



## **Instructional Stance as Indicated by Words: A Lexicometrical Analysis of Teacher Usage of an Inquiry-Based Technological Tool in High School Classrooms**

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## **Abstract**

During the first year of the Interactive Learning and Collaboration Environment (InterLACE) Project, we designed a Web-based technological tool in concert with high school physics and engineering teachers for use in their classrooms and engaged them in professional development activities that centered on design-based inquiry instruction to help them maximize the success of that tool when it debuted in the spring of 2012. Called the Thought Cloud, the tool allows teachers to upload questions that students can view and answer through any Internet-connected device (desktop, laptop, tablet, etc.); the students' posts are then displayed on a centrally located screen to promote discussion and collective sense-making and to serve as a virtual public work space. Since words constitute a large share of the data that the Thought Cloud collects, we felt that lexicometry, a relatively new form of statistical textual analysis, would be a good way to examine just how our teachers used the tool. Using a lexicometric software program, we conducted an exploration of the respective vocabularies, or lexica, that each of our teachers employed to construct their questions in order to see what patterns emerged within the aggregate of these lexica, or corpus, and to determine what factors might have shaped these patterns and if they indicate a teacher's particular instructional stance—be it a traditional lecture style, an inquiry-based approach, or something in between. In doing so, we have defined three lexical categories—content-centric, process-oriented, and student-centric—and found that the teacher who used the tool the most tended to employ words that were student-centric, or focused on evoking student reasoning, and those who used the tool least favored words that were content-centric, or intended to merely transmit information. A closer examination of the corpus revealed that this link between lack of use and content-centric lexica does not necessarily indicate an aversion to inquiry instruction but rather the pedagogical goals the teachers had set when using the Thought Cloud in their classrooms. These results have provided us with valuable insight into the instructional stances teachers take when using our tool; therefore, we believe that incorporating lexicometry into future analyses can serve as a sort of diagnostic metric that we can use to inform our professional development activities in the coming years.

## **Introduction**

Motivated by the call to promote authentic science and engineering practice among K–12 students—most recently and notably made by the Next Generation Science Standards (National Academy of Sciences [NAS], 2012)—we established the Interactive Learning and Collaboration Environment (InterLACE) Project so that we could create technologies to support the implementation of collaborative design-based inquiry instruction in high school physics and engineering classrooms. The combination of design-based projects with the pedagogical stance of inquiry is a good fit for the current shift toward providing students with “opportunities to experience how science is done” (NAS, 2012; p. 1) and encouraging them to focus on “modeling, developing explanations, and engaging in critique and evaluation” (NAS, 2012; p. 41). Not only can collaborative design-based projects faithfully enact authentic science and engineering practices, they have also been shown to help students reach a deeper understanding

of the concepts (Crismond, 2001; Fortus et al, 2004; Kolodner, 2006; Sadler, Coyle & Schwartz, 1991), gain theory-building, argumentation, and collaboration skills (Fortus et al, 2005; Kolodner, 2003; Mehalik, Doppelt & Schunn, 2008), and improve students' attitude toward science and engineering in general (Haury, 1993). And because inquiry instruction calls upon teachers to adopt the view that "the class is the arena for...exploration of students' participation, knowledge, and reason" (Hammer, 2005; p. 503), it fosters an educational environment in which student reasoning can be laid bare through debate, discussion, and collective exploration. Creating such a learning community within the classroom is important, because as Beatty et al (2006) have observed, "Telling students what to think is notoriously ineffective; eliciting their thinking, confronting it with alternatives, and seeking resolution works better."

