

***Solvitur Ambulando:***  
**Interrupting Secondary English Literature Education**  
**Through Conversation with the Sciences**

by

Jennifer Ann Crumpton

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### Abstract

Though the world at large is a complex system of interdisciplinarity, secondary classrooms continue to be divided by subject, a modernist orientation, drawing lines between disciplines in lieu of nurturing conversations between them. Ultimately, what results are students who are made to keep containers and categories of information in silos of brain-space, rarely concerned with the patterns and connections between the models of thinking they represent. To date, the research for metacognition and analogous thinking gives teachers reason to pursue interdisciplinary efforts and cross-curricular paradigms. However, in my view as a seasoned English Language Arts teacher at an Alberta secondary school, without harnessing such instruments of cognitive dissonance like metaphor and allegoresis within interdisciplinarity, teachers are not exploiting opportunities for students to find patterns and connections, to entertain actual conversation. What results is an interdisciplinarity that merely checks a box, cross-curricula that dissolves one field into the other, or steals pieces of one to feed lack in another. What results is a student who is made to keep containers and categories of information in silos of brain-space, rarely concerned with the patterns and connections between the models of thinking they represent.

This thesis emerges from the view that educators might benefit from a model that honours all disciplines and synergises something new from the *interdependence* founded in *interconnectivity*. Our current classrooms are not properly tapping into those models of thinking that transcend discipline and comprise humanity, though our students walk across those lines daily. My intent is to explore the power of alien disciplines (Biology, Chemistry, Physics) in my classroom, building up the foundation of metacognition and taxonomies of interdisciplinary

interaction, then using that foundation to harnesses the power of true allegoresis by way of metaphor. What results is an interdisciplinarity that fosters cognitive dissonance and helps students pattern their learning and teachers pattern their teaching. In implementing this reframing in my own teaching context, my own immersion in the current system will serve as an opportunity to question that system, and allow students to anchor their learning somewhere deeper than the categories in which the disciplines are currently expected to live.

**Keywords: interdisciplinarity, cross-curricula, metacognition, analogous thinking, cognitive dissonance, allegoresis, metaphor.**

## **Preface**

This thesis is an original work by Jennifer Ann Crumpton. No part of this thesis has been previously published.

### Acknowledgements

Special thanks to my team at WP Wagner High School for supporting my development of this new understanding and approach to pedagogical experiences, including their willingness to engage with this document in its many draft forms. A number of people talked me off a number of ledges, encouraging me to push and strive and reach further. Of particular importance is David Wasmuth, my colleague and friend, who stood with me in many places on this journey, offering his support and perspective, contributing constructive criticism, helping me see where to take my next steps. He was one of the first to weave my efforts into his own classroom and explore its possibilities with his own students. As much as I was always excited to follow through in my own classroom, it turns out that David's willingness to trust my experience and translate it to his own was crucial in helping me see new angles and new possibilities as this ~~continued~~ continues to evolve.

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*A word regarding my title, which will unfold for the reader:*

**Solvitur Ambulando:** Latin phrase, lit. '(the problem) is solved by walking.' Also as *n.phr.*

An appeal to practical experience for the solution of a problem or proof of a statement. Also in shortened form **ambulando** adv. by experience; in the course of things. Originally an allusion to the reported proof by Diogenes the Cynic [to Zeno of Elea's *Paradoxes of Motion*]: as Zeno argued his paradoxes, the story goes, Diogenes eventually stood, declaring this phrase, then walked away, his actions instantly disproving the theories that sat on the table behind him.

—Solvitur Ambulando phr. (n.d.)

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## Chapter One: Introduction

I remember driving through the mountains and looking out the window. I would have been eight or nine, my younger sisters next to me in the back seat, my parents up front. We were at that stage of the journey where people are mostly quiet, ready to be there already. “Is that sedimentary rock?” I asked the car. My parents both looked. “Which one?” dad asked. “The one with all the layers,” I said, “That one.” I could hear the smile when dad replied, “What are all the layers?” I remembered, “Different kinds of rocks, laid down over centuries.” We then talked about what else has layers (“trees!”), and how damage is the only thing that can interrupt layers and expose them to the world. The conversation ended before we arrived, but continued to rattle around in my head when my parents were finished with their part. *Plate tectonics shift the earth; trees have to be cut. Layers are revealed. Alberta does not get earthquakes because our mountains were exposed long, long ago. Trees do not choose to expose their layers; people do. People can become the force that shifts the surface of the earth. Everything was connected and entangled.* That was always the lesson I learned from my first teachers: everything is connected and entangled. And this has always been the way I teach, by way of the rest of my life and the understandings I have gleaned therein. I speak in terms of Biology and Chemistry and Physics, of Mathematics and History and Art: I speak in terms of life. I believe many teachers teach the way they themselves learned. In my case, my education was never trapped in textbooks and classrooms, but were lessons I could see play out all around me. *Solvitur ambulando*: my education has always been proven with practical experience, always grounded in the real world, in connections. It would follow, therefore, that my teaching would also manifest this understanding.

A couple of years ago, I found myself sitting with a group of junior high teachers from my school's catchment, working in an English Language Learner focus group. A grade nine science teacher in the group was struggling with the vocabulary demands in an 'Electricity Unit,' and how considering the amount of time she had and how many words the students needed to master, getting to the skills beyond the language was near impossible. I asked for the list and spent about ten seconds looking at it before I told her that not only was it manageable, I could help her feel that way too. Within a week, I sent her a slideshow explaining how some minor adjustments could make 73 Electricity words a walk in the park: what seemed to be a daunting list actually only contained four measurement units and nine unique terms, while the rest could be patterned and derived from one another, building off previous knowledge and expertise. I pointed to the Greek and Latin roots at the cores of these words and started to ask why teachers (and students) were not looking at these cores more often: why everyone was memorising definitions and drawing lines between words instead of relationships, why students were not being taught to associate resistors with transistors and assistance, or insulation with peninsula, or perimeter measurement with peripheral characters, or electrical conductivity with abductor muscles. To more fully expose these relationships, Figures 1 and 2 showcase two slides from the slideshow I designed<sup>1</sup>. Every time I show this presentation, teachers marvel at the exposed pieces, complimenting an insight that does not belong to me, but belongs to our coded language. It turns out teachers largely do not know these associations exist and that these terms are indeed connected. How then could their students ever hope to draw such relationships?

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<sup>1</sup> For further context, the complete slideshow can be accessed here: <https://goo.gl/NeK3Wx>



Figure 1. Electricity terms broken down.



Figure 2. Connections beyond Electricity.

I spent the next few months dissecting vocabulary lists from every resource I could pillage, scouring for roots and affixes and sorting them in an effort to make them usable for everyone. This generated two posters two-feet high by six-feet wide, one for roots<sup>2</sup> and one for prefixes<sup>3</sup>. In September of 2017, my high school printed a hundred pairs, half of which were sent to our junior high and elementary feeder schools and half of which were meant for teachers at my school. Although I cannot speak for what happened to the ones we sent away, as of January 2018 only about twenty of these were up at my school of a hundred and fifty classrooms. The rest are rolled up and tucked into corners, lost with good intentions and waiting for the day teachers have the time to remember them. The lines dividing disciplines remain firmly intact. Impressed as they were when I exposed the pieces in my presentation, the next step is not one that takes itself. Clearly, providing the tool is not enough. *Solvitur ambulando*: I needed to do some walking with those tools before teachers could invest in my ‘proof.’

<sup>2</sup> For further context, the roots poster can be accessed here: <https://goo.gl/txjhzp>

<sup>3</sup> For further context, the prefixes poster can be accessed here: <https://goo.gl/GFXYf7>

It was in this walking the course that I found myself in a place where I would want to engage with a bigger kind of interdisciplinarity, one where the lines of conceptualisation would become bridges instead of barriers. I know in my heart that interdisciplinarity makes me stronger, but I needed to know why and how and when it can make our students and their teachers stronger as well, a need that is met by first unpacking the problem before attempting to understand its solution.

### **Issue/Problem: Realising We Are Stuck**

According to Chambers (2008), an engaging classroom is one with “environmentally situated action—to be perceptually engaged in an activity in the environment where the skill is practiced, not in a situation removed from it” (p. 119); “as [students] learn and practice the skills necessary to live in that particular place[,] they become who they are” (p. 117). I wonder, therefore, what would happen if educators committed to making an engaging *school*, instead of just being concerned with their own classrooms? What if we did *not* stay fixed in our disciplinary silos, such that the learning could echo the relationships of the world beyond our classrooms? Unfortunately, our inability to achieve Chamber’s target of engagement is compounded by our current educational model that (especially at the high school level) divides time into units of study: individual subjects and courses and foci. This is the legacy of Enlightenment-thinking. With only so much time in a day, choices have to be made, and they are not the kind that yield a balanced selection. It is increasingly clear that the Humanities and Arts are being lost in favour of Science, Technology, Engineering, and Math (Cunha, 2016). That those disciplines are referred to with the acronym STEM, suggests just how rooted into our value system they have

become, repeating the modernist legacy. In my own school, we regularly struggle to help students see that a brain used for an extended period of time with only one kind of thinking is a tired and worn out brain; allotting time to a Pottery class or a Design class or a Drama class or even an English class is not dividing their time, but is strengthening the whole student's grasp of their world. Wisdom is a journey of breadth and depth, and not simply distance. STEM runs too quickly and too far, without the footing of Arts and Literature and History to anchor it. Jardine (2008) reminds us that "worthwhileness has to do with a way of treating things, a way of composing our understanding of something, seeking its kinships [...] and verisimilitudes" (p. 3), not drawing lines and borders, but finding connections. This is the difference between resemblances as categories and similitudes of differences (Foucault, 1983).

This thesis suggests that a pedagogical reframing is in order, not one that abandons the importance of teacher expertise or of student willingness to learn, but one that simultaneously exploits student expertise *and* teacher willingness to invite alien (as in strange) expertise into their worlds. Current pedagogy is either aimed toward conforming or toward "dividing and selecting, for noting and disregarding" (McGraw, 2011, p. 105), though within those series of lines and borders and edges, "learners must learn how to actively make connections between their own lived conditions and being, and the making of reality that has occurred to date" (McLaren, 1999, p. 51). High school teachers are meant to be experts of their disciplines; however, students are asked to be experts of all disciplines: the province of Alberta will only grant high school diplomas to students enrolled in a variety of courses, each taken to a

designated level of proficiency<sup>4</sup>. These requirements ask students to reach far and wide across disciplines, while their teachers remain isolated in worlds of independent disciplinarity: educators ask students to find expertise in many places and *then* do little to harness the power that fulfilling such a request could yield. Teaching —and therefore learning—in disciplinary silos undoes the potential we should be able to realise in a high school of experts.

