Developing best practices for teaching scientific documentation: Toward a better understand of how lab notebooks contribute to knowledge-building in engineering design and experime...

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Developing best practices for teaching scientific documentation: Toward a better understand of how lab notebooks contribute to knowledge-building in engineering design and experimentation.

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Developing best practices for teaching scientific documentation: Toward a better understand of how lab notebooks contribute to knowledge-building in engineering design and experimentation.

Introduction

There are many reasons for various disciplines within the sciences and engineering to require laboratory (hereafter lab) courses or courses with labs associated with them. Perhaps paramount among those reasons is that labs introduce students to the very specific knowledge practices that enable "cumulative knowledge-building" related to those disciplines [1]. In a way similar to studios and their connection with some of the visual arts, e.g., painting, sculpture, photography, printmaking, labs within the sciences and engineering provide students with practical and sometimes quite authentic experiences of what it means to be a disciplinary participant. One of those important knowledge practices is scientific documentation or keeping a lab notebook. Lab notebooks perform a number of key functions. They at once provide a record of a scientist's or engineer's work, serve as an important reference for other scientific genres, e.g., future reports and/or articles, and perform as a kind of journal that enables questioning presuppositions, considering new approaches, and generating new ideas.

Given the importance of notebooks, there is surprisingly little scholarship on how to teach their use. Stanley and Lewandowski [2] surveyed students in undergraduate laboratory courses and evaluated how their notebooks were being used. They found that "few [students] … thought that their lab classes successfully taught them the benefit of maintaining a lab notebook." Moreover, the authors' later survey of the literature and of college faculty led them to conclude that in undergraduate lab courses "little formal attention has been paid to addressing what is considered 'best practice' for scientific documentation …[or even] how researchers come to learn these practices" [3].

At Cornell University, two courses, ***Interfacing the Digital Domain with the Analog World*** and ***Engineering Communications*** are taught in conjunction. The first course is housed in the Applied Engineering and Physics department, and the second in the Engineering Communications Program. In the former, students use a computer to control equipment and acquire measurements in an engineering design and experimentation lab. Lab activities such as the development of a computer interface for an oscilloscope, a set of motors, and a photodiode culminate in the realization of an automated laser scanning microscope system. In the latter, students receive instruction and feedback on their lab notebook entries, in addition to engaging in routine peer review of each others' notebooks; and, in turn, use those notebooks as a resource for preparing a Progress Report and an Instrument Design Report. The instructors collaborate in order to facilitate improvement of students' skills in the art of notebook use, e.g., create a rubric for assessment, while also allowing them to develop these skills and personal style through trial and error during the research and design process. The primary learning objectives are: 1) to enable students to engage in real engineering design and lab research; and 2) to develop proficiency with select genres associated with that research. The educational research objectives are: 1) to study students' developing proficiency in order to generate best practices for teaching and learning scientific documentation, i.e., how to perform lab notebooks; and 2) to better understand the contribution of scientific documentation to the teaching and learning of the engineering design and experimentation process.

Because there is scant prior research and because guidance appears to be mostly anecdotal, we spent a good deal of time casting about for an approach that might allow us realize those two aforementioned educational research objectives. We believe that we have found that approach in Legitimation Code Theory (LCT), and in particular, how LCT can be combined with Systematic Functional Linguistics (SFL) to bring both theories together in a complementary analysis of the same data [4]. Since our research is still very much a work-in-progress, our aims for this paper are modest. First, we briefly introduce LCT and SFL, suggesting how their complementary use can provide both an opportunity for us to realize our educational research objectives and offer a pathway for continuing such research. Second, through an application of LCT and SFL to a single entry of one student's lab notebook, we demonstrate how LCT when combined with SFL offers a better understanding of the contribution of scientific documentation or how lab notebooks support the teaching and learning of the engineering design and experimentation process.