The focus of this paper will lean more toward the inquiry instruction piece of our project and how that pedagogical stance was or was not enacted by the six high school physics and engineering educators who formed our Design Team, as evidenced by the words they used in a classroom communication system (Dufresne et al, 1996) we jointly created with them. From the start, we took the view that teaching practice is an endeavor of lifelong learning (Hammer et al, 2005) and were cognizant of the fact that working with teachers to adapt their views and practices would take time and focused work (Darling-Hammond, 2006). Therefore, our aim was not only to co-construct an educational technology with our Design Team teachers but also to work together to develop teaching practices based in inquiry instruction that would maximize the benefits of our classroom communication system. In the fall of 2011, we started the first leg of our project by collecting data from our Design Team members. Informed by an analysis of interviews with and observations of our teachers, we formulated a set of design principles that called for technology that (1) could use existing resources within any classroom environment, thus minimizing its technological footprint, (2) would make students' thoughts readily visible so that they could engage in discussion and collective knowledge building, and (3) would help teachers focus on student thinking. The result was the "Thought Cloud," a Web-based platform that aggregates and shares students' ideas. Before class, a teacher constructs a lesson plan, or module, consisting of questions, prompts, or design challenges. Students are asked to express their ideas using text and/or images and upload their contributions. The students' posts can then be viewed on a centralized projection screen to encourage a subsequent class-wide discussion and exploration of ideas (see Figure 1). Both the teacher and the students are granted the ability to manipulate the display of posts by moving them around on the screen so as to group them by similarity, for example. The teacher can also highlight or compare student posts and add questions to the module on the fly.

In order to meet the goal of promoting a student-centered classroom in which teachers focus on their students' ideas, we conducted professional development activities with our teachers such as discussions of the inquiry-focused literature and presentations of videotaped examples of student discussion. Since the data collected by the Thought Cloud was largely textual, we looked to lexicometry as a way to assess to what extent teachers were eliciting rich explanations from their students thus indicating if our interventions were bearing fruit. An emerging form of multivariate statistical analysis, lexicometry is a powerful way to compare, classify, and analyze textual data (Lebart, 1998; Bautista et al, 2010; Schuerer, 2009) that distinguishes itself from other forms of analysis because of its ability to visualize emergent trends in an immediate and accessible form. With it, we realized we could quickly and easily ascertain the general character of the respective

lexica the Design Team members used in posing questions to their students with an eye toward improving the Thought Cloud and future professional development activities. Specifically, we wanted to answer the following questions:

- 1) How did the teachers stack up against one another?
- 2) Were there any factors that united or separated them?
- 3) Did their words reflect a shift toward the exposure of student reasoning or did they remain firmly rooted in the delivery of content?
- 4) In what ways can we characterize words that open a window on students' minds and those that merely transmit information?

The screenshot shows the InterLACE web interface. At the top, there is a header with the Tufts University logo and the text "Center for Engineering Education and Outreach". Below the header, there is a navigation bar with "Overview" and a dropdown menu set to "Acceleration". To the right of the navigation bar, there is a font size control set to "15 px".

The main content area displays a physics problem: "On that same graph, draw a sketch of what you think the X-acceleration looks like. Do this in a third color. Explain your thoughts." Below the problem, there are three student responses, each with a video thumbnail and text:

- Response 1:** "It accelerates at a constant rate, then decelerates at a constant rate, then accelerates and that rate, and so on. Yeah. Its also because velocity is the derivative of the x position, and acceleration is the derivative of the velocity." (1 response)
- Response 2:** "our old one was wrong." (0 responses)
- Response 3:** "Red is velocity, Black is position, and Green is acceleration. As the" (0 responses)

Each response includes a "Respond" button and links for "1 responses", "Compare", and "Highlight".

**Figure 1:** A recent iteration of the Thought Cloud, a classroom communication system designed by the InterLACE Project to support design-based inquiry activities in high school physics and engineering classrooms.

## Methods

### Participants

Assembling our Design Team was an informal process. We contacted high school physics and engineering teachers from the Northeast who were known to us through past participation in various projects. Our Design Team leader, Grant, possesses 20 years of teaching experience and works at a small urban private school. During the first year of our project, he was on sabbatical so that he could focus his attention on the InterLACE Project and the development of the Thought Cloud. Sam, a graduate student who was new to teaching, took over for Grant and consulted him regularly regarding curriculum and the various ways he could use the Thought

Cloud in the classroom. The other Design Team members included Daniel, who has 21 years of experience and works at a small rural private school; Charles, who has 16 years of experience and works at a medium-size rural public high school; Kraig, who has six years of experience and works at a large suburban public high school; and Caroline, who has four years of experience and works at a medium-size urban high school.