### **Rationale: Why Bother?**

Pedagogy is a precious charge; its meaning is derived from the Greek roots *paidos* and *agogos*. The former identifying the subjects of our charge — *students* — and the latter illuminating our agenda therein — *to bring forth or arouse purpose*. Dividing the school and its days according to the expertise of its teachers is a one-sided agenda (that of teachers alone); it ignores those subjects and defies the proper agenda. In lieu of the etymological roots of our craft, we continue to perpetuate a fourteenth century malapropism of this word: doing more to embody the “slave who escorts boys to school and generally supervises them” (“Pedagogue,” n.d.). As outlined in Figure 3, in teaching, my pedagogical function is not simply to keep my students in the box of a classroom; it is to *pretend*, to hold them in safety such that I may stretch them, test their mettle and push them to new ends:

<b>PRE-</b>	<b>TEND</b>	<b>-ING</b>	<b>PEDA-</b>	<b>GOGY</b>
before	hold/stretch	continuously	students	arouse purpose

Figure 3. *Pretending a pedagogy: the etymological pieces of the job we do as teachers.*

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<sup>4</sup> For further context, visit <https://education.alberta.ca/graduation-requirements-credentials-credits/high-school-diploma/everyone/diploma-requirements/> for current Alberta High School Diploma Requirements



It is especially important to do this when they are children, before the ‘real world’ makes demands on their adulthood, before they need to harness those skills after high school, when the safety and security of pedagogical care has been removed. Until then, in these moments of stretching, of expansion and contraction, nothing is set permanently. As Fairbanks (1976) observes, “a person is not composed of ‘mental’ ideas encased in a ‘material’ container or body. A [person] is in fact a process of fusion, a melding, a blend of signs” (p. 21). Countless hours in classrooms, and this is how we ruin so many kids, by ignoring Fairbanks’ observation, turning them into receptacles instead of harnessing the investigators they were born to be. The notion that students are “stamped” (Russell, 2015, p. 343) and forced into molds is disturbing, and certainly belies the potential for “constant encoding, decoding, and recoding” (p. 344) in a classroom, something that is dependent on “dynamic interactions and similarly heterogeneous milieu” (p. 344).

Currently, high school classrooms are largely catalogues of knowledge, wherein organic interrelationships between concepts are removed and replaced with artifice. After high school, society expects students to apply *all* of their lessons to *all* of their lives, but during high school, educators do not truly help them know how to do that; schools divide and isolate, and risk subverting actual meaning. Once students hit junior high, they pour themselves into and out of different classrooms, as many containers in which to fit the separate disciplines. This effect is compounded with every passing school year, with every degree further into specialisation. Our high school system is, therefore, founded on lines and categories and division. In light of this, educators are indeed confused about the futures we desire for children, ones we imagine based on our own lives, our own educational histories, and not the needs of the learners sitting before

us here and now (P. Kelly, 2001; Shernoff, 2012). We are products of our own system and perpetuate its fallacies when we process students as we ourselves were once processed.

### **Purpose: To Bother**

What if the conversation between disciplines was not cursory or incidental, but fundamental to learning, a genuine conversation, a comparison between known and unknown that bridges the two as interrelationships, that networks knowledge instead of isolating it in pockets, that allows our pigeons to fly instead of insisting they get back in their holes? These teaching silos are learning silos: *that is what I would like to see undone*. What if the Biology teacher made my English teaching easier? Not because she could provide more time or fewer students, but because we started teaching the *same* students, tapping into patterns of thinking that transcend disciplinary lines and more completely address humanity. I want to explore the power of Math *and* Biology *and* Chemistry *and* Physics *and and and* in my English classroom. The Province of Alberta (with their diploma requirements) has asked that my students become experts in a variety of disciplines. The Alberta Education (2003/2014a/2014b/2014c) *Programs of Studies*<sup>5</sup> for these courses outlines exactly what it is that my students are expected to know. These efforts do not undermine my own expertise, but tap into it where it is relevant: I am an expert on hearing Literature—the expression of the human condition—inside of those disciplines. I am thus proposing a world where not only is the morphology of the English language interdisciplinary, but the structures and thinking and processes are transcendent, where a student's confidence with the trigonometric geometry could reveal nuance in character

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<sup>5</sup> Current versions of these publications can also be found here: <https://education.alberta.ca/programs-of-study/>

development, where the satisfaction of a stoichiometrically balanced equation could expose ambiguity in conflict resolution, where antagonists are viruses and positive feedback loops evoke momentum, where conic sections are human interrelationships. What if we have been looking at the wrong pieces to teach more effectively and make learning come alive, to restore the meaning in *pedagogy*? It seems to me that many of our current pedagogical efforts are either over-translating or inappropriately translating, simply reducing subjects to their lowest common denominators to make content easily digestible. Instead of reduction, we should be building connections: the subjects and disciplines need to feed one another more explicitly, nurturing as many connections as there are pieces of students.

## Chapter Two: The Plan

### Research Questions: Asking

I came into this stage of my Master's adventure with these research questions in mind:

1. How can teachers support more interdisciplinarity between the study of literature and science?
2. How can this interdisciplinarity avoid narrow or reductive cognitive consonance?

These questions are born of practical application. As much as I want this approach to be founded in sound and respected research, I do not simply want this thesis to exist in the world of theory. Instead, I want teachers to understand *how* this approach could look in their own classrooms.

### Research Design: Doing

It is crucial that I begin a project like this with a literature review such that any grand ideas and concerns are grounded in sound academic ethos. My literature review encapsulates the process I endured to understand what our learning and teaching must offer the brains in our classrooms. My efforts took me through metacognition to examine our current interdisciplinary efforts. This allowed me to evaluate that interdisciplinarity. Such an understanding hinged on one of *allegoresis*<sup>6</sup>, a mental process that is activated with metaphor and which fosters cognitive dissonance. This helps students pattern their learning and teachers pattern their teaching. Such an approach allowed me to build a comprehensive matrix, one which teachers should be able to bring into their classrooms, to nurture allegoresis and harness the power of a robust interdisciplinarity. In implementing this reframing in my own teaching context, I propose to showcase not only the theoretical foundation for such an approach, but its viability in practice in

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<sup>6</sup> In *Chapter Three: Literature Review*, I provide a comprehensive unpacking of these terms. Until then, it is enough to understand that *allegoresis* is the process that the brain undergoes when interacting with metaphor and navigating a figurative understanding in lieu of a simply literal one.

my own English Language Arts classroom. In the true fashion of *solvitur ambulando*, I will struggle to (re)solve the question of practical application by walking the course: modelling real-world examples of theory, crafting my matrix, and showcasing the potential for this approach to resonate in classrooms, with students. Specifically, I plan on concentrating on an “intersectional analysis [that] looks at self- identifications, social identifications, and cultural signifiers . . . to interrogate how overlapping and seemingly opposing identity affiliations influence our personal lives, relationships, and narratives” (Boylorn and Orbe, as cited by Mulvihill & Swaminathan, 2017, p. 54). Each piece of *Chapter Four: Experiments* will include all of the resources teachers might need to bring such an approach into their own classrooms. In the anecdotal observations sections that follow each set of resources, I will share my own experiences in using these resources in my own classroom, including my students’ revelations therein, to expose the allegoresis that highlights higher level metacognitive dissonance. Each story/vignette within the case studies will comprise a pairing of scientific theory with a literary dynamic. Readers unfamiliar with the scientific theory in question can rest assured: I have provided a section highlighting each of the new terms, concepts, relationships that students come to learn in those classes. Those unfamiliar with the literature being explored will also find comfort in having a summary section, highlighting the major plot points and the dynamics and relationships created by the characters and their contexts. It is my intention that by first outlining the non-English Language Arts expertise that students bring from their Science classrooms, I might situate my reader in the language of those sciences. Shifting to the literature *will* feel as jarring as we make it for our students, when they arrive in an English Language Arts classroom with competing curricular understandings swimming in their heads, as we ask them to find purchase in literature.

Then, readers will experience the exact explanation provided to students in situ, wherein I model my own unpacking of the literature using those science terms and techniques and perspectives, as I attempt to ask that the competition for our students' focus may fall away as robust interdisciplinarity is given the opportunity to shine. I will offer an analysis of a piece of literature by way of a science lens, as a model of the allegoresis that navigates the metacognitive dissonance to achieve closure.

In each case, these analyses were provided to students to help them later enter the same process and discover the same benefits of allegoresis. As such, these explanations should also expose the baseline with which students in those classes can bring into an English Language Arts class, the pairings that synergize the learning in the Sciences with that in English Literature. What follows in each case is then my experience with the reception of this unorthodox pairing process, both as understood with my students as well as my colleagues and administration. These anecdotal observations are borne of unstructured observations from class discussions, and generated by field notes recorded immediately following each lesson. I refer to student work, using that work as artifacts to demonstrate how the internalized shift or change is manifesting itself for the most important stakeholders in this process, my students. It is crucial that I remain the filter for these understandings, as part of the dual role I must maintain is my preparing students properly for the competencies derived from the *English Language Arts Program of Studies* (2003). This cannot fall by the wayside in my bringing this new intervention into my classroom. As such, modifications and adjustments are *always* to the benefit of student experiences with our ELA outcomes. More specifically, for these efforts, I will use the Alberta Programs of Studies to pull the units or areas of expertise expected of students. In drawing one

unit from each of the 20- and 30-levels, I will generate six case studies. Table 1 outlines the choices made in this approach.

Table 1. *Science units of study and proposed literature connections*

Subject	Units of Study	Key Concepts of Chosen Unit(s)	Literature Selection
<b>Biology 20</b>	<b>A. Energy &amp; Matter Exchange in the Biosphere</b> B. Ecosystems & Population Change <b>C. Photosynthesis &amp; Cellular Respiration</b> D. Human Systems	<b>Energy &amp; Matter Exchange in the Biosphere:</b> - <i>biosphere</i> - <i>equilibrium</i> - <i>trophic levels</i> - <i>food chains, food webs &amp; ecological pyramids</i> - carbon, nitrogen, oxygen and phosphorus cycles - water properties <b>Photosynthesis &amp; Cellular Respiration:</b> - Absorption of light by pigments - <i>Light-dependent and independent reactions</i> - <i>Glycolysis</i> - Krebs cycle - Electron transport systems - <i>Aerobic and anaerobic respiration</i>	<i>A Streetcar Named Desire</i> by Tennessee Williams
<b>Biology 30</b>	<b>A. Nervous &amp; Endocrine Systems</b> B. Reproduction & Development C. Cell Division, Genetics, & Molecular Biology D. Population & Community Dynamics	<b>Nervous &amp; Endocrine Systems</b> - <i>Neuron</i> - <i>Nerve impulse transmission</i> - <i>Central &amp; peripheral nervous systems</i> - <i>Reflex arcs</i> - <i>Sensory receptors</i> - Endocrine system & hormones - <i>Homeostasis &amp; feedback systems</i> - Endocrine & nervous system interactions	<i>Hamlet</i> by William Shakespeare
<b>Chemistry 20</b>	<b>A. Diversity of Matter &amp; Chemical Bonding</b> B. Forms of Matter: Gases C. Matter as Solutions, Acids & Bases D. Quantitative Relationships in Chemical Changes	<b>Diversity of Matter &amp; Chemical Bonding</b> - <i>Chemical bond</i> - Ionic bond - Covalent bond - Electronegativity - Polarity - Valence electron - <i>Intramolecular &amp; intermolecular forces</i> - Hydrogen bond - Electron dot diagrams - Lewis structures - Valence-shell electron-pair repulsion (VSEPR) theory	<i>The Wars</i> by Timothy Findley
<b>Chemistry 30</b>	<b>A. Thermochemical changes</b> B. Electrochemical changes C. Chemical Changes of Organic Compounds D. Chemical Equilibrium Focusing on Acid-Base Systems	<b>Thermochemical changes</b> - <i>Enthalpy of formation</i> - <i>Enthalpy of reaction</i> - $\Delta H$ notation - Hess' law - <i>Molar enthalpy</i> - Energy diagrams - <i>Activation energy</i> - <i>Catalysts</i> - <i>Calorimetry</i> - <i>Fuels and energy efficiency</i>	<i>The Great Gatsby</i> by F. Scott Fitzgerald