Legitimation Code Theory (LCT)

Karl Maton [1] begins ***Knowledge and Knowers: Towards a Realist Sociology of Education*** by discussing the "knowledge paradox." He states that while we declare knowledge as "the defining feature of modern societies;" we ignore "what that knowledge is, its forms and its effects" [1]. The result is "knowledge-blindness" or the reduction of knowledge to the individual's experience of knowing [1]. LCT, he asserts, provides a "multidimensional toolkit" that "enables knowledge practices to be seen, their organizing principles to be conceptualized, and their effects to be explored" [1].

The LCT toolkit provides both an organizing framework, *specialization codes* for classifying and differentiating disciplines' knowledge practices; and an analytic framework, *semantic codes* for classifying and differentiating cumulative knowledge-building. Specialization codes offer a plane divided by two axes shown in Figure 1 below.

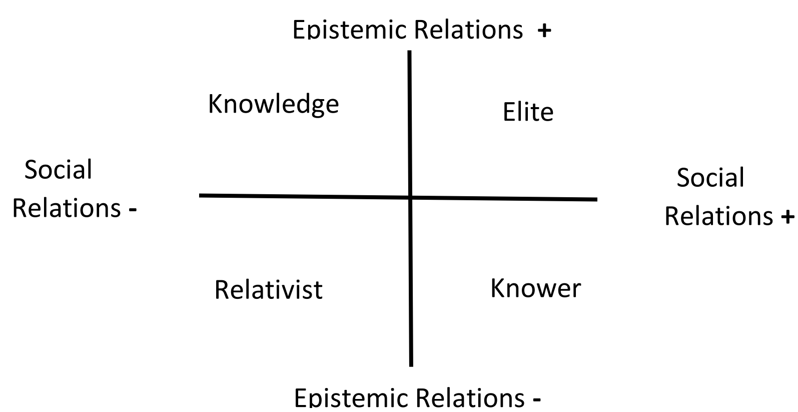

Figure 1. The specialization plane.

The x and y axes provide continua that divide the plane into four quadrants. The quadrants of interest for our research are the upper left and, for the purposes of contrast, the lower right. A discipline that can be located in the upper left quadrant focuses on "*what* can be legitimately described as knowledge (epistemic relations)," while the lower right focuses on "*who* can claim to be a legitimate knower (social relations)" [1]. Physics is a discipline that could be located in the upper left quadrant because its practices and the objects of study are focused on the empirical world. By contrast, literary criticism is a discipline that could be located in the lower right quadrant because its practices and objects of study are focused on the literary critic or the one enacting the practices. For the purposes of our research, most disciplines in engineering could be located somewhere within that upper left quadrant. This is important because in those disciplines the "possession of specialized knowledge of specific … [empirical] objects of study is emphasized as a basis of achievement and the attributes of actors are downplayed" [1].

This does not mean to suggest that actors in physics are unimportant or that knowledge in literary criticism is not related to the world. LCT rejects such "false dichotomies" indeed considers them "debilitating" [4]. Rather what the specialization codes and the specialization plane and quadrants offer is a way to see and therefore to be able to classify and differentiate disciplinary knowledge practices. They offer a way to see and therefore determine the principles and concepts around which those practices are organized. And finally, they offer a way to see and therefore explore their effects. One of those effects for those disciplines within the sciences and engineering would most certainly be cumulative knowledge-building.

Elaborating briefly on the contrast of physics and literary criticism may prove helpful. Physics, like most of the sciences, is understood to have a "vertical knowledge structure," that is 'an explicit, coherent, systematically principled … organization of knowledge" and knowledge practices [5]. This knowledge and praxis develop "through the integration of knowledge [and praxis] at lower levels and across an expanding range of phenomena" [1]. At the top of this vertical structure are "a minimum number of propositions or axioms … embracing a maximum number of empirical phenomena" [1]. Conversely, literary criticism is understood to have a horizontal knowledge structure, that is a collection of diverse "knowers, each with specialized modes of being, thinking, feeling, and acting … based on different trajectories and experiences" [1]. Knowers and praxis develop through competing claims, "each with its own specialized modes of interrogation and … with non-comparable principles of description based on different and, often opposed, assumptions" [5]. There is no top or bottom to a horizontal knowledge structure only an ever- expanding collection of knowers.