### *Procedure*

The data we culled from our Design Team teachers consists of the questions, prompts, and challenges they uploaded to version 2 of the Thought Cloud, which was introduced in late March and remained active till the end of the spring semester. The modules that the team members created addressed myriad physics concepts such as kinematics, Newton’s laws, energy and work, sound and light waves, and heat transfer. Additionally, each teacher devised his or her own InterLACE module based on the topic of pendulums. Before the lexicometric software program processed the data, it was edited to remedy inconsistencies, misspellings, and other such errors, but essentially it represented the teachers’ own words.

### *Data Analysis*

Once we exported the data from InterLACE’s Web platform, we performed various lexicometrical procedures on the teachers’ lexica using the 5.5 version of Dtm-Vic, a software program designed to perform analyses of multidimensional numerical and textual data. Derived from innovations in linguistics, statistics, and computer science, lexicometry is relatively new to the educational field. Lexicometric software programs such as Dtm-Vic afford an objective window on a congregation of lexica, which is often referred to as a corpus, through “a panoply of approaches which seek to capture the different properties” of the textual data (Williams, 1999). Initially, the program is fed the corpus, which constitutes all the words of all the research subjects (in our case, the teachers), and proceeds to count the number of times every distinct word appears. Once a frequency threshold is applied, meaning a parameter is drawn around the corpus that excludes words that appear fewer than a certain number of times, the program forms a contingency table, a matrix data structure that records frequency distributions in which each lexicon occupies its own row and each distinct word in the corpus is placed in its own column, thus illustrating how many times a subject used a particular word in the corpus (see Table 1). The program can then visualize the data by projecting it onto a factorial plane and/or constructing a Kohonen map. Additional aspects of the program allow users to identify not only the most favored words but also the most favored sentence fragments and to group subjects by illustrative variables such as gender or years of experience to ascertain if those characteristics in any way correlate with their combined lexica.

### **ABBREVIATED CONTINGENCY TABLE**

	describe	explain	knowledge	power	report
Caroline’s lexicon	1	0	0	17	4
Charles’ lexicon	1	2	0	0	2
Daniel’s lexicon	11	0	11	1	2
Kraig’s lexicon	5	1	0	0	0
Sam’s lexicon	7	14	0	0	0

**Table 1: *If the matrix above represented the entire contingency table of our data, there would 111 columns of words. We can already see a divergence here between Caroline and Sam: While she used the word describe once and power 17 times, Sam used describe seven times and never used the word power.***

Since we were examining the contributions of just five teachers, we started with a simple direct correspondence analysis to see where each educator stood in terms of their respective lexica. Because no a priori categorization is applied to the data, direct correspondence analysis represents the most straightforward exploration of the corpus. After inspecting the axes view of the factorial plane and the Kohonen map that the data produced, we took a look at the words the program identified as characteristic and anticharacteristic, or most favored and least favored, and then performed a segment analysis to pinpoint which sentence fragments appeared most often in each contributive lexicon. Once we identified the words and sentence fragments the teachers used most, we pored through the modules to locate the ones that seemed most representative of the program’s findings.

## Results

The corpus consisted of 5,716 words, 1,037 of which were distinct. In all, Caroline’s questions accounted for 259 words in the corpus; Charles, 658; Kraig, 1,196; Daniel, 757; and Sam, 2,846. (For a complete breakdown of the number of words, modules, and questions each teacher uploaded to the Thought Cloud, see Table 2.) Once the corpus was loaded into the program, we applied a threshold of nine words, so that the analysis would focus on words in the contingency table that were used nine or more times by the teachers. This process reduced the corpus to 3,815 words and 111 distinct words. The program creates two galaxies, if you will: one containing the respective lexicons of each teacher and one containing all the words of the corpus. These two galaxies are merged and ordered by dimensions, or axes, that are defined by the frequency with which each word appears and how evenly or unevenly each of those frequencies is distributed among the teachers’ lexica; therefore the first two axes represent the lexica and words that make the most pronounced contributions to the multidimensional space in which the corpus exists.