<b>Physics 20</b>	A. Kinematics B. Dynamics C. Circular Motion, Work & Energy <b>D. Oscillatory Motion &amp; Mechanical Waves</b>	<b>Oscillatory Motion &amp; Mechanical Waves</b> - <i>Oscillatory motion</i> - <i>Simple harmonic motion</i> - <i>Restoring force</i> - Oscillating spring, <i>pendulum</i> - Mechanical resonance - <i>Mechanical waves</i> — longitudinal & transverse - <i>Universal wave equation</i> - Reflection - <i>Interference</i> - Acoustic resonance - Doppler effect	<i>The Accidental Tourist</i> by Anne Tyler
<b>Physics 30</b>	<b>A. Momentum &amp; Impulse</b> B. Forces & Fields C. Electromagnetic Radiation D. Atomic Physics	<b>Momentum &amp; Impulse</b> - <i>Impulse</i> - <i>Momentum</i> - Newton's laws of motion - <i>Elastic collisions</i> - <i>Inelastic collisions</i>	<i>Macbeth</i> by William Shakespeare

*Note:* Each science subject and level comprises four units of study. These are pulled from the relevant Alberta Education Programs of Study. This table does not exist in any of those publications, but was compiled here to help summarize the resources. The **bolded** terms are those units I have selected from the programs of studies. Within each unit, the *italicized* terms are those highlighted in this demonstration. For more information on the units of study, refer to: Biology 20 (2014a, p. 14), Biology 30 (2014a, p. 48), Chemistry 20 (2014b, p. 14), Chemistry 30 (2014b, p. 40), Physics 20 (2014c, p. 14), Physics 30 (2014c, p.39). For more information on the key concepts of each unit refer to their chapter within the program of study as follows: Biology 20 (2014a, p. 17, p. 31), Biology 30 (2014a, p. 51), Chemistry 20 (2014b, p. 16), Chemistry 30 (2014b, p. 42), Physics 20 (2014c, p. 33), Physics 30 (2014c, p. 42).

## Research Analysis: Seeing

For classroom observations, it was fundamental for me to maintain the same trust relationships we have always had in my classroom: I wanted to be sure the dual roles of teacher and researcher did not change the nature of my classroom, pressuring students to behave ‘inauthentically’ because they were being addressed differently. The paraphrasing remains unattributed beyond the context of my classroom. This is meant to situate the reader in the classroom and within the experience, as I was. The idea here is that my research is addressing a singularity, an experiment that initiates the cross-fertilization of concepts between Science and Literature. Such research is *particular* to my situation. This work is not meant to be generalizable to every highschool ELA program. Rather, its *particularity* is to generate the potential for such a pedagogy.



During classroom conversations, we all become one voice, myself participating in turn like the students. Certainly, I guide discussions and shape lessons, but students are also afforded agency to shift the shape of things. It is the topological *shape* of the conversation that I endeavor to represent accurately, especially if I hope that other teachers will be able to identify with their own classrooms in my depiction, and to do so as a *similitude*, a similarity that marks a difference with is of use. Likewise, I have used language that is ‘authentic’ to our work in those lessons: these are the ways we talk about literature and the ways my students explore their understandings. Though it is fundamental that I filter much of the experience through the academic foundation of this paper, I wanted to maintain the authenticity of these realizations and understandings, especially since they are evoked by efforts I was not sure would work when I began this journey. Still, in some cases, like any new classroom approach, my efforts are not successful; and still, I have included all aspects of the experience. I have tried to articulate these ‘experiments’ knowing full well that they are indeed partial and certainly subject to other interpretations. Nevertheless, I attempt to recognise as many successes and failings as the situations allowed. In brief, as a researcher, I am implicated in the web of relationships in my classroom.

The final step occurs in *Chapter Five: Metacognitive Dissonance Fostering Allegoresis Matrix Analysis*. This chapter is a return to the literature to anchor my findings in the academia, to give my readers an assurance to trust what I know is happening in my classroom. By way of the comprehensive *metacognitive-dissonance-fostering-allegoresis- matrix* I have built in the final stage of my literature review, I process these case studies through and from such a construct to expose the closure that helps these epistemologies find more robust purchase in the learner,

thereby opening up the conversation of interdisciplinary studies in ways that are not simply blending (or dissolving or stealing), which I see in our current interdisciplinary efforts. As my intention with the critical aspect of this investigation is to serve as a catalyst for change, this analysis occurs within the framework of the Alberta Education context in which I find myself pedagogically situated. I originally intended to do this once for each of the sciences, but (as will become apparent), once I pulled the boundaries away from English and Science, my students also began to tear down the lines between the sciences. This meant I needed to adjust my approach to best suit the demands of the stakeholders, an expectation to be reckoned with in any action research model. As such, in chapter five, a more holistic Science matrix discussion follows the complete set of findings.

### **Conceptual Framework: The Parlor of Experts**

In my effort to redesign a learning matrix, my literature review presents the conceptual framework that is already in place, an academically sound foundation that exists but has not necessarily been exploited or harnessed or exposed for its true potential in allegoresis. By assembling that framework, I arrange the scaffolding upon which I can build my own learning matrix in the following chapter. My literature review begins with metacognition, a notion that has been bouncing around academia for over forty years. During my undergraduate degree, I am not sure I ever really appreciated what it could offer our students, instead assuming it was simply a code word to get into the staff room, so frequent was its mention in my university classes. I am sure I have always encouraged metacognition in my classroom, but not as sure that I understood what doors I was opening when I did, until now. Imagine my surprise when it started to appear in my research, finding home in interdisciplinary and cross-curricular efforts, to force real-world

connection for students by exposing their theory to practicality in application. Much of this connecting happens by way of analogous thinking, which incites the process of allegoresis in the learner. This process is the brain's capacity for metaphor to stretch the bounds of reality and rework its fissures and bridges. It is an imaginary, yet crucial force. However, our current cross-curricular efforts are directed more to achieve *blending* than they are to exploit the real strength of allegoresis. Allegoresis opens up the world of cognitive dissonance, which compels the human brain to solve in far more active ways than similar and blended and like-minded circumstances allow. Including a comprehensive explanation of the strange 'beast' that is allegoresis, my literature review will move through each of these steps in setting the foundation for the unique approach that is the basis for this thesis. Once I have this framework established, at the end of chapter three, I will be able to build my own matrix atop this foundation such that I may find purchase for it in my own school context in chapter four.

The ultimate triangulation anchor, however, belongs to the literature review. It is my hope that the application of a comprehensive academic matrix from the literature review should preclude my own investment, only to become a subjective burden when extending this investigation beyond my own world. The generated construct becomes a 'tool' to pry open the potentials of allegoresis so that interdisciplinarity finds another level of engagement in Alberta schools.

Let us begin.

### Chapter Three: Literature Review

#### Metacognition: Representing the Absent

According to the founder of metacognition, John H. Flavell (1985), “it is called *metacognition* because its core meaning is ‘cognition about cognition’” (p. 164, emphasis in original). Since first coined by Flavell (1979), studying metacognition is consistently discussed as studying *thinking about thinking* (De Costa, 1986; Eichbaum, 2014; Kuhn & Dean, 2004; Neuenhaus, Artelt, & Schneider, 2013). Flavell worked to apply this as an adjective, a modifier for the time spent learning, such that for him, experiences became “*metacognitive* experiences... any conscious cognitive or affective experiences that accompany and pertain to any intellectual enterprise” (1979, p. 906, emphasis mine), and therein changed the way academics talked about thinking (Artelt & Schneider, 2015; Schneider, 2008), reasoning (Kuhn, & Dean, 2004; Kuhn, Zilmer, Crowell, & Zavala, 2013), memory (Linden, , Löffler, & Schneider, 2015; Lockl & Schneider, 2007), and feeling (Lagattuta, Wellman, & Flavell, 1997; Roeser & Eccles, 2015). This must be why metacognition, in addition to being featured so regularly in my undergraduate degree, appears on the second page of the *Program of Studies* for English Language Arts (Alberta Education, 2003) and is given three paragraphs of explanation. Clearly it is a key concept.

Since its origin with Flavell, understanding the workings of metacognition has often centred around the educator’s desire “to develop in students the conceptual skills that will prepare them to contribute to a democratic society” (Kuhn & Dean, 2004, p. 268), to do more for children than simply fill their brains with facts, to give students a way to interact with those facts. This desire is a goal echoed by many researchers in this field: being a part of society is

more than simply occupying space within it. Children learn how to be a part of something beyond themselves by making connections between *what is inside of them* with *what is beyond them*; they learn to respond to their worlds by reaching inside of themselves in specific ways (Callender, Franco-Watkins, & Roberts, 2016; De Costa, 1986; Eichbaum, 2014; Flanagan, 1993; Kuhn & Dean, 2004; Wiersema & Licklider, 2009). Without metacognition in the conversation, it is difficult for teachers to hone the strategies that could develop something as seemingly elusive as *thinking*, which “deals with invisibles, with representations of things that are absent” (Arendt, 1971, p. 446). And teachers do not seem to have the time for honing strategies to nurture elusive things. Kuhn and Dean (2004) suggest that teachers focus their energies instead on paths of least resistance:

In the past, when educators have turned to academics for assistance, the role the academic has been asked to play is that of technician: Here is what we want students to know; can you advise us of the most efficient means for them to acquire it? (p. 269)

Efficiency is an element born of a problem with the time allotted to a teacher to achieve the curricular goals. Strategies like metacognition *take* time to nurture because they are not solutions unto themselves, but strategies of activation, ways to cultivate agency in the learner (De Costa, 1986; Neuenhaus et al, 2013). Still, in an effort to make the invisible visible, metacognition was certainly the piece that unlocked that discussion. De Costa (1986) shows us that

Perception, learning, and reasoning (cognitive skills) play a role in this process of course, but the direction of the mind in exactly how to deal with a problem and to arrive at a viable solution (metacognitive skills) are crucial to creative interactive thought. (p. 5)

Teachers I speak with tend to agree with Wiersema and Licklider’s (2009) claim that “good grades earned from typical students’ practices, such as memorizing and recall, are not necessarily accurate indicators of the students’ abilities to do the thinking required for solving real-world

problems” (p. 117). They also agree with De Costa’s (1986) claim that “people become educated, as against trained, insofar as they achieve a grasp of critical principles and an ability to choose, organize and shape their own ideas and living beliefs by means of them” (p. 14). This way of becoming educated is superior to simply becoming trained, yet there is very little literature on how to recognise the former is happening in situ. When I push the conversation there with my colleagues, they dismiss the answer with “That’s the question, isn’t it?” or (worse still) “Kids today!” In fact, “practitioners traditionally have ignored the question. ‘We all know good thinking when we see it,’ their attitude has been, ‘so let’s focus on finding effective techniques to foster it’” (Kuhn & Dean, 2004, p. 269), rather than asking what actually comprises “good thinking,” and being able to recognise the *becoming* of students as it happens so, as teachers, they can interrupt and adjust as necessary. I suspect that this is born of the treatment of metacognition in the English *Program of Studies* (Alberta Education, 2003), where that concept is used as a catch-all solution, first reduced to simplistic actions, and then translated into the verbs that must prove it is occurring:

Essentially, metacognition involves reflection, critical awareness and analysis, monitoring, and reinvention. Students who are engaged in metacognition recognize the requirements of the task at hand, reflect on the strategies and skills they may employ, appraise their strengths and weaknesses in the use of these strategies and skills, make modifications, and monitor subsequent strategies. (p. 2)

I supposed that seeing students “recognize” and “reflect” and “appraise” and “make modifications” and “monitor” is a kind of metacognition, but it also seems that there are varying calibre of these behaviours. If it is true that, “people do not simply reason, they learn to reason” (Bender & Beller, 2013, p. 47), how then can teachers *see* that learning to help students

not only access it where once they could not, but also become better at accessing it, and at doing so in complex and innovative ways? Metacognition is certainly a starting point, but it seems to me that it should not be a binary present/absent model. Brown (as cited by Neuenhaus et al., 2013) agrees, suggesting that while metacognitive development “increases substantially between early childhood and early adulthood, [...] elaborated declarative metacognition cannot be taken for granted” (p. 165). Hannah Arendt (1971) offers the next step: if “thinking’s chief characteristic is that it interrupts all doing, all ordinary activities no matter what they happen to be” (p. 423), then metacognition—thinking about thinking—must be *thinking about that interruption to doing*, “as though we moved into a different world” (p. 423). And since, “[People] learn when they feel that they are a part of what is going on — when they are personally involved” (De Costa, 1986, p. 4), learning occurs when the student *moves away to become a part of* what is happening — moves into an ‘alien’ discipline to better understand the original discipline, in this case moves into the language of science to better appreciate the nature of English literature. It seems to me that metacognition should reach for interdisciplinarity as a *fixture* of learning.

### **Current Interdisciplinary & Cross-curricular Efforts: Interrupting the Ordinary**

One of the most obvious ways to contrive circumstance to *interrupt* ordinary activities is to insert something foreign (or alien) into the experience, something heterogeneous to the existing norms. After elementary school, students are more distinctly sorted into silos of expertise, more of a divide-and-conquer model than a complete educational perspective that more accurately mimics adult-world interchange: “reality is ambiguous, irresolvably so, but the

disciplinary fragmentation of human inquiry has exacerbated this ambiguity as each discipline develops its own unique epistemological approach” (T. Paxson, 1996, p. 80). Interdisciplinary and cross-curricular efforts are meant to undo these silos of learning; they endeavor to erase these lines. There is plenty of scholarship on interdisciplinarity and cross-curricular efforts, and the language those scholars use to argue their theory often seems to dovetail nicely with that of metacognition. For example, Gouvea, Sawtell, Geller, & Turpen, (2013) suggest that of the aims of interdisciplinary education, paramount are “developing deeper levels of conceptual coherence” (p. 188) and “metacognition and adaptive interdisciplinary expertise” (p. 189). In all cases, “one of the great benefits of interdisciplinary study is that it can illuminate the presuppositions and fundamental methodological standpoints of the different disciplines brought into play. It can bring them to participants' awareness in especially fruitful ways” (T. Paxson, 1996, p. 84). In all cases, interdisciplinary education offers opportunity for layered understanding because it fosters skills like creativity and innovation (Dali, 2016; Krahe, Lalley, & Solomons, 2014; Petersen, Finnegan, & Spencer, 2015), teamwork and collaboration (Poole, Egan, & Iqbal, 2009; St Hill & Yazici, 2013), problem solving (Lawlor, Kreuter, Sebert-Kuhlmann, & McBride, 2015; Sandhu, Hosang, & Madsen, 2015), and cultural development (Klein, 2005; Zaydivska, Rymar, & Malanchuk, 2015). Interdisciplinarity indeed seems like the perfect place for students to hone metacognition. What becomes problematic, however, is when theory meets application, in the ways the different disciplines are asked to interact within the classrooms. Teachers are fighting to cover ever-growing course content while still hoping to make that content real, as Thomas Paxson (1996) contends:



We are caught between demands to transcend the boundaries and perspectives of the separate disciplines, in order to obtain a more complete understanding, and demands to ground inquiry in disciplines, in order to secure an epistemic foundation. This is the locus of interdisciplinary study, but it is caught uncomfortably between these two conflicting demands, unwilling to concede wholly to either. (p. 80)

This is indeed the struggle I see manifest in my own school, where teachers seem to know the adult world expectations for students, but just don't have enough *time* to move too far beyond content. As such, "much of the current conversation in interdisciplinary studies focuses on the concept of integration" (J. Kelly, 1996, p. 95), a line of best fit that hopes to fulfill the expectations of multiple disciplines. Sometimes this manifests as one skill—usually literacy—which transcends disciplinary lines (Airey, 2011; Plaster, 2010). In most cases, however, what results is largely one of two outcomes, both derived from a model of *blending*. First, where two subjects fit nicely together and have natural means for one subject to access the other (Gouveau et al, 2013; Harris & Grenfell, 2004; Harris, Harrison, & McFahn, 2012), but where one discipline disappears or dissolves into the other: it is hardly surprising that there is Math in Physics and in Chemistry. Second, where the Humanities and Arts are meant to fix the one sided brain issue of science and mathematics study, such that taking from the former can make the latter more creative, a process of stealing, where one discipline is subservient to the other (Colletti, 2018; Fletcher-Wood, 2016; Ippolito & Adler, 2018; Robelen, 2011; Young-Mi & Hye-Jeon, 2016; Watson-Newlin, 1994). What becomes *problematic*, therefore, is not in the teacher's battle for time and resources, but in the response to that battle: blending occurs through either dissolving or stealing, where disciplines are either subsumed or consumed by the agenda of the

dominant discipline(s). This blending is not conducive to the *moving away to become a part of* the alien that is necessary for a true metacognitive process.

### **Evaluating Interdisciplinarity: Starting at the Beginning**

In an effort to rethink our current cross-curricular efforts and lost interruptions, I reach now to Thomas Paxson (1996), seminal to establishing a framework for interaction between disciplines in his *Taxonomy of Interactions* (p. 83). This access point allows teachers to evaluate the kind and quality of interdisciplinarity currently at play in their classrooms. I have outlined the fundamental thresholds in Table 2. A taxonomy like this also allows teachers to

Table 2. *Thomas Paxson's (1996) Taxonomy of Interactions*

Level	Threshold of interaction at this level
<b>I</b>	“notice is taken... [but] there is no engagement with the other discipline as such. Neither discipline is modified. The interaction is not an occasion or consequence of one discipline’s challenging another.”
<b>II</b>	“one discipline is affected by that interaction, but the interaction is not of the sort which involves the growth of one or more disciplines at the interface of their theories or subject matters.”
<b>III</b>	growth, “interaction occurs because two or more disciplines are exploring from their different vantage points either the same general phenomena or phenomena so closely related that they illuminate one another. As a result the practitioners of a participating discipline come to rely increasingly on advances made in the other participating disciplines.”
<b>IV</b>	“interactions which serve to connect the interacting disciplines as such. These range from the fairly modest connection of sharing some key concepts all the way to the joining of two disciplines into one more comprehensive discipline.”

Note: These levels and their explanations are adapted from T. Paxson, 1996, p. 83.

see where current models might be falling short of higher level interaction. This is not a framework that undermines the efforts of current collaboration with like-minded folk. Still, it is a framework that allows for other dimensions of interdisciplinary work, and one that does not see the “unique epistemological approaches” (T. Paxson, 1996, p. 80) as obstacles or reasons to

reach simply for blending and therefore a line of best fit. This is a framework that has plenty of room for alien entities and interruptions, but which does so in the kind of matrix that nurtures teacher observation and cultivates professional judgment. Without this, there are simply too many ways to ask complex variables to interact. With this, teachers are equipped to choose an interaction that will help them map the cognitive processing demanded by analogy, a complex map to be sure (Berek, 1978; Harris & Tolmie, 2011; Oswick, Keenoy, & Grant, 2002; Thagard, 2011). Therefore, T. Paxson (1996) appreciates that “general education should provide students not only experience and practice in bringing different disciplines into interaction, but in doing so on many different levels” (p. 81).

Scholars continue to see merit in T. Paxson’s (1996) model, acknowledging that “[his] focus is cognitive and epistemological; that is, he is concerned with the development of knowledge and decisions about how particular kinds of knowledge are negotiated when different disciplines are brought into interaction with one another” (Gouvea et al., 2013, p. 190) and appreciating that the utility of a framework isn’t simply to characterise tasks, “but as a tool that can help guide task creation and revision, [...] [to] both reflect on the process and make intentional changes” (p. 196-197). I propose, therefore, that this is the perfect basis for my own more comprehensive matrix, one that factors in analogous thinking and provides space for cognitive dissonance. I also propose, however, that we can build a more comprehensive model well-suited to 2019 and the academia that 23 years has engendered.

## **Analogous Thinking: A New Piece to the Puzzle**

### **Allegoresis.**

Appreciating that the current interdisciplinary model — *blending* through dissolving or stealing — does not provide nearly the *moving away* students need for metacognition, and that exploiting one discipline to serve another does not move into enough of the levels in T. Paxson's (1996) Taxonomy, there is still something counterintuitive about seeking out divergence in lieu of harmony in a classroom. An opportunity is lost when teachers cannot harness this interaction effectively. Fletcher (2010) tells us that allegory helps remedy this concern and secure confidence in interruption:

Allegory is a method of double meanings that organizes utterance (in any medium) according to its expression of analogical parallels between different networks of iconic likeness. In setting up its correspondences [...] the method usually gives a vague impression of system. (p. 10)

Simultaneously similar and dissimilar, allegory establishes juxtaposition in lieu of parallelism. Instead of blending, students are exposed to difference, contrast, divergence, sometimes complete opposition, but not in structure; the juxtaposition is in the surface features that often blind us to the structures underneath, and in sifting past them to dismantle the underlying structure, those structures are exposed (Berek, 1978; Baldwin, Landau, & Swanson, 2018; Harris & Tolmie; Hult, 1999; Kubat, 2014; Mikolaj, 2017; Oswick et al, 2002). This contrary direction is not a roadblock, but an opportunity to engage higher order thinking strategies: deep cognition and rich networking and thicker conceptualisation comes to pass through the interpretive process called *allegoresis* (Berek, 1978; Gibbs, 2011; Harris, & Tolmie, 2011; Hult, 1999; J. Kelly, 1996; Kubat, 2014; Mikolaj, 2017; Thagard, 2011).

Allegoresis, the ‘allegorical impulse’ that is fundamental to human cognition, in which we continually seek to connect, in diverse ways, the immediate here and now with more abstract, enduring symbolic themes. The evocation of these symbolic themes creates diverse, rich networks of meaning that are both metaphorical and often deeply embodied. (Gibbs, 2011, p. 122).