Specialization codes are the organizing framework associated with LCT; they locate fields and disciplines. Semantic codes are the analytic framework, they help us to see how learning or cumulative knowledge-building happens in these various disciplines. Semantic codes also offer a plane divided by two axes shown in Figure 2 below.

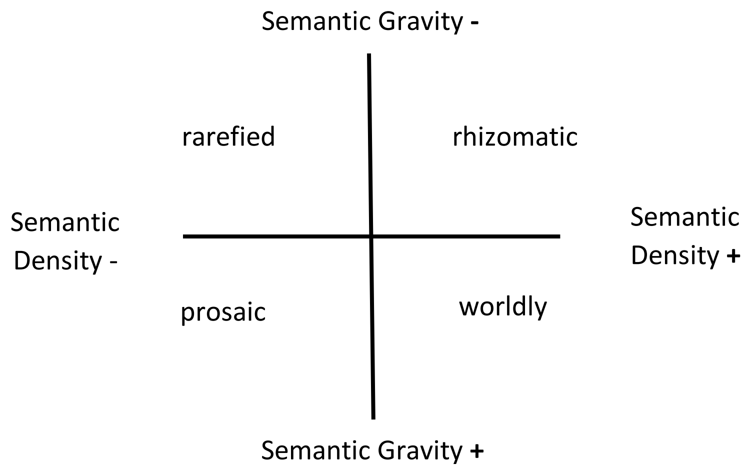

Figure 2. The semantic plane.

The x and y axes provide continua that again divide the plane into four quadrants. For the purposes of our research, our interest here lies more with the axes. What semantic gravity (SG) or the vertical axis "refers to is the degree to which meaning is dependent on context" [4]. SG+ is very dependent and SG- is less dependent. Descending down the axis suggests "moving from generalized ideas toward concrete and delimited cases" [4]. Semantic density (SD) or the horizontal axis "refers to the degree of condensation of meaning within practices" [4]. SD+ is more concentrated and SD- is less concentrated. For example, experimentation is a nominalization or a noun that represents a collection of actions or a process. Experimentation would be SG-/SD+. It is SG- because our understanding is not dependent upon any particular experimental process or context within which a specific experiment is taking place. It is SD+ because it refers to a generally understood collection of actions or a process typical of disciplines associated with the sciences and engineering. As such it consolidates what may be (actually are) differing processes into a single referent. Conversely, verbs like, calibrate, scale, image tend to be more SG+/SD-. These verbs are more SG+ because they tend to be associated with specific practices in specific experiments. In other words, they have an immediate context. They are SD- because they only refer to those practices associated with that experiment.

Again, this may just seem to be a more complicated way of saying that something is either abstract or concrete, theoretical or practical [4]. However and again, LCT rejects such false dichotomies. Since knowledge in the sciences and engineering is both context-dependent ***and*** condensed; the semantic codes, plane and axes offer to way to see knowledge and knowledge practices as they move from condensed forms to context-dependent forms and from context-dependent forms back to condensed forms. Indeed, LCT offers a way to generate a semantic profile, the "rules of the game" or a representation of that movement over time [4] and semantic waves or those movements and how they might vary within disciplines and across different disciplines.

Let's return for a moment to physics. Maton [6] refers to "a down escalator profile" that he claims is a typical semantic wave in physics classrooms. See Figure 3 below.