## TEACHER USAGE

Teacher	Number of Words	Number of Questions	Number of Modules
Caroline	259	15	2
Charles	658	21	5
Daniel	1,196	30	8
Kraig	757	41	8
Sam	2,846	84	24

**Table 2: *The matrix above shows how many words, questions, and modules each Design Team teacher uploaded to the Thought Cloud. In the case of Caroline and Sam, the difference in usage is startling: Sam uploaded 10 times more words, 9 times more questions, and 12 times more modules.***

Once this space is formed by the program, it can then project the data onto the factorial plane, thus allowing us to see if the teachers' lexica are similar, different, or somewhere in between and which words each teacher used most. When we projected our lexica onto the factorial plane (see Figure 2), we observed that Charles' and Caroline's lexica congregated toward the top left corner of the plane, meaning that theirs resembled each other, while Sam's and Daniel's lexica lay at the bottom corners of the plane—Sam to the left and Daniel to the right—indicating not only an opposition between Charles and Caroline's and Sam and Daniel's lexica but also a palpable difference between Sam's and Daniel's lexica. Thus the words Charles and Caroline used for the questions and challenges were alike, while the words used by Sam and Daniel were distinct from the words in Charles and Caroline's and in each other's modules. Kraig's lexicon sat rather near to the first two axes, signaling that his contribution lacked significance, and in fact, when we referred back to the coordinate and contribution table, we verified that his contribution was not meaningful to the first or second axes but was consequential to the lesser third axis (see Table 3). Accordingly, we focused our attention to Charles', Caroline's, Daniel's, and Sam's lexica and discounted Kraig's.

### COORDINATE AND CONTRIBUTION TABLE

name	weight	disto2 *	coordinates						*	absolute contributions						*	squared cosines						*
			f1	f2	f3	f4	f5	f6		f1	f2	f3	f4	f5	f6		f1	f2	f3	f4	f5	f6	
charles	.100	1.16 *	-.09	.88	-.47	.40	.00	.00 *	.3	52.5	19.9	17.3	.0	.0 *	.01	.66	.19	.14	.00	.00 *			
caroline	.047	2.25 *	-.35	.85	.29	-1.15	.00	.00 *	2.3	22.9	3.5	66.7	.0	.0 *	.06	.32	.04	.59	.00	.00 *			
daniel	.207	.95 *	-.97	-.05	.03	-.05	.00	.00 *	78.2	.4	.2	.5	.0	.0 *	.99	.00	.00	.00	.00	.00 *			
kraig	.122	.82 *	-.25	.13	.79	.34	.00	.00 *	3.1	1.5	68.3	14.9	.0	.0 *	.08	.02	.76	.14	.00	.00 *			
sam	.525	.16 *	-.28	-.25	-.13	-.03	.00	.00 *	16.0	22.7	8.2	.6	.0	.0 *	.48	.40	.11	.01	.00	.00 *			

**Table 3:** Above we can see the contributions that each teacher's lexicon made to the axes formed by the overall corpus. Here, they are labeled f1, f2, f3, etc.; accordingly, f1 corresponds to the first axis and so on. A significant contribution is determined by dividing 100 by the number of subjects. Since there are five lexicons in our example, a contribution would be deemed consequential if it is equal to or greater than 20.