Specific to discussions of allegoresis is the absence of dissolving and stealing that is present in current interdisciplinarity; instead, there is a marked presence of the language of affect, especially as centred in diversity in lieu of simple similarity (Berek, 1978; Harris & Tolmie, 2011; McDonough, 2015; Oswick et al, 2002). Furthermore, these affectual diversities are not enough unto themselves; they are not an end-point. In fact, without the addition of allegoresis, students would *only* see roadblocks. With allegoresis activated, the divergence exists for the purpose of cohesion: “allegory breaks down the division between the mind of the text and the mind of the reader as the two are engaged in a circuit” (Teskey, as cited by Harris & Tolmie, 2011, p. 114), a machine (J. Paxson, 2010), a system (Berek, 1978), a network (Baldwin et al, 2018), an operation (Macbeth, 2008), an apparatus (Camp, 2006). Allegories are active and engaging and involved. Allegories create functions of understanding beyond what the literal can do alone. Furthermore, they let people engage reality in ways that allow them to step outside of the expected and typical, to move beyond the trends and find innovation (Dawson, 2015; Dyson, 2018; Hult, 1999; Oswick et al, 2002). Allegories activate agency in the learner (Berek, 1978; Fletcher, 2010; Harris & Tolmie, 2011; Hult, 1999), which makes them well-suited tools of metacognition. They “lead us to imagine a set of meanings located on the other side of this hermeneutic wall” (Fletcher, 2010, p. 10), exploiting time and space and shifting point of view and setting (Berek, 1978; Harris & Tolmie, 2011; J. Kelly, 1996; Kubat, 2014; J. Paxson,

2010). If this sounds like the language of literature and mimesis, rest assured, for James Paxson

(2010) suggests that

some of the most important advances in modern science, namely in physics, rely on tacitly allegorical structure [...] acknowledging not the separation of science from figurality but its dependence on figure — simile, metaphor, hyperbole, prosopopeia or personification, paradox, irony, and so on. (pp. 249-250)

Figurative thinking is not restricted (or relegated) to the humanities and the arts; it is a way to process and understand and expose the connections that already exist between all things

(Baldwin et al, 2018; Dawson, 2015; J. Kelly, 1996).

### **Metaphor.**

If the metaphorical (in lieu of the literal) is at the core of allegoresis, let us be clear on the definition of metaphor, as it is used by academics in this field, and how it relates to our purposes here. According to Sopory & Dillard (2002),

Metaphors are linguistic comparisons of the form ‘A is B.’ For example, the expression ‘Television is poison’ consists of two parts A (television) and B (poison). A and B are different concepts or conceptual domains; metaphor links one to the other. The terminology associated with A and B varies from theorist to theorist [...]. In keeping with more recent usage, we call A the target and B the base [...]. These terms capture a fundamental feature of metaphor, the notion that meaning is passed from B to A. (p. 383)

This academically-accepted definition<sup>7</sup> and application works especially well for the purposes of this discussion. Analogies contrive division and comparison, and “instantiate cognitive processes similar to those induced by metaphor” (Sopory & Dillard, 2002, p. 383). Gibbs and Cameron

(2008) tell us that

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<sup>7</sup> Unlike Sopory & Dillard (2002), I found far more academics using “target” and “source” to define A and B (Bernárdez, 2013; Brandt, 2005; Camp, 2006; Grady, 2005; Harris & Tolmie, 2011; Lancor, 2014; Oswick et al, 2002; Ruiz de Mendoza Ibanez & Perez Hernandez, 2011; Shutova, Devereax, & Korhonen, 2013; Stickles, David, Dodge, & Jisup, 2016; Tendahl & Gibbs, 2008; Velasco-Sacristán, 2010). Still, the explanation is sound and certainly synonymous to those who do prefer “base” (for instance Chen, Widick, & Chatterjee, 2008).

One of the major developments in metaphor research over the past 30 years is the claim that metaphor is not merely a figure of speech, but is a specific mental, and neural mapping that influences a good deal of how people think, reason, and imagine in everyday life. (p. 65)

Just as with allegoresis, this discussion of metaphor is indeed one of metacognition. There is a ready-made partnership waiting to be exploited in our classrooms.

Two major players in metaphor theory are Hannah Arendt and Hans Blumenberg (Bajohr, 2015; Feldman, 2010; Gibbs & Cameron, 2008), and “what unites [them] is the fact that both put a premium on the basic function of metaphor as epistemically securing the access of humans to and their relationship with the world” (Bajohr, 2015, p. 56), not *in* the world or *to* the world, but *with* it and *within* it, an *interaction* (Berek, 1978; Harris & Tolmie, 2011; Lancor, 2014). This mantle, “that the intention to speak metaphorically, as opposed to using some other form of language, results from a person’s self-organising tendency even before the intention to do so reaches awareness” (Gibbs & Cameron, 2008, p. 74). Metaphors are cognitive frameworks for cognitive processes; they contrive circumstance for understanding and allow minds to stand in new places to see new truths (Baldwin et al, 2018; Berek, 1978; Geiger & Finch, 2010; Ippolito & Adler, 2018; Tendahl & Gibbs, 2008). Therefore, metaphorical language is a key marker of metacognition actually taking place, and not just being fostered. Likewise, “given the importance of metaphor to philosophical inquiry, it is clear that for Arendt ‘vitaly metaphorical’ language is epistemologically productive, on one hand, because it discovers conceptual relations or even forms the condition of abstract thought” (as cited by Feldman, 2010, p. 239): we need metaphor in places like classrooms where we mean to nurture complex learning. Metaphors create and open doors, since “For Blumenberg, they make an outside accessible to an inside [and] for

Arendt, they make an inside accessible to an outside. Blumenberg highlights the interpretive, Arendt the expressive aspect of metaphor in achieving the unity of the world” (Bajohr, 2015, p. 57), especially in a world of lines and boxes and limitations. Our human need to categorise is certainly practical, but not necessarily a way to grant accessibility or to expose false binaries and force the interaction of internal and external processes; categories certainly do not welcome abstraction from commonly accepted norms (Baldwin et al, 2018; Camp, 2006; Geiger & Finch, 2010; Lancor, 2014; Macbeth, 2008; Oswick et al, 2002). In any metaphorical case, “what must be bridged is a rift between the world and a creature that is not made for it” (Bajohr, 2015, p. 52). Indeed, what better tool than metaphor to engage interdisciplinarity, to “bridge the ‘abyss between inward and invisible mental activities and the world of appearances,’ and thus to perform a carrying-over that has corporeal relevance” (Arendt, as cited by Bajohr, 2015, p. 55). Metaphors cross lines and open boxes and undo limitations; they interrupt a world of categorisation for one of connection, to allow a shift in perception, and certainly, should one change the metaphor, one would change the perception, and therein make innovation possible (Dyson, 2018; Ippolito & Adler, 2018; McDonough, 2015; Oswick et al, 2002). This is certainly an appropriate fit with metacognition, and moreover with what I hope to see more of in our classrooms, where thinking the same things in the same ways is training and not education, and certainly not progress (Petersen et al, 2015; Poole et al, 2009; Sandhu et al, 2015).

### **Cognitive Dissonance: The Target**

Shifting away from current interdisciplinary and cross-curricular models towards designing a matrix of understanding that harnesses the power of allegoresis and metaphor would



therefore demand a matrix with cognitive dissonance at its core. Instead of hitting a ceiling with our current efforts, where other disciplines are subsumed or consumed, and ambiguity, innovation, abstraction have no place (T. Paxson, 1996, p. 93), it is the addition of cognitive dissonance which indicates higher level interaction. Outlined by Harmon-Jones and Mills (1999), cognitive dissonance has been discussed academically for almost sixty years:

As presented by [Leon] Festinger in 1957, dissonance theory began by postulating that pairs of cognitions (elements of knowledge) can be relevant or irrelevant to one another. If two cognitions are relevant to one another, they are either consonant or dissonant. Two cognitions are consonant if one follows from the other, and they are dissonant if the obverse (opposite) of one cognition follows from the other. The existence of dissonance, being psychologically uncomfortable, motivates the person to reduce the dissonance and leads to avoidance of information likely to increase the dissonance. The greater the magnitude of the dissonance, the greater is the pressure to reduce dissonance. (p. 3)

Not only does this fit the language of metaphor, it also gives even more footing to the concept of purposeful and intentionally designed interruptions, ones which contrive difference, distance, distanciation, tension (Fletcher, 2010; J. Kelly, 1996; J. Paxson, 2010; Sopory & Dillard, 2002). Once perceived, they must be considered deeply to achieve synthesis and therefore closure and relief (Baldwin et al, 2018; Sopory & Dillard, 2002; Woods, 2012). Indeed, the only way for a student to reject the literal meaning and dismantle a hermeneutic line is by way of cognitive dissonance (Berek, 1978; McDonough, 2015). When the internal system at work matches the external system at work, there is no demand for change, no interruption to commonly held beliefs, and no evolution of thought. Cognitive discomfort zones fashioned by *incongruent* and *ironic* allegory activate the learner (Berek, 1978; Ozwick, Keenoy, & Grant, 2002), thereby “exposing hidden assumptions and develop[ing] a new conceptualization” (Mason, as cited by Woods, 2012, p. 139). To truly function well, metacognition *needs* cognitive dissonance. Our

path there is by way of interdisciplinary models that do not *simply* chase solutions, but *demand* allegoresis through metaphor *before* finding a solution. Our current model simply skips too many opportunities for complex patterning and connection and bridging, far too often asking students to simply contain knowledge in subject compartments and never really struggle with it in meaningful and complex ways.

### **A Comprehensive Matrix: Where We Go Next**

Relying solely on a taxonomy designed in 1996 undermines the evolution that the academic discussion has undergone since then. To expose the relationships between the theories, I have plotted each theory against the framework established by T. Paxson (1996). It is this conversation that becomes the *metacognitive-dissonance-fostering-allegoresis-matrix* for my thesis. Each of these studies address interactions between unlike concepts and truths. Each of these studies discusses the qualities of those interactions as they move to higher levels in the relationship. Table 3 plots this conversation visually<sup>8</sup>.

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<sup>8</sup> As the conversation grew, the table became more and more complex. Still, I think the visual arrangement is helpful in seeing the commonalities in the academia. A clearer version of this table can be found here: <https://goo.gl/es29as>

Table 3. *Academic Conversation of the Theories Behind Interdisciplinarity, Metacognition, and Allegory*

	<b>Paxson (1996) Taxonomy of interaction</b>	<b>Kuhn &amp; Dean (2004) Inquiry &amp; argumentative discourse</b>	<b>Klein (2005) Integrative interdisciplinarity</b>
Infancy			
Childhood	<b>Level I:</b> Notice (w/o engagement). Neither discipline is modified. One discipline does not challenge another.	<b>Realist</b> - demonstrating what one already accepts as true - assertions are copies of reality	<b>Absolutist</b> - assertions are facts to represent reality
Adolescence	<b>Level II:</b> Engagement. One discipline is affected by the other. No growth in theory or subject.	- prevailing over an opponent without deep-level processing the opponent's argument <b>Multiplist</b> - assertions are opinions accountable only to their owners	Nurtured through traditional teaching functions: - telling, delivering, directing - sage on the stage
	<i>Structured conditions   Absence of critical thinking</i>		
	<i>Unstructured conditions   Presence of critical thinking</i>	- the object is awareness and reflection of the thinking of self and of others	Nurtured through teaching models of - mentor, mediator, facilitator - coach and guide
	<b>Level III:</b> Growth. Exploring same phenomena from different vantage points. Illumination & dependence.	<b>Evaluativist</b> - allowing the structure of the argument to become a structure for thinking - assertions are judgements that can be evaluated and compared - thinking in terms of issues or claims with facts summoned in service	Demonstrated by the ability to - ask meaningful questions about complex issues and problems - locate multiple sources of knowledge, information, and perspectives
	<b>Level IV:</b> Connection. Two disciplines share concepts or become one, more comprehensive discipline.		Demonstrated by the ability to - create an integrative framework and more holistic understanding

*Note:* Thomas Paxson seems to have started the conversation with his 1996 Taxonomy of Interactions, so I too have started with his understanding. Thereafter, the table moves chronologically through the academia, arranging their discussion physically to meet the distinctions of the initial taxonomy. These are the theories that I intend to bring together in my metacognitive-dissonance-fostering-allegoresis-matrix. The **bolded** terms are ones that those authors use in their work, and the explanations are paraphrasals of their understandings. (Specific citations can be found in the body of my writing.) The interpretations that have generated this arrangement are my own.