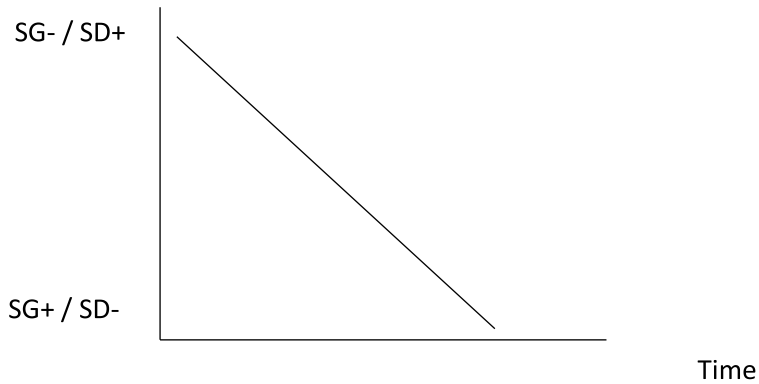

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Figure 3. A ‘down escalator’ profile

A down escalator profile occurs when instructors begin with “highly condensed and decontextualized ideas” (SG-/SD+) and move for the purposes of illustration “toward simpler, more concrete understandings, often including examples from everyday life” or (SG+/SD-) [6]. Helen Georgiou [7] in her study of first-year physics students and a large metropolitan university found that moving down the down escalator was not sufficient. Students also need to move back up the up escalator or from the more concrete (SG+/SD-) to the more condensed (SG-/SD+); and, even more importantly, in their answers to physics questions, they had to learn just “how abstract and how concrete one needs to be” [7]. In other words, learning physics meant that students had to become proficient in determining the appropriate semantic range. See Figure 4 below.

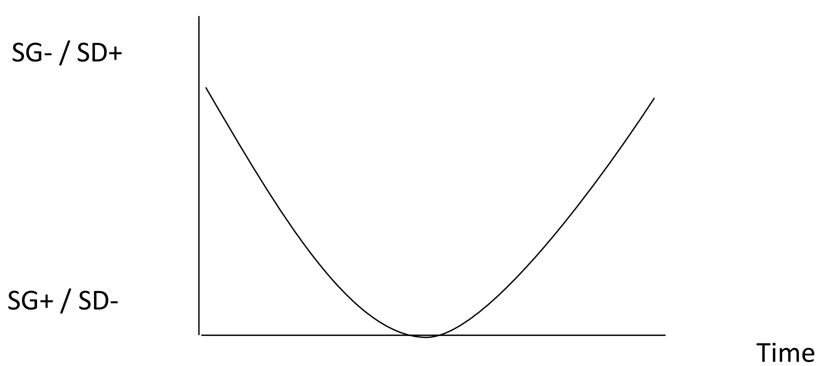

Figure 4. A semantic wave and range

There is a growing body of research that uses semantic codes, profiles and waves to investigate knowledge forms and knowledge practices in various disciplines: design studies [8] English [9], engineering [10], jazz education [11], physics [12], [13], sociology [14] and more. Again, LCT through specialization codes helps us to locate disciplines. Semantic codes helps us to see how learning happens and eventually perhaps what proficiency looks like in these various disciplines.

<u>Legitimation Code Theory (LCT) and Systematic Functional Linguistics (SFL)</u>

There is a long and evolving relationship and collaboration between LCT and SFL. In fact, the relationship actually began before there was an LCT. It was a relationship between SFL and code theory as it was first proposed by Basil Bernstein [15]. LCT represents a further development of Bernstein's original code theory. A recent instance of collaboration between the LCT and SFL is the DISKS (Disciplinary, Knowledge and Schooling) Project. The DISKs Project "was a nationally-funded, three-year research study" located at the University of Sydney [4]. The aims were to "analyze the bases of knowledge-building" across a range of secondary school subjects and "develop pedagogical practices" that might better promote cumulative knowledge-building [4]. Indeed, the studies cited just above also represent examples of that relationship and collaboration.