When looking at the configuration of words on the factorial plane, we found that *model*, *mass*, *time*, *each*, and *following* lay near Charles and Caroline, while *water*, *wave*, *words*, *have*, *sure*, *be*, and *give* were located around Daniel and *explain*, *you*, *would*, *think*, and *simulation* encircled Sam. Because the visual representation of the factorial plane is two dimensional while data itself is multidimensional, a sort of parallax—to go back to our earlier astronomy metaphor—happens in which two words seem to be making equal contributions to the factorial plane because they appear to sit adjacent to each other, but closer inspection of the data reveals that the contribution of each word is actually separated by a considerable distance. Thus a Kohonen map, a self-organizing feature map that provides another way to visualize multidimensional data, provides a complementary view of the teachers' lexica by showing the words in the corpus that are situated the closest to each lexicon (see Figure 3). Again, we observed that Sam favored *you* and *think*, but we also noted that he was linked to *different*, *data*, *energy*, and *graph* and seemed farther away from *would*. Similarly, Daniel was once more tied to *sure*, *has*, and *be*, but he was additionally connected to *comments*, *knowledge*, *method*, and *describe*. Charles' and Caroline's lexicons drifted slightly apart, with Charles appearing much closer to *your* and *when* and Caroline grouped with *motion*, *mass*, and *angle*.