Thagard (2011) Systematic comparisons	Neuenhaus, Artelt, & Schneider (2013) Spontaneous transfer	Thompson & Johnson (2014) Dual process theory	Mishra & Mehta (2017) 3 x 3 model of 21st century learning
<p><b>Similarity</b> - correspondence in terms of appearance</p> <p><b>Similarity</b> - correspondence in terms of meaning</p>	<p><b>Observation</b></p> <p><b>Emulation</b></p> <p><b>Self-control</b> - executing strategies</p>	<p><b>Type 1 processes</b> - autonomous - faster - often default - emotion, habit, or belief-based</p>	<p><b>Foundational knowledge (to know)</b> - knowledge of the disciplines - a way to access that knowledge (literacy) - declarative</p>
<i>Structured conditions   Absence of critical thinking</i>			
<p><b>Purpose</b> - cognitive function the allegory means to achieve</p> <p><b>Structure</b> - correspondences are system bound - relationships carry from source to target</p> <p>Dynamic Process - mental representation involves ongoing change in interconnections</p>	<p><b>Cognitivistic perspective</b> - similarity in principle, attention, motivation, knowledge, strategy - founded on metacognitive knowledge: actively choose and evaluate strategies, consider resources, receive feedback, assess readiness</p> <p><b>Self-regulation</b> - use and adapt strategies flexibly in response to changing contextual demands</p> <p>- apply these strategies and schema in diverse settings and domains</p>	<p><i>Unstructured conditions   Presence of critical thinking</i></p> <p><b>Type 2 processes</b> - demand working memory capacity - slower - actively intervene type 1 processes - can engage deliberate cognitive processes (probability/logic, hypothetical thinking, conflict resolution)</p>	<p><b>Metaknowledge (to act)</b> - creativity &amp; innovation - problem solving &amp; critical thinking - communication &amp; collaboration - procedural knowledge</p> <p><b>Humanistic knowledge (to value)</b> - ethical/emotional awareness - cultural competence - conditional knowledge</p>

At Level I, T. Paxson (1996) suggests that the disciplines merely sit near one another, but do not challenge one another and certainly do not modify one another (p. 83). Kuhn and Dean (2004) introduce two stages that fit within this first level, the first called “Realist” (p. 270, 272) where truths are already established copies of reality, and the second called “Absolutist” (p. 271, 272) where assertions are facts to represent reality. Clearly, this fits with correspondence being founded in surface qualities and appearances (Thagard, 2011, p. 132), allowing students at this

stage to emulate a clearly associated model (Neuenhaus et al., 2013, p. 219). At Level II, T. Paxson (1996), suggests the disciplines indeed engage one another, but there is certainly no growth experienced with theory or subject (p. 83). For Kuhn and Dean (2004), this manifests as the absence of deep-processing of the opponent's arguments, as the only goal of interaction is simply is to be the owner of the prevailing argument (p. 270). Here, they name the stage "Multiplist" (p. 271, 272), where assertions are opinions "freely chosen by and accountable only to their owners" (p. 272). This discourse is possible because the target and base already match one another so closely, a relationship of similarity founded in correspondence of meaning (Thagard, 2011, p. 132). Here, a measure of self-control enters the equation, but only to match "executing strategies under structured conditions" (Neuenhaus, 2013, p. 219). These first two levels are nurtured through teacher models of "telling, delivering, and directing, and being a sage on the stage" (Klein, 2005, p. 10), where similarities are associational, based on task, and students are asked only to match procedural knowledge (Neuenhaus et al., 2013, p. 215). These processes are autonomous, default, habitual, and fast (Thompson & Johnson, 2014, p. 215-216). Ultimately these processes are simply to assert and declare knowledge of the disciplines, nothing more (Mishra & Mehra, 2017, p. 8).

The interactions of Levels I and II *rely* on structured conditions and the absence of critical thinking (Kuhn & Dean, 2004; Neuenhaus et al., 2013; Thompson & Johnson, 2014), whereas Levels III and IV depend on its definitive presence (Klein, 2005; Mishra & Mehta, 2017; Thagard, 2011; Thompson & Johnson, 2014). According to Kuhn and Dean (2004), students progress naturally through the first two levels without much deliberate pedagogical practice from their teachers:

The transitions from realist to absolutist to multiplist epistemological understanding don't seem to require a great deal of tending by those wishing to scaffold children's development. [...] The last major transition, however, from multiplist to evaluativist, is another story. It is helping young people climb out of the multiplist well that requires the concerned attention of parents and educators, especially if it is this progression that provides the necessary foundation for intellectual values. (pp. 272-273)

Likewise, while metacognitive development “increases substantially between early childhood and early adulthood, [...] elaborated declarative metacognition cannot be taken for granted” (Brown, as cited by Neuenhaus et al., 2013, p. 165). These last two levels, therefore, mark a definite shift in the nature of the student and certainly in the role of teacher in nurturing those skills. Readiness for Level III is indicated by the ability to ask meaningful questions about complex issues and problems, to locate multiple sources of knowledge, information, and perspectives (Klein, 2005, p. 10). At this point, the object is “awareness [...] and reflection on the thinking of self and of others” (Kuhn & Dean, 2004, p. 270), where students are able to express purpose through correspondence of the “cognitive function that the allegory is supposed to accomplish” (Thagard, 2011, p. 132). These interactions move into meta- knowledge and action with “creativity and innovation, problem solving/critical thinking, and communication/ collaboration” (Mishra & Mehta, 2017, p. 8). Level III therefore includes Kuhn and Dean's (2004) “Evaluativist” stage (p. 271, 272), which allows the structures of the argument to become the structures for thinking; here, assertions are judgments that can be evaluated and compared, and thinking is demonstrated “in terms of issues or claims, with facts summoned in their service, rather than the reverse—storing up facts with the idea that some conclusion may emerge from them” (p. 270). Students are therefore able to demonstrate this integrative interdisciplinarity by comparing and contrasting concepts to reveal patterns and connections (Klein, 2005, p. 10).

Level III is about growth, where students explore the same phenomena from different perspectives; it allows illumination because of the dependence of one discipline on principles of the other (T. Paxson, 1996, p. 83). Here, correspondences are structural, system-bound as these relationships carry from base to target (Thagard, 2011, p. 132). Students are not simply controlling themselves, but regulating themselves: using and adapting strategies flexibly in response to changing contextual demands (Neuenhaus et al., 2013, p. 214). Level IV moves beyond the growth and illumination of Level III, beyond the Kuhn and Dean's (2004) evaluativist stage and into something transcendent: connection, where two disciplines share concepts or become "one more comprehensive discipline" (T. Paxson, 1996, p. 83). This is demonstrated by students' ability to create an integrative framework and more holistic understanding. Because this is a dynamic process, mental representation involves ongoing change in interconnection (Thagard, 2011, p. 133), strategies and schema that can be applied "in diverse settings and domains" (Neuenhaus et al., 2013, p. 219), and ultimately engender interesting and unusual perspectives on knowledge, including ethical awareness, cultural competence, and conditional knowledge and values (Mishra & Mehta, 2017, p. 8).

## Chapter Four: Experiments

Instead of sitting at a table, like Zeno of Elea hoped, waxing poetically about the possibilities and impossibilities of theory, I stand, as Diogenes the Cynic once did, ready to prove with practical application in walking the course. This chapter provides not only models for the real-world examples of theory, but also brings those models into my classroom. Each case study includes all of the resources teachers might need to bring such an approach into their own classrooms:

- A. Goals from the Alberta Education Program of Studies**
- B. Science Baseline**
- C. Literature Baseline**
- D. Science Interrupting Literature**
- E. Pedagogical Extractions**

I begin with the intentions of the relevant Program of Studies (section A), then offer a summary of the baseline understandings our students are expected to glean from the Science Unit in question (section B), including major terms and concepts<sup>9</sup>. I then provide a summary of the baseline understandings from the Literature Unit, including major plot points, character dynamics, and thematic understandings (section C). The interdisciplinary model that follows, pairing scientific theory with literary dynamic, is meant to be more than one of blending or stealing or dissolving, to demonstrate thinking that achieves the highest level of metacognitive dissonance by way of allegoresis, and serve as a model for students to scaffold their own efforts (section D). As mentioned before, readers of this thesis can experience the exact explanation provided to students in situ. I model my own unpacking of the literature using those science

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<sup>9</sup> These were crafted by teaching myself the unit using the same textbooks the students would use, then speaking with science teachers in my school to ensure I had learned what the students are meant to learn.



terms and techniques and perspectives, modelling robust interdisciplinarity. Each case study culminates with pedagogical extractions (section E), wherein I highlight the experiences in using these resources in my own classroom with my own students.

## **Biology Case Studies**

### **Experiment 1 — Biology 20: Energy/Matter Exchange in the Biosphere.**

#### ***1A: Goals from the Alberta Education Program of Studies.***

“Students will: (1) explain the constant flow of energy through the biosphere and ecosystems (2) explain the cycling of matter through the biosphere [and] (3) explain the balance of energy and matter exchange in the biosphere, as an open system, and explain how this maintains equilibrium” (Alberta Education, 2014a, p. 17). “Students will: (1) relate photosynthesis to storage of energy in organic compounds [and] (2) explain the role of cellular respiration in releasing potential energy from organic compounds” (Alberta Education, 2014a, p. 31).

#### ***1B: Science Baseline — Ecology, Photosynthesis, Food Chains.***

*Ecology* was first coined in 1866 and is derived from the Greek for house or home. It includes the study of the relationship between organisms and their environment, everything from cellular processes to planetary trends. Ecology includes observations about the *biosphere*, an *ecological system*: the life-system of the Earth, which may include natural, cultural, or technological dimensions. Any system is separated from its surroundings by a boundary, real or arbitrary. If energy and matter can cross the system’s boundary, that system is *open*; if they cannot, it is *closed*. “In terms of matter, Earth is essentially a closed system. [...] In terms of energy, Earth is an open system” (Colbourne, Constantin, Dobel, & Fehres, 2007, p. 5).

Animals are an organism that procure energy by consuming other organisms; this necessity makes them *consumers* or *heterotrophs* (from the Greek meaning other-feeder).