So what is SFL exactly and why is there interdisciplinary collaboration between this area of linguistics and a sociology of education? Systematic Functional Linguistics (SFL) was originally developed by MAK Halliday now more than six decades ago and has offered a profoundly useful theoretical framework for studies into the use of everyday language, literacies and even specialized varieties of language, e.g., ***Writing Science: Literacy and discursive power*** by MAK Halliday and J.R. Martin [16]. At its core are three so-called metafunctions of language. First, when we use language, we typically do so "with one or more people" [17]. Second, when we use language, we typically do so "about something" [17].Third, when we use language with people and about something, we do so in a particular way relevant to context or there is a particular structure or even design to our interaction [17]. These metafunctions are generally referred to as the interpersonal, the ideational and the textual respectively. As communication happens, these three metafunctions are intertwined in such a way that communicators can achieve all three simultaneously. In other words, SFL enables us to look at texts or any representation of communication and identify these different metafunctions realized by different patterns of meaning.

Now why the collaboration. Both SFL and code theory, as it originated and was developed through the work of Basil Bernstein and as it has been further developed in LCT, are interested in social justice as it gets realized in our schools. ***Learning to Write, Reading to Learn: Genre, Knowledge and Pedagogy in the Sydney School*** by David Rose and J.R. Martin [17] is a recent example of SFLs efforts to make sure that all students, regardless of their ethnic, social or economic backgrounds, have adequate preparation to learn and to succeed. The DISKS Project referred to above reveals that "key to social inclusion and social justice in education and civic life" are the "organizing principles of knowledge" [1]. LCT asserts that "any social justice agenda" that ignores those principles will most likely fail because the knowledge practices associated with those principles "are anything but neutral" [1]. LCT helps us to better understand knowledge in the various disciplines and to see how learning happens and perhaps what proficiency looks like. SFL helps us to better understand the who, what and how of language use, those metafunctions above, related to that knowledge and perhaps can support learning and facilitate proficiency. When both are combined, we believe that we have a framework and an approach to realize our two educational research objectives stated above: 1) to study students' developing proficiency in order to generate best practices for teaching and learning scientific documentation; and 2) to better understand the contribution of scientific documentation to the teaching and learning of the engineering design and experimentation process.

Jaun's Lab Notebook

In an article describing the modern evolution of the experimental report in physics, Charles Bazerman [18] states: "How a discipline decides to communicate with itself, what it presents as contributions to knowledge and how it conceives and argues for those potential contributions, are essential parts of how a discipline constitutes itself in fulfillment of its task of creating knowledge." We would only add that learning those disciplinary ways of communicating also constitute avenues into disciplinary participation and that familiarity and experienced performance or proficiency suggests disciplinary membership. We believe lab notebooks can offer novice students both specific knowledge practices that, as they become more proficient, encourage both their evolving participation and membership. We also believe that lab notebooks can serve as a representation, a tangible artifact, of their learning. In what follows, we will illustrate how LCT when combined with SFL offers a better understanding of how lab notebooks support the teaching and learning of the engineering design and experimentation process.

Briefly reviewing again, LCT suggests that physics (in our case, physics as it is embodied in the engineering design and experimentation process) has a vertical knowledge structure, where knowledge and praxis develop at lower levels and across an expanding range phenomena and yield a minimum number of propositions or axioms embracing that expanding range. In addition, LCT also suggests the semantic profile for teaching and learning of physics involves an initial movement down from those propositions or axioms (SG-/SD+) toward empirical phenomena (SG+/SD-), those concrete and delimited cases; followed by a movement back up toward propositions or axioms, those highly condensed and decontextualized ideas. The aim is for the teaching and learning process to replicate the entire semantic wave (see again Figure 4) along with understanding just how abstract and concrete one needs to be or realizing an appropriate semantic range. So, let's look at a selective re-presentation of Jaun's (pseudonym) final lab notebook entry. As a reminder and a bit of background, students' lab activities over the semester focus on the realization of an automated laser scanning microscope. During the lab classes, Jaun was paired with another student, so that both together would conduct the experiment. However, both students were required to keep their own lab notebooks. Our question: Does LCT when combined with SFL offer a better understanding of how lab notebooks support teaching and learning and does that entry serve as a representation, a tangible artifact, of the students' learning?

