about his Boe-Bot. It is clear that the initial recording of this data represents his understanding of his Boe-Bot's physical characteristics. Through this process, Timmy selects the qualities of his Boe-Bot that he wants to represent and communicate. These events form the initial transfer of physical characteristics to text.

Second, after the initial transformation of his Boe-Bot to text, Timmy further transforms that text into a visual format. He does this by formatting his data into the aforementioned Excel table. By carefully formatting his data into several columns that make it easy to interpret through qualitative analysis, Timmy transfers his knowledge of his Boe-Bot's physical characteristics and corresponding code into the visual text of a chart. This visual text then represents the servo speeds of the Boe-Bot and allows Timmy to easily understand the relationship between the pulse count and servo speed, without physically interacting with the Boe-Bot. This visual text format aids Timmy's understanding of the Boe-Bot and allows him to represent a large amount of data clearly with a diagram.

Finally, Timmy's visual text forms a channel for communicating his information to others. By representing his Boe-Bot as a text in a visual format, communicating his data requires very few words in the traditional sense. Timmy lets the format and structure of the diagram, and the data, do the communicating of the properties of his Boe-Bot to his instructor. Through using diagrams to communicate, Timmy and his instructor both feel the benefits of this quicker and more effective form of communication. Instead of writing several paragraphs or a paper on the subject of his Boe-Bot, Timmy is able to speed up the composing process of his text, and is able to show the reader his data and the relationship between them. In addition, his instructor can directly observe the relationship between the Pulsout duration and the servo speed through quantitative analysis without extraneous wordy explanations. This demonstrates how Timmy's creation of a diagram becomes a method of communicating.

Overall, by turning the physical characteristics of his Boe-Bot into a text, and then converting that text into an Excel diagram, Timmy is able to facilitate the communication of information to himself and others. In the context of the assignment, Timmy was able to compose his text faster, his instructor was able to interpret it faster, and the information about his Boe-Bot was able to be communicated quickly and clearly.

Kenneth

In the previous section, I addressed how Timmy communicates information with his EXCEL chart for an assignment in the EGS lab. In this section, I will address how Kenneth utilizes diagrams to learn quicker and more effectively. I will begin with some background on Kenneth. Kenneth is an 18-year-old introductory engineering student. His major is currently declared as electrical engineering, and he is also taking several courses on the track towards his major, including Principles of Chemistry, College Algebra, and the Introduction to the Engineering Profession course. Similarly to Timmy, I will also be specifically looking at Kenneth's interaction with diagrams in the EGS course.

Kenneth interacts with a plethora of diagrams in his EGS lab related to the Boe-Bot. Unlike Timmy's case study, I will demonstrate how Kenneth interprets diagrams present in the *Robotics with the Boe-Bot* text in order to learn how to construct his Boe-Bot, learn how to code his Boe-Bot, and how to understand and use his Boe-Bot. Figure 2 below includes two examples of the types of diagrams that Kenneth utilizes to learn about his Boe-Bot.

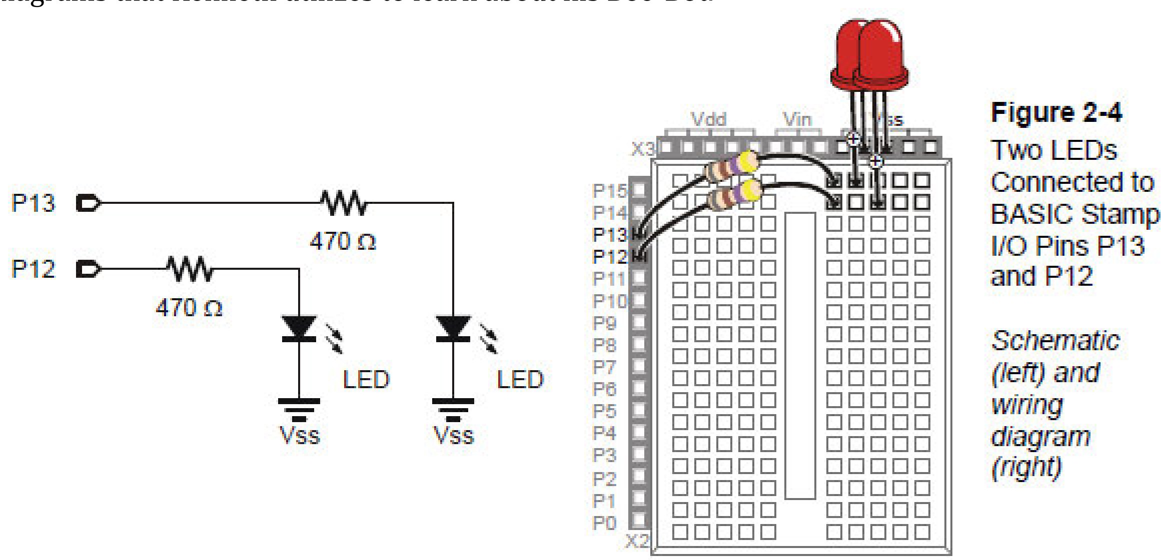

Figure 2: Diagrams from *Robotics with the Boe-Bot.*

This diagram was taken from page 30, of the *Robotics with the Boe-Bot* text, and is composed of a wiring schematic, or circuit diagram, and a wiring diagram. It is one part of the beginning assignments of the Boe-Bot curriculum that is intended to teach users to construct and use their servos. This specific circuit would be used as an indicator that would light up anytime a signal was sent to the servo. Kenneth constructed this as a part of his second lab in the EGS lab section on September 25, 2015. Completing this lab is intended to familiarize EGS students with the work required to construct and operate the Boe-Bot.