Conversely, organisms that create their own food are known as *producers* or *autotrophs* (from the Greek meaning self-feeder). In the case of autotrophs, plants, algae, and some kinds of bacteria use the Sun's light energy to convert carbon dioxide from the air into chemical energy ( $C_6H_{12}O_6$  or glucose) through a process called *photosynthesis*; other kinds of bacteria cannot access the sun's light energy and therefore capture the energy stored in chemical bonds through a process called *chemosynthesis*. In all cases, *cellular respiration* is the process that marks the using and releasing of stored energy. *Glycolysis* is a process of energy release that occurs in cellular respiration. Once the energy is captured, glycolysis breaks it down to generate energy in the form of adenosine triphosphate (ATP). "This molecule is sometimes referred to as 'the energy currency' of cells because when cells need energy they 'spend' ATP" (Colbourne et al., 2007, p. 163). Most of the species in the Earth's biosphere release energy by way of *cellular respiration*. *Aerobic cellular respiration* requires oxygen to produce ATP. Oxygen is key to the transport of electrons; as the final electron-accepting molecule, it permits the chain reaction that builds an energy store and generates ATP molecules. *Anaerobic cellular respiration* does not require oxygen. In anaerobic cellular respiration, an inorganic chemical takes the place of the final electron-accepting molecule, again permitting the chain reaction that yields ATP. A third type of metabolic pathway is *fermentation*, which is indeed an anaerobic process, but is considered separate from anaerobic cellular respiration, because it does not employ an electron transport system to generate ATP molecules. Two common types of this metabolic pathway are lactate fermentation and ethanol fermentation. The first type occurs during aerobic cellular respiration, when the oxygen has been exhausted and therefore cannot sustain glycolysis; as such, the cells produce lactate (lactic acid), which is stored temporarily until oxygen is again present and

glycolysis can resume. In the case of muscle fatigue, this presents as a cramp to indicate the missing oxygen. The second type occurs in organisms that can function both aerobically and anaerobically. When they function anaerobically, they produce ethanol and carbon dioxide. In the case of breweries, this creates wines and ciders and beers.

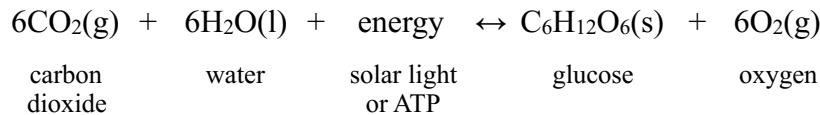


Figure 4. *The chemical equations for both cellular respiration and photosynthesis.*

In this arrangement, photosynthesis moves left to right and uses energy in the form of solar light; cellular respiration moves right to left and generates energy in the form of ATP.

As shown in Figure 4, chemically, cellular respiration is a complete inversion of photosynthesis: “Photosynthesis uses the products of respiration as its starting reactants, and cellular respiration uses the products of photosynthesis as its starting reactants” (Colbourne et al., 2007, p. 165). Producers and consumers are linked through these processes in the system of the biosphere. Of the solar energy that emits from the sun, about a third of it is reflected back into space; the vast majority is absorbed either by gases in the atmosphere or at the Earth’s surface, which then serves to warm our planet or is radiated back into space. Only one to two percent of solar energy is captured by producers to be converted to chemical energy through photosynthesis. Still, “producers generate about 150 billion tonnes to 200 billion tonnes of organic (carbon-containing) matter each year. This amount of life-sustaining matter supports most life on Earth” (Colbourne et al., 2007, p. 12). Because only producers can capture energy from the sun, all other organisms somehow depend on producers to procure their own energy.

*Primary consumers* (herbivores like some birds, insects, grazing animals) are the first to consume producers; *secondary consumers* (carnivores like some birds, spiders, frogs, bats)

consume *primary consumers*; *tertiary consumers* consume secondary consumers. (Theoretically, these *trophic levels* of consumption can continue higher.) Another consumer group, called *decomposers* (like fungi, bacteria, earthworms, and insects) obtain energy by consuming leftover or waste material from living organisms, dead bodies or parts of bodies. Tracking a pathway through trophic levels, from producers to consumers are called a *food chain*. *Food webs* expose the connections between food chains, as shown in Figure 5.

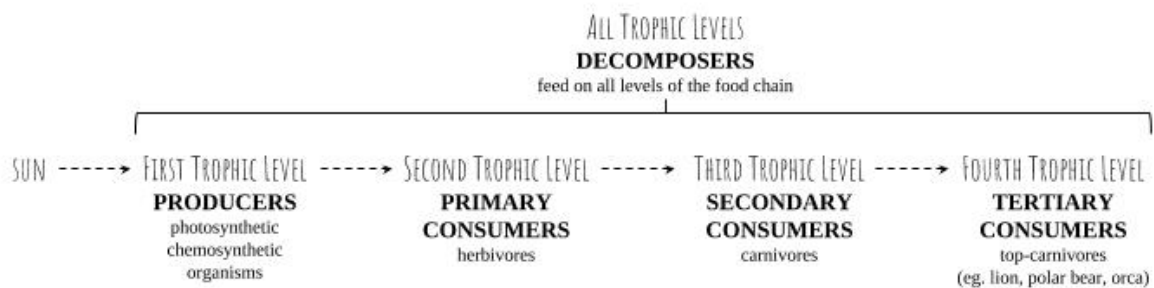


Figure 5. *Feeding relationships in ecosystems.*

Adapted from Figure 1.8 by Colbourne et al., 2007, p. 16. Copyright 2007 by McGraw-Hill Ryerson.

All components within the biosphere work together in cycle, and as “Earth is a closed system to matter [...] Atoms and molecules are cycled—used and reused endlessly—in the biosphere” (Colbourne et al., 2007, p. 14). As such, this group is crucial to returning matter to the soil, air, and water to then be used again by producers.

Producers are therefore key to procuring new usable energy from outside of the biosphere. Because Earth is an open system to energy, it cannot be cycled in quite the same way. The first law of thermodynamics states that energy cannot be created or destroyed, only converted or transferred, and the second law of thermodynamics acknowledges that no conversion or transfer system is completely efficient, losing energy with each process (Colbourne et al., 2007, p. 14). Ultimately, much of the glucose that is produced during

photosynthesis becomes cellulose and other structural tissues for the plant, though some becomes carbohydrates (starch) and amino acids (proteins). Plants also produce poisons and fragrances and oils and many other organic molecules and tissues for a variety of functions. Furthermore, some of the energy released during cellular respiration is dispersed into the environment as unusable heat, and thereafter cannot be used further to support living systems. In consumers, much of the energy becomes waste product and heat with very little going to growth and maintenance. Ecologists estimate only 5 to 20 percent of energy moves up a trophic level; for convenience, they often assume a 10 percent transfer of energy. As such, consumers at higher trophic levels tend to need access to far more organisms at lower trophic levels, which created a pyramid of numbers, where each level represents a trophic level. They also tend to be bigger than the food they eat, which creates a pyramid of biomass to arrange the trophic levels. However, these tendencies are not the rule, as there are cases where a single tree can provide food for hundreds of thousands of insects, or the biomass of phytoplankton can be significantly less than that of zooplankton. A truly stable ecological pyramid is the pyramid of energy which can be used to track the energy transfer from level to level.

*This is the liminal space between science and literature that students occupy when they walk between classrooms and therefore between disciplines of thought. We are not simply asking them to 'switch gears,' but to switch cars and roads and cities. Jarring, isn't it, to read pages and pages on the biosphere and then walk right into The Crucible? Imagine being a student who has just spent eighty-three minutes living in the world of Biology, and is then asked to instantaneously shift in much the same way. Our school has four blocks in its day; four transitions that each have the capacity to be equally jarring... or not.*

***1C: Literature Baseline — The Crucible by Arthur Miller.***

The year is 1692; the place is Salem, Massachusetts. Girls are playing in the forest. There is singing and dancing. There is a Barbadian slave woman speaking a West African dialect. These elements are enough to make the town minister nervous, and when Reverend Parris investigates, he hears rumours of witchcraft and begins to worry about his reputation, especially seeing as his daughter, Betty, and his slave, Tituba, were central in these activities. One of the girls, Abigail, emerges as a kind of leader of the group. She tells Parris what he fears most, that Tituba was conjuring spirits in the forest. When Abigail is alone with a farmer named John Proctor, however, she confesses to him that there was no witchcraft. It is also revealed that she and Proctor had an affair when she worked as a servant in Proctor's house. Proctor insists it is over; Abigail insists he still loves her. In an adjoining room, Betty begins to scream and what seems to be the whole town fills the room, arguing over witchcraft and other town politics. Reverend Hale, an expert in witchcraft, arrives and most of the townspeople leave. Hale offers Tituba two options: confess to consorting with the devil or be whipped, never acknowledging the possibility of a non-witchcraft truth. Tituba makes the only choice she can and admits witchcraft, then names the others in presence, essentially naming them witches as well. Abigail, seeing the choices set to Tituba, defies her confession to Proctor, and names the other girls in the forest. Betty breaks her comatose state to join in.

About a week passes, and the next scene picks up in the Proctor house, where Elizabeth has made a rabbit stew. John eats and they discuss the witchcraft charges that are being made in Salem. They learn from their current servant, Mary Warren, that Elizabeth herself is accused of being a witch. They realize this is a jealous ploy of Abigail's to get Elizabeth out of the picture

because of her feelings for Proctor. As they argue about the fallout of the affair and John's guilt, Reverend Hale arrives. Proctor tries to prove his piousness by reciting the commandments, but ironically misses the one about adultery. The authorities arrive and arrest Elizabeth.

Scene three has us back in the town, this time in court, where Proctor intends to have Mary expose the witchcraft as lies. Mary gives an embarrassing testimony and Abigail, seeing what is at stake, denies everything. Proctor reveals his affair in an extreme attempt to prove Abigail's motives and her dishonesty. He also says his wife, Elizabeth cannot tell a lie, and the court can use her to test the verity of Proctor's revelation. The officiate, Deputy Governor Danforth, calls Elizabeth forth, but she denies the affair out of loyalty to Proctor, trying to protect his honour. Abigail, seeing opportunity here to anchor her victim status, pretends Mary's spirit is attacking them. The other girls, including Mary, join in. Proctor appears to be in league with the devil and is arrested. Hale, watching the proceedings, believes Proctor, but is powerless to stop the momentum of the court. All of the hangings are set to proceed, unless the accused confess and repent their sins. Unlike Tituba and the girls at the outset of the play, Proctor refuses to confess to a crime he did not commit, simply to avoid punishment. Elizabeth, however, is pregnant, a fact that stays her execution. She goes to Proctor to get him to confess so they can be together again. He indeed signs the confession, but cannot bring himself to hand it over, saying his name is all he has and he cannot destroy it with lies, that his life is worth nothing without his name. He tears up the statement and goes to be hanged. The play ends with Elizabeth understanding that John Proctor has redeemed his goodness.