An overview of Jaun's final notebook entry shows her adherence to the science macrogenre IMRaD or ***i****ntroduction,* ***m****ethods,* ***r****esults,* ***a****nd* ***d****iscussion*, a predominant and recurring discourse structure that can be found in any number of genres in science and engineering [19]. Indeed, Jaun uses the headings "Introduction," "Procedure," "Data & Observations," and "Conclusion." Referring again to Bazerman [19], he notes that IMRaD is an emerging structure, with many variations, of course, and that "after 1950, section headings were a consistent feature of almost all articles." Two of those variations noted by Martin and Rose [19] is the experimental report and scientific documentation, both beginning with purpose, equipment and materials, moving then to method, followed by results and conclusion. IMRaD is the way the science and engineering disciplines present their contributions and use to communicate with themselves. It is how they conceive and argue for potential contributions, and it reveals the procedure for how those disciplines fulfill their task of creating and building knowledge. That Jaun so structures her notebook entry reveals not only the ability to participate but also membership. The headings also suggest Jaun's awareness that the sequential staging of a lab notebook entry is related a particular experimentation process.

Introductions can serve a number of purposes and often do in science or engineering reports and/or research articles. A statement of the goal of a particular lab session is more typical of scientific documentation and lab notebook entries. That is how Jaun begins her lab notebook entry. In stage 1 or in the section labeled "Introduction," Jaun states her general goal:

Stage 1

Jaun starts her lab notebook entry happy (or perhaps relieved) that after all these lab sessions

> ***we will finally see the microscope in action and gather some images***

She then offers an elaboration of that goal, suggesting what is necessary to test the adequacy of the microscope:

> ***determine spatial resolution***

Stage 2

Before the lab session, the students were given directions, a handout, suggesting how they might realize the above goals. In order to determine the appropriate calibration, they were encouraged to

> ***image … calibrate … image***

And then, in order to determine the spatial resolution, they were encouraged to

> ***develop … explain … implement***

Then, in order to test that calibration and realize a useful spatial resolution, they were asked to

> ***image at least two samples … with a calibrated scale***

Jaun includes these directions in an abbreviated fashion in her "Procedures" section, stage 2. Clearly, by including these directions, she is acknowledging that she understands that these are the more specific practices required to realize the above goals.

It is important to note that within and across these first two sections of her entry or stages of the testing process, Jaun recognizes that she must descend down the down escalator. What does it mean to "see the microscope in action?" To see her microscope in action is to determine the appropriate calibration and spatial resolution. To determine the appropriate calibration is to image, then calibrate, then image again. To determine spatial resolution is to develop, explain and implement. And while these latter terms – develop, explain, and implement – are still semantically dense, they will become grounded in the particular knowledge practices in Stage 3, "Data & Observations:"

Stage 3

Jaun begins by restating her specific goal and the initial set-up for imaging

> ***to determine the calibration***
>
> > ***our initial front panel settings were a step rate of 2KHz***
> > ***x and y range of 500 µm***
> > ***calibration factor of 10 steps per µm, x and y points = 125 points***

The result is that

> ***the image has a lot of horizontal distortion which is most likely due to the rubber attached to the activators controlling the mirror position***

The solution is to

> ***remove the metal motor mount and change the position of the rubber grippers … allowing ample room between the grip and the mount***

Following this adjustment, a second image is captured. Again, there is a problem.