Kenneth's utilization of these diagrams teaches him how to physically construct the Boe-Bot and the circuits for its instruments. In addition, allowing Kenneth to see visual representations of the Boe-Bot construction and the instrument circuits facilitates and augments his ability to learn about, and perform, the exercises and assignments presented to him by his instructor.

First, Kenneth reads the assignment and the instructions. By doing so, Kenneth understands the purpose of his work and the requirements that his Boe-Bot must fulfill. The circuit and wiring diagrams facilitate this process by giving Kenneth a visual representation of that same final goal, guiding his learning process towards a final result. In addition, any mistakes he made can be corrected by observing the final correct result, and in this regard, the diagram acts almost like an answer key. The process of reaching that answer is where Kenneth does all of his learning. All in all, by understanding the purpose and final product of an activity, Kenneth takes the first step to expediting his learning process through diagrams.

Second, after understanding the requirements of the activity, Kenneth is able to utilize the circuit and wiring diagrams as a model to help him learn how to complete those requirements. For instance, the schematic on the left of the aforementioned diagram represents the circuit that must be completed to make the LEDs work and the wiring diagram on the right gives Kenneth a visual representation of this circuit. Both diagrams facilitate Kenneth's learning process in separate ways. The schematic on the left represents the inner workings of the circuit and is designed to let the student gain a more in-depth knowledge of the circuit's workings. The other wiring diagram has to do more with the physical construction of the circuit on the Boe-Bot and becomes a model to base the construction of the Boe-Bot on. By learning different things from the diagrams, Kenneth can both understand his circuit and construct it very quickly. Instead of having to read many paragraphs on the exact positions of the components or the inner workings of the circuit, Kenneth can directly learn from the information being communicated to him through the communicative channel of diagrams. Representing physical concepts and dimensions can be cumbersome with typical text, but through diagrams these properties can be easily transmitted to the learner. This speeds up the construction and learning process for Kenneth considerably since many of the future labs are much more complex and would be very difficult to explain through standard text.

Finally, Kenneth's learning process is expedited and facilitated by the diagrams presented earlier. Through understanding his assignment, having a model of the circuit, and by having a diagram to explain the workings of the circuit, Kenneth can construct and understand his Boe-Bot much faster than if he was presented text in the form of paragraphs. This allows Kenneth to finish his lab assignment correctly, quickly, and more effectively. In addition, this also facilitates his progression through the curriculum since Kenneth and his classmates can proceed through material more efficiently, making them learn more in a shorter period of time.

Discussion

In light of the case studies on Timmy's construction of an Excel chart and Kenneth's utilization of circuit and wiring diagrams, what does observing how introductory engineering students utilize diagrams to learn and communicate bring to our understanding of education and communication in the engineering discourse community? I argue that this illuminates the vast amount of information that can be communicated quickly through diagrams. Encountering assignments in the EGS lab often makes Timmy create diagrams, and these diagrams must be effective in communicating information to his instructor. By representing his Boe-Bot as a text and formatting that text into a diagram, Timmy speeds up the composing and interpretation process for his work on the assignment. Timmy also represents a large amount of information quickly through the format of the diagram, allowing information to be communicated quicker and more effectively. Timmy's proficiency in converting an object into text is also a proficiency in communicating with others, fulfilling the purpose of writing to "attain communal acceptance of those ideas, thus turning them into knowledge" (Winsor, *Invention* 234).

This analysis of diagrams for introductory engineering students also illuminates how these students learn faster and more effectively. Kenneth's interpretation of the diagrams present in the *Robotics with the Boe-Bot* text, both facilitates and augments his ability to learn about his Boe-Bot. Through circuit schematics and wiring diagrams, Kenneth learns a vast amount of information on the process required to construct the Boe-Bot and how its circuits work. The text communicates this information through the medium of diagram, and Kenneth's interpretation of these diagrams teaches him the skills necessary to understand the information being transmitted to him, in addition to skills associated with tactile work. Without diagrams, Kenneth's learning process would be slowed by the inability of typical text to express the information on his Boe-Bot effectively.