***1D: Biology 20 Interrupting The Crucible.***

*Ecology* is derived from the Greek for house or home and includes the study of the relationship between organisms and their environment. This is an ideal connection to *The Crucible*, which centres around a number of people losing control of their homes and ultimately of the city they hold dear. In the year 1692, the town of fictional-Salem is an ecological system, and essentially a closed one in terms of energy, with its own laws and social structures in place to manipulate and control the citizens. Reverend Parris' portion of the biosphere, for instance, comprises his daughter and their slave — Betty and Tituba respectively — and when it is revealed that they are not conducting themselves according to the rules of this biosphere, the cycle that preserves homeostasis is at risk, and Reverend Parris brings new matter into the biosphere to protect the closed system of energy in their home. Reverend Hale does not allow for the possibility of survival for this new behaviour. He offers Tituba two options: confess to consorting with the devil or be whipped, in either case destroying the behaviour without understanding its nature: the girls of the town are bored and are trying to grow beyond the ecosystem of their birth. This is also true of the men, but in momentum that runs counter to that of the women. The men of the town are heterotrophs, consuming everything produced by the autotrophs, the women of Salem. Reverend Parris demands golden candlesticks for his church because pewter is beneath him; Farmer Walcott's negligence kills a pig and he demands a refund for its purchase price; John Proctor steps outside of his marriage vows for an affair with his housemaid. At the outset of the play, none of these men is willing to look inside of their own behaviour for the solution, putting the responsibility and therefore the consequences of their actions outside of themselves and their homes. The women, conversely, respond autotrophically,



adding new definition to their worlds. Betty and Tituba respond with a party in the woods; Martha Corey tries to tell Walcott where the responsibility truly sits; Elizabeth Proctor newly understands her husband and redefines their marriage. Each of these women is then accused of witchcraft, stripped of their agency, and fed back into the consumption cycle for the heterotrophs to feed. Young girls are not allowed to play; older women are now allowed to read books; wives must simply make rabbit stew. Their lives are defined by their capacity to feed the lives of their husbands, never themselves.

The town of Salem has shifted from an aerobic metabolic pathway to an anaerobic one. In the beginning, this humble town of farmers and wives and families found their energy in the most common pathway of aerobic cellular respiration, in partnership with the earth. Unfortunately, their human laws and conduct interrupted these pathways. When Salem's own minister (Parris) and judge (Hathorne) fail at renewing homeostatic Salem, they call upon reinforcements, first with the addition of Reverend Hale, then with Deputy Governor Danforth, but these efforts work only to perpetuate those same interruptions to the organic process that founded Salem. In this new case, the inorganic chemicals of church and state take the place of the final electron-accepting molecule and forever alter the chain reaction that builds an energy store and generates the energy currency of the town. Instead of a metabolic pathway that gives the citizens of Salem their nourishment, what results is a metabolic pathway that *uses* the citizens of Salem to provide nourishment to a new system: blame. Danforth is introduced with "exact loyalty to his position and his cause" (Miller, 1952/1976, p. 85). He speaks in terms of sun and night that evoke comparisons to photosynthesis:

This is a sharp time, now, a precise time—we live no longer in the dusky afternoon when evil mixed itself with good and befuddled the world. Now, by God’s grace, the shining sun is up, and them that fear not light will surely praise it. I hope you will be one of those. (Miller, 1952/1976, p. 94)

However, Salem is currently awash in bacteria that cannot access the sun’s light energy, instead capturing energy through chemosynthesis. With the focus on the inorganic chemicals of church and state dominating this ecosystem, chemosynthesis is the only metabolic pathway left to Salem, capturing the energy in the chemical bonds of its citizens. Furthermore, this pathway is an enduring one. Case-in-point is when Danforth declares that “four hundred are in the jails [...] and seventy-two condemned to hang by [his] signature” (Miller, 1952/1976, p. 87), and that they must stay the course that Salem is on.

Reprieve or pardon must cast doubt upon the guilt of them that died till now [...] I should hang ten thousand that dared to rise against the law, and an ocean of salt tears could not melt the resolution of the statutes. Now draw yourselves up like men and help me, as you are bound by Heaven to do. (Miller, 1952/1976, p. 129)

The citizens have no purpose but to feed a process apparently designed by Heaven and under the protection of the law. Church and state have replaced all organic processes herein.

Unlike that of the other men in the town, John Proctor’s metabolic pathway is especially interesting because it is anaerobic without being chemosynthetic. Stripped of the oxygen in their marriage, but still bound by the vows that keep them ecologically related, John and Elizabeth’s every interaction is marked by cramp and muscle fatigue. In Act Two, when John relays Act One’s interaction with Abigail, every line seems to pull more and more oxygen from the room. The conversation is marked with unfinished sentences, stage directions filled with with *hurt*, *anger*, *violent undertones*, *solemn warnings*, *bitter laughter* (Miller, 1952/1976, pp. 53-55).

Producers capture energy from the sun, but without oxygen, Elizabeth is unable to generate energy for their marriage. Instead, she is *cold* (Miller, 1952/1976, p. 53); John is *drained* (p. 55). When Mary Warren enters, she is described as *decayed* and *exhausted* (Miller, 1952/1976, p. 56). This biosphere is far from homeostatic and dangerously unsustainable. So ruined is the electron transport system that fermentation is the only possibility, the cells produce lactic acid, which is stored temporarily until oxygen is again present and glycolysis can resume. Of course, their world is *bitter* (Miller, 1952/1976, p. 55) and *painful* (p. 67): they are drowning in lactic acid. However, once John identifies Abigail as the cause of the oxygen deprivation for not only his marriage but the ecosystem of Salem, he confesses his adultery to the townspeople in an effort to remove her from affecting that system. However, because Abigail remains, so too does her ability to deprive the Proctors and ultimately the town of oxygen. While the town replaces the oxygen with the inorganic compounds of church and state, the Proctors enter a stalling pattern, storing lactic acid until oxygen is again present and organic glycolysis can resume. Ultimately, when Abigail skips town to avoid her own persecution, the oxygen is returned to the system that is their marriage: each spouse forgives the other, resuming their place in a functioning energy system. John, so secure in his renewal of self, refuses to confess to a crime that is not his own, committing himself to death with only his name and reputation intact. Elizabeth, so secure in her belief of her husband's goodness and redemption, is primed to again contribute to the ecosystem of Salem, pregnant with another child for the new generation of trophic citizen.

***1E: Pedagogical Extractions.***

Though I have certainly spoken about literature in terms of science before now, when I taught Arthur Miller's *The Crucible* to my 20AP English class this year, it was the first time I did

it so explicitly. We had been studying the play for a couple of weeks and were at the point when we were trying to unpack Miller's larger structures and human commentary. Students were provided with the summary and then the Biology explanation, and finally the conversation of the two. After each, I asked them for comments. The play-summary elicited very little; the science explanation elicited a few (fairly good-humoured) groans and laughs, and some confusion. One student told me that she loved this Biosphere/Ecology unit. I told her, "Good, we'll need that." I asked all of the students to trust me as I distributed the "Biology 20 is *The Crucible*" explanation, then read it to them. I asked if an approach like this was exciting, and hands moved into the air. I asked if an approach like this was scary, and hands moved into the air. I asked if anyone felt both responses were true for them, and hands moved into the air. When it came time for comments, I left the discussion largely in their hands. I invited them to address how this might offer opportunity *and* how it might indeed be broken. I reminded them that education is never supposed to feel like a trap, so it was vital that we figure out what needs to be in place for something like this to work. Students therefore talked about both how this worked and how it did not: how it demanded a certain level of comfort with the base component of the metaphor (Biology) before students could reach the connections in the target (*The Crucible*). The student who loved this Bio unit talked about all of the layers in *The Crucible* that had been hidden to her until *Energy and Matter Exchange in the Biosphere* became her framework for reasoning. Another student pointed out that a feminist agenda had been exposed by the Biology lens, that this process had actually opened another door for her into Social Studies and Psychology, that Literature and Biology and Social Studies and Psychology were partners here. Again, this interaction depended on strength in each of the source subjects to unpack the relational structural

links with the target text. A few students told me that Biology was not their favorite, and though this did not impair their understanding of *The Crucible*, it did not seem to be helping them as it was their peers. I drew them in further, asking what subject they would have chosen if they were at the helm of this activity. The first few answered and then, quite quickly, a number of hands shot into the air, more joining them as each student decided their own way in. This was how we came to use the rest of the period. My students had explicitly told me that they could engage *authentically* with the text, if only we could make such adjustments. And so we did.

Some students worked individually; some worked in teams. Each group was given a four foot by eight foot whiteboard, markers, and the choice of one of the science units they knew and felt strength with. Then, they were given twenty minutes to re-process their understanding of *The Crucible* through this new lens. Having provided my model as a starting point, now I simply got out their way.

We needed two classrooms to make this work, so we were using an available space across the hall. I moved back and forth between the two spaces, watching them argue and discover and reveal and understand. About five minutes in, it became apparent that something magical was happening and I went to grab the Assistant Principal under whose purview the English department falls.

He was in a meeting.

I asked the admin assistant how important that meeting was, and she asked me how important any meeting is. “Not very?” I asked with a smile. She told me she thought I should probably interrupt that meeting. I did.

“I realize that you’re discussing very important things in a very important meeting and hardly need a disruption, but I need to steal Tom. Something really cool is happening, and I’m selfishly the only one who is witnessing it.”

Tom came upstairs with me. I apologized for the interruption, and he told me that I had saved him, and added something pithy about how any meeting over 20 minutes is a waste of time. Later, after seeing these kids in action, his initial tell would be upgraded to “Oh, how you saved me. This is something truly special, Jenn” (T. Fowler, personal communication, November 15, 2018). I showed him the two rooms, pointed to the boards where the Biology and Physics and Chemistry students had found new purchase in *The Crucible*. A few minutes later, the rest of the administration team arrived, goodnaturedly, to see what the emergency was. Instead, they found themselves marvelling as Tom and I were.

Here, Salem was a pumping heart, trying to rid itself of clots with inappropriate solutions (medication, bandaids, surgery), all ineffective without dealing with the source of the clots. There, Abigail’s momentum was bound by Newton’s laws of motion, where the net force cannot be zero because of the acceleration caused by witchcraft. Now, witchcraft was a pathogen that arrived in the weakened body of Salem and was therefore allowed to consume the entire system. Then, Salem was a pressure cooker, each page redefining volume and pressure and temperature, and matching the direction of proportionality. Students came to understand that paranoia within the vessel of Salem is dependent on power’s response to hysteria: if you understand the societal pressure, only then can you cross the divide to fix the paranoia, which John Proctor does, but too late for action.

The tragedy had new and deliberate clarity.

My students wandered the rooms and checked out one another's interpretations, trying to stand where their peers had and see what they saw. When we returned to our original positions and revisited the class discussion, one student asked why they had never done anything like this before. "I don't know. That's a pretty important question. I guess I wonder if there's a better answer in what we do next." And the bell rang, as if I had planned it that way all along.

### **Experiment 2 — Biology 30: Nervous & Endocrine Systems.**

#### ***2A: Goals from the Alberta Education Program of Studies.***

"Students will: (1) explain how the nervous system controls physiological processes [and] (2) explain how the endocrine system contributes to homeostasis" (Alberta Education, 2014a, p. 51).

#### ***2B: Science Baseline — Nervous System, Homeostasis, Sensory Reception.***

There are trillions of cells that make up a human body. Those that work toward the same end make up *tissues* that are then organized as *organs*, which work as *systems*. These systems could be transport systems (circulatory, lymphatic, immune), maintenance systems (digestive, respiratory, excretory), sensory systems (integumentary, muscular, skeletal), reproductive systems, or control systems (nervous, endocrine). This latter