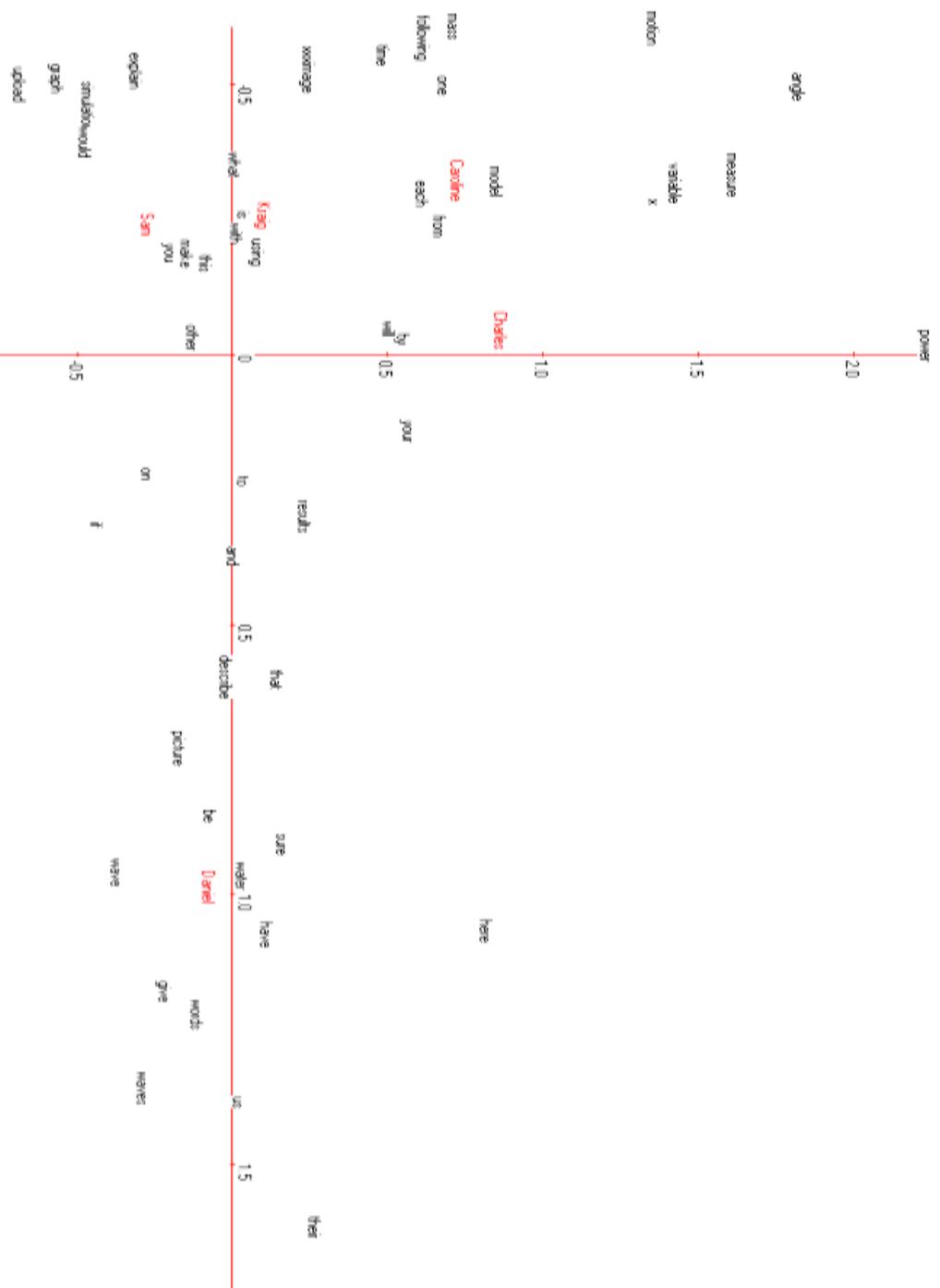


Figure 2: The Design Team members are projected onto the factorial plane. Caroline and Charles are located rather close to each other, while Sam and Daniel are in opposition not only with each other but with Charles and Caroline as well, and Kraig lies too close to the center of the first two axes to make a meaningful contribution.

<p>would upload sketch simulation point field explain every draw diagram cm clock bob acceleration</p>	<p>xxxxlink if as about</p>	<p>have picture be any</p>	<p>words waves water us their react presentation method knowledge itself have give comments <b>Daniel</b></p>
<p>think pendulum happens graph energy different data <b>San</b></p>	<p>you this of not make in a</p>	<p>use to results or on it can are and</p>	<p>that sure here has describe</p>
<p>swing period like gravity forth does back</p>	<p>with what velocity using the test other for experiment at an</p>	<p>your seconds by <b>Charles</b></p>	<p>xxxxsin when</p>
<p>xxxximage why one much is how each do change <b>Kraig</b></p>	<p>will which model from</p>	<p>x variable time power measure length</p>	<p>motion mass following angle all <b>Caroline</b></p>

Figure 3: The cells adjacent to the ones containing the teachers' names (which are highlighted in red) represent the words each instructor favored in the questions and challenges that he or she uploaded to the Thought Cloud.

Next we turned our attention toward the words that the program identified as characteristic and anticharacteristic—or most and least used in relation to the corpus—for each teacher (see Table 4). In this process, words are considered consequential if they have a significant test value, meaning they rank above 1.96 or below -1.96, which indicates that their *p* value is less than 0.05. Charles showed a preference for words like *power*, *variable*, *measure*, and *model*; Caroline, *motion*, *angle*, *mass*, and *time*; Daniel, *presentation*, *react*, *knowledge*, *method*, *be*, and *has*; and Sam, *draw*, *sketch*, *you*, and *would*. Alternately, Charles refrained from using words such as *if* and *or*; Daniel, *explain* and *you*; and Sam, *power* and *method*; Caroline had just one anticharacteristic word, *and*, which might be a consequence of the fact that she used the fewest words among the teachers, but its test value of -1.837 falls short of the abovementioned cutoff.

**CHARACTERISTIC AND ANTICHAARACTERISTIC WORDS WITH SIGNIFICANT TEST VALUES**

<b>Teacher</b>	<b>Characteristic Words (Test Value)</b>	<b>Anticharacteristic Words (Test Value)</b>
Charles	power (8.253) variable (3.163) measure (3.163) model (2.981)	if (-2.305) or (-2.305)
Caroline	motion (5.641) angle (4.073) mass (3.779) time (3.716)	explain (-2.603) you (-2.085)
Daniel	presentation (7.997) react (5.438) knowledge (5.438) method (5.438) be (4.933) has (3.649)	power (-4.696) method (-3.471)
Sam	draw (3.979) sketch (3.823) you (3.088) would (2.785)	and (-1.837)