> ***there are some irregularities near the left of the image***

To determine if this is an anomaly, Jaun and her lab partner run the VI a second time with the result that

> ***there is a non-uniform grid consistent in both the left sides of the images***

In response, they

> ***used the cursor and the zoom function of the front panel of the VI***

and

> ***found that the vertical axis dimension of the pitch was approximately 90 µm not the approximate 60 µm as needed***

They then

> ***changed the y-scale multiplier in the block diagram to be divided by 1.5 of what the original was … this led to the correct scaling of the y axis***

Notice what is occurring. In order to “determine the appropriate calibration,” Jaun undertakes a series of even more detailed practices, a sequence of trial-error-fix, to realize that goal. She is descending even further down the down escalator and engaging in a process and particular practices immediately relevant to her goal. Having arrived at the correct calibration, Jaun and her lab partner then attempt to determine spatial resolution. She begins this part of her notebook entry by describing her “set up:”

some variables to the user controls on the front panel of the GUI.vi

> ***x range [µm] =*** L_x
> ***y range[µm] =*** L_y
> ***# of x points [points] =*** N_x
> ***# of y points [points] =*** N_y
> ***calibration factor [steps/µm] = C***

And, because she is or they are

> ***interested in calculating the spatial resolution of microscopes usually defined in units of pixels per unit length … we want units of points per µm …. we can use dimensional analysis to obtain this … letting spatial resolution be assigned a variable A***
>
> ***[points/µm] = [points] [1/µm]***
> $A = N_x \times 1/L_x$
>
> ***to increase the spatial resolution, you could either decrease the range or increase the # of points***
>
> ***… to calculate A***
> $A = N_x / L_x$ ***= 200 points / 400 µm = ½ pts/µm or, in more sensible terms, 2 µm every point***

Again, notice what is occurring. Through a process, very roughly analogous to “develop … explain … implement,” the students use their set-up to analyze how to calculate and increase spatial resolution, finally arriving at what they believe to be the best solution. Having determined the calibration and spatial resolution, Jaun and her partner

> ***went ahead and imaged a Bell Lab computer chip … with the settings of an x and y range of 300 µm and 200 x and y points***

Jaun did not comment on the success or failure of imaging the computer chip, but did include a figure picturing that computer chip. Additionally, they chode a goldfish scale and while

the details of the scale are most likely too small to capture with this microscope … there is a very clearly reflective region of the scale and some interesting contour lines

Stage 4

Jaun ends her entry with stage 4, the “Conclusion.”

the … lab resulted in imaging samples and determining the calibration factor for the microscope. The microscope can now be used to scan other samples suitable for its level of resolution

There are a number of very interesting things happening in Jaun’s lab notebook entry. Let’s begin with what we already mentioned. Jaun is aware of the predominant and recurring discourse structure common to many genres in science and engineering. According to J.R. Martin, SFL scholar and collaborator with Karl Maton and LCT, such an understanding of how “knowledge is packaged as texts” is crucial to participation and membership [20]. Martin [20] refers to such knowledge as “power composition” or the ability to organize the presentation of knowledge in “predictable waves of information.” The power composition or the predictable waves of information are apparent in the IMRaD structure evidenced most clearly by the headings, but also by the content of each of the sections. In addition, we know that throughout her entry Jaun descends from the nominalized goals of calibration and spatial resolution, both of which can be characterized SG-/SD+, down to the specific, concrete knowledge practices of the experiment, all of which are SG+/SD-. Indeed, she uses most of space of her entry describing those knowledge practices and their results. We know that once those practices have been completed, she moves upward again back toward those goals in her “Conclusion.” This movement allows us to create a semantic wave for how learning, cumulative knowledge-building in engineering design and experimentation happened in this particular lab session. If we were to see this wave replicated in other lab sessions, we could plausibly argue that in engineering design and experimentation such is the semantic profile for how cumulative knowledge-building happens. See Figure 5 below.