In addition to demonstrating how diagrams enhance the learning and communicating processes for Timmy and Kenneth, this study illuminates the interdependent nature between the utilization and creation of diagrams, and learning and communication. Even though Timmy primarily created the chart to communicate information about his Boe-Bot to his instructor, he also experienced learning similar to Kenneth. By creating his Excel diagram, Timmy learned about his Boe-Bot through experiment and quantitative analysis, and transferred that knowledge to others. Through this process, Timmy became more intimate with his Boe-Bot's functionality and was able to optimize his code for servo rotation speed. Communicating that information represents an understanding of what one is trying to convey, and Timmy's Excel table represents not only his Boe-Bot as a text, but Timmy's learning as well.

Kenneth's experience also reveals the interdependent nature of learning and communication through diagrams. The visual medium of diagrams in relation to the Boe-Bot and the *Robotics with the Boe-Bot* text teaches Kenneth the skills necessary to understand the information being communicated to him. These skills are important because Kenneth's aptitude with interpreting graphs also relates to the process of composing and inscribing diagrams. By becoming more proficient with receiving information from diagrams, Kenneth discovers what the final product of properly inscribing a diagram looks like. He also discovers what types of information to transmit and the format to present it in. Utilizing this knowledge, Kenneth begins to understand some of the steps required to compose and inscribe a diagram. The relationship between interpreting and creating diagrams becomes apparent when looking at these processes through the lens of Kenneth's experiences. Overall, Timmy and Kenneth's skill with creating and interpreting diagrams in their EGS course forms the foundation for communicating and learning information more effectively.

Conclusions

The findings of this study contribute to the scholarship that addresses technical communication and learning with respect to diagrams in three ways. To begin with, observing the data presented in each of the case studies illuminates the creation and use of diagrams as a key factor in the learning and communication process of engineering students. Representing an object as text (Winsor, *Invention*) and composing text based on lab work (Prendergast) also represent key processes present in the learning and communication process for engineering students. Diagrams also allow introductory engineering students the ability to practice skills like quantitative analysis and technical communication. Diagrams augment this process and allow for information to be learned much more effectively and communicated quicker.

This paper also contributes to the development of methods for making student's use of diagrams much more clear. In order to improve future studies and scholarship on the topic, data collected with respect to lab work, engineering projects, and student studies should be broadened to include more emphasis on diagrams. First, the data collected needs to account for the broad definition of "diagram." Content, such as charts, tables, graphs, pictures of components, and maps represent some of the possible forms of diagrams. By collecting and observing the diagrams created and utilized by the participants of a study, one can discover the skills being utilized and information being learned and communicated. Second, the diagrams collected must be analyzed with respect to what is being learned and how it is being communicated. This can be achieved by observing the circumstances surrounding the diagram created or utilized and by observing the format and medium of those diagrams. Overall, diagrams should be analyzed as a powerful tool that can augment the learning and communication process, and the processes involved in obtaining, formatting, and utilizing diagrams are important to understanding their role.

Finally, this paper contributes to the development of teaching approaches that can augment current pedagogical practices by engineering professors. Through utilizing more methods to teach engineering students the skills required to create and interpret diagrams, professors can augment the student's ability to develop these skills for future courses. Methods such as integrating an Excel lesson into either an EGS course or a technical communication class to get students familiar with creating diagrams can impact both learning and communication. In addition, offering three-dimensional modeling courses could also enrich students' aptitude with diagrams by exposing them to models and spreadsheets of parts. These spreadsheets can improve communication by representing parts in a visual medium, and the process of creating those parts can augment learning by interacting with those parts through 3D diagrams. Further utilizing pedagogical approaches to increasing aptitude with diagrams, teachers can account for extracurricular diagram usage and can promote it in the classroom. Using engineering clubs or assignments that promote diagram usage with practical applications would be a viable way to improve students' aptitude with diagrams. Finally, offering group assignments that involve creating diagrams can instruct students to not only learn through diagram, but to communicate with much larger audiences through presentations.

Representing an object as text and composing text based on lab work also represent key processes present in the learning and communication process for engineering students.

Overall, previous writing studies scholars were right to observe technical communication (Winsor, *Invention*; Winsor, *Writing Power*; Wolfe) and the role of experiment with relation to academic paper writing (Poe, Lerner, and Craig; Prendergast), yet they did not place enough emphasis on the importance of diagrams for those in the scientific and engineering community. Winsor's idea of converting an object to text forms the backbone of much of the work those do in engineering, and this notion should be broadened to include the transformation of an object to a visual text (*Invention*). Furthermore, diagrams should be viewed in a new light with regards to academic paper writing because the processes of technical inventiveness, composing, and inscribing a text are nonspecific to academic paper writing and diagram creation shares these steps. By considering this, academic papers and diagram utilization can be improved by looking at diagrams with a similar level of complexity in which academic papers are viewed (Winsor, *Invention*; Prendergast).

In conclusion, by broadening the view of the traditional learning and communication processes associated with text in the engineering community, the importance and relevance of diagrams can be revealed. By further observing diagrams and other texts, the learning and communication process for engineers, engineering students, and other members of the scientific community can be refined and augmented for the future.

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