**Table 4: The words Charles, Caroline, Daniel, and Sam used most and least.**

Additionally, we performed segment analyses of Charles’ and Caroline’s lexica jointly and Daniel’s and Sam’s lexica separately to see which sentence fragments appeared most often in their modules. (Again, we set aside Kraig’s data since his lexicon failed to contribute meaningfully to the corpus.) For Charles’ and Caroline’s segment analysis, the standout fragments included *power your machine* and *your units*; for Daniel’s, *your own words*, *that is okay*, *react to*, *if it has to be a link*, *comments on the*, and *be sure to put their phrasing in quotes*; and for Sam, *if you*, *what happens to the*, *what is the* and *based on your*.

## Discussion

The most compelling result of our lexicometrical exploration is the similarity found between Charles’ and Caroline’s lexica and the opposition detected among their, Daniel’s, and Sam’s lexica. Referring to Table 2, we can see that one factor that links Charles and Caroline and distinguishes them from Daniel and all three from Sam is the number of times each teacher used the Thought Cloud in his or her classroom: Caroline’s usage was exceedingly low; Charles’, just

a tad more robust; Daniel, better still; and Sam's, extraordinarily high. Could these varying levels of usage indicate a gravitation either toward or away from the inquiry stance a teacher must adopt to maximize the benefits of the Thought Cloud?

On the surface, our lexicometrical analyses seem to support this suspicion. From our results, we could place each teacher's lexicon into one of three categories: student-centric, process-oriented, and content-centric. Sam favored words such as *you*, *would*, *think*, *different*, and *other*, which denotes an approach that's more focused on steering students to "think about thinking and learning" (Beatty, 2006; p. 6). Daniel tended toward nouns like *knowledge* and *method* and stative verbs like *be* and *have*, which might have prompted his students to frame the activities as ones in which the primary concern was that of procedural rectitude. Charles' and Caroline's lexica indicate a desire to transmit information; *power*, *mass*, *angle*, and *motion* are intrinsically linked to physical phenomena, and although these words are not bad in isolation and sometimes absolutely necessary for clarity and comprehension, they also possess the proclivity to slide toward a wordiness that Elstgeest (1985) depicted as "purely verbal questions, which require wordy answers, often neatly dressed in bookish phrases" and thus "draw away from scientific problem solving" (p. 36).

Each teacher's use of *your* as revealed in the segment analysis appear to augment the abovementioned conjecture: When Charles and Caroline used *your*, it was attached to the content-centric words *units* and *machine*; when Daniel and Sam used the same possessive adjective, they seemed focused on student expression (Daniel: *your own words*) and observation (Sam: *based on your*). However, a deeper examination of the modules that were most representative of the outcomes of our lexicometrical analyses in terms of most favored words and sentence fragments showed a greater divide between Charles' and Caroline's pedagogical goals when using the Thought Cloud. The module most representative of Charles' lexical leanings revolved around the rather demanding design challenge of constructing a wind turbine out of LEGOs; therefore it seems fitting that Charles leaned rather heavily upon content-centric words to ensure that his students had a clear understanding of what they were doing, why they were doing it, and what they needed to be looking for. Caroline's representative module, on the other hand, involved viewing a video of a pendulum in motion, filling out a virtual worksheet, and tinkering with the usual variables. So even though Charles used a lot of content-centric words, his activity relied upon student innovation; Caroline similarly drew heavily from a content-centric vocabulary, but her activity led students by the nose through proscribed steps. (For the complete modules, see the Appendix.)