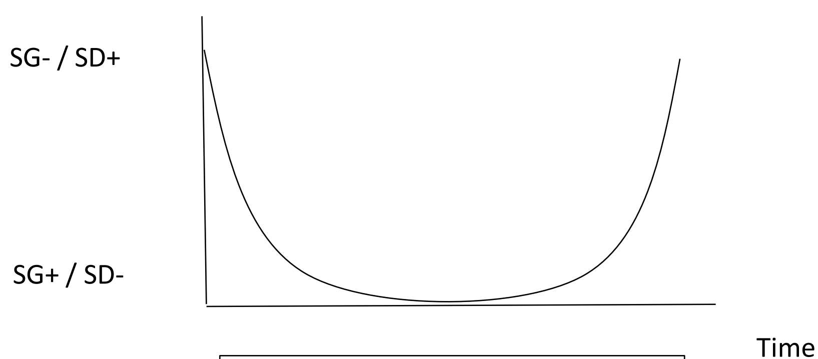

Figure 5. A semantic profile

From the goals, there is a precipitous descent into the specific practices, those knowledge practices of the particular experiment. Once those practices actualize desired results, there is a rapid ascent back to the goals. Indeed, it should be possible to represent the series of experiments in an engineering design process with successive and possibly similar semantic waves.

Perhaps less obvious, but still important is Jaun's linking of specific practices with the nominalizations of calibration and spatial resolution, revealing that both (like experimentation referred to above) are processes. Nominalizations are common in the varieties of language used in science and engineering. Martin [20] refers to such words a "power words." Power words have relatively stronger semantic density and are critical for students to be able to understand and use appropriately if they are going to be able to participate in a field with a vertical knowledge structure. Recall that at the top of such a knowledge structure is a minimal number of propositions or axioms that embrace a maximum number of empirical phenomena. Nominalizations allow for the necessary concentration of meaning at the top of that knowledge structure.

Finally, we might consider what, for those teaching lab courses, will most likely not be obvious at all. Recall the three metafunctions – the interpersonal, ideational and textual – and how SFL enables us to look at texts and identify these different metafunctions realized by different patterns of meaning. In her entry, who is Jaun writing to? Jaun is writing to other participants in her field. We know that from her use of power words and power composition. And, who are the expected audiences for scientific documentation or lab notebooks – other participants in the field. Jaun is learning how the discipline communicates with itself and presents contributions of knowledge. In her entry, what is Jaun writing about? Jaun is recounting, re-presenting through language the knowledge practices associated with engineering design and experimentation. And not just any practices, rather those specific, concrete, and detailed practices necessary for testing and maximizing the efficacy of the microscope that she and her lab partner have designed. The experience and the re-presentation of that experience with language that is also specific, concrete and detailed reveals both those practices and the process. In her entry, what is the design or the presentational organization? As we have suggested above, there are stages or a sequence of information flow that does generally correspond to the IMRaD macrogenre. However, perhaps more important is the descent from the abstract goals to the grounded and granular practices and remaining at the level of those practices until the results allow for an ascent again to the abstract realization of those goals. We certainly do not want to make an unsubstantiated claim from a single entry. However, Jaun seems to be learning when and just how abstract and concrete she needs to be as someone engaged in engineering design and experimentation.

Because scientists and engineers surely understand the importance of scientific documentation or of keeping lab notebooks, it is surprising that both best practice and teaching best practice seem to have been ignored. From the above, we would argue that determining and teaching best practice make at least three important contributions to science and engineering education. First, they offer students a contextualized experience for cumulative knowledge-building and then an opportunity to present that knowledge in ways consistent with a vertical knowledge structure that the community of scientists and engineers both understands and values. Second, too often lab notebooks are trivialized as simple recounts. That may provide some explanation for the lack of guidance. But, as we see in Jaun's entry, notebooks can serve several purposes, e.g., planning, problem-solving, realizing the best possible solution (rather than the ‘right’ solution typical of homework problem sets) – actual knowledge practices critical to her participation. Third, lab notebooks offer an opportunity to connect the discourse with knowledge, suggesting perhaps the structures of both are mutually reinforcing. Lab notebooks offer an initial way for students to engage with how a discipline decides to communicate with itself, to conceive and argue for what a particular discipline might consider are contributions, and to participate albeit as a novice in the fulfillment of its task of creating knowledge.”

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