## Conclusion, Implications, and Future Work

A classroom communication system, which by its very nature possesses the potential to expose student thinking, is rendered useless if it is populated by questions that require students to merely recall information obtained from a textbook or lecture. To maximize the effectiveness of such technology, we need to train users to design questions that "seek to help students explore, organize, integrate, and extend their knowledge" (Beatty, 2006; p. 2). The lexicometrical analyses we performed point toward the possibility of using the results to categorize teachers' words as more student- or content-centric, thus allowing us to identify teachers whose questions might be improved so that we can help them craft queries and challenges that are more evocative

of rich student thought. Our results highlight the fact that more work needs to be done with teachers to maximize the benefits of the Thought Cloud. The implications of this finding indicate the need for continued professional development and evaluation of the usage of the Thought Cloud, and, potentially, other similar Internet-based, collaborative classroom environments. We encourage users of the Thought Cloud and other classroom communication systems to consider how the phrasing of teachers' questions can reveal their particular pedagogical stance and that the analysis of their choice of words can help inform technology developers and educational researchers on the various approaches. A key limitation in the work we have presented here is that we do not include the analysis of student responses to the teachers' prompts. To address this shortcoming, we will perform additional lexicometrical analyses on the data collected by the Thought Cloud to test the verity of these initial findings and see what effects student-centric, process-oriented, and content-centric phrasings have on the quality of student answers.

In terms of features we could add to the Thought Cloud, we have considered developing an application that allows teachers to perform their own lexicometrical visualizations of the data that they upload to the tool, thus increasing their awareness of the words they and their students use. And in terms of professional development activities, we are discussing the establishment of video clubs in which teachers analyze clips recorded in their classrooms to help strengthen their ability to attend to student thinking and create questions that best reveal it.

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## Appendix

### SAMPLE MODULES

#### *Caroline's Pendulum Module*

- 1) What parameters might be important to how a pendulum works?
- 2) What can we measure in this video that might help us?
- 3) List the 3 variables you can change in this experiment. But remember, you can only change them ONE at a time!!
- 4) Which variable will you measure for all your trials?
- 5) Report your results by clicking on Add New Idea. Show your parameters in the following format:

**Angle:**  
**Mass:**  
**Length:**  
**Time:**

For example:

**Angle:** 10 degrees

**Mass:** 40.4 grams

**Length:** 50 cm

**Time:** 14.3 seconds/10 cycles

6) Report your best result here. Show your parameters in the following format:

**Angle:**

**Mass:**

**Length:**

**Time:**

7) What happened to the time when you changed the angle? Use evidence from ALL of the groups' data to explain your answer.

8) What happened to the time when you changed the length of the string? Use evidence from ALL of the groups' data to explain your answer.

9) What happened to the time when you changed the mass?

10) Which parameter had the biggest effect on the time it took the pendulum to complete 10 cycles? (angle, mass or length)

### *Charles' LEGO Wind Turbine Module*

1) In separate idea posts, describe ALL of your designs. For each design add a response and report the results of your test: a) distance from fan b) fan speed c) voltage.

2) Pick ONE of your fan systems. Using the voltage AND current sensors, measure and calculate the power produced by your fan (power = voltage x current; power measures how many joules per second of energy your system is transferring; units of power are watts). Report: fan speed, distance from fan, and power.

3) Calculate the maximum power attainable for your wind generator:  $\text{Power} = 0.5 \times \text{Swept Area} \times \text{Air Density} \times \text{Velocity}^3$  NOTE: Swept area is the area of wind captured by your turbine. Use area of rectangle and circle equations to help you figure this out. Air density is in kg per cubic meter (use  $1.2 \text{ kg/m}^3$ ). Measure the wind velocity with the Vernier Anemometer. Make sure you cube the result in your equation above. Keep your units to kg, m, and seconds. Be careful with your area measurement. Make sure you convert your units to meters before you calculate area.

4) Report here the power your machine produced to lift the LEGO weight AND the power your machine used to lift the weight. Power your machine produced: To calculate the power produced

to lift your weight, use the work/time equation where work is the amount of PE gained by the weight. Keep your units to kg, m, and seconds. Power your machine used: To calculate the power your machine produced, measure the voltage AND current used by your machine. Multiply voltage by current and you will get the power your machine used.

5) Measure the available power from the leaf blower. Measure the power your turbine generates to light a lightbulb. Calculate the percentage of power your turbine obtained from the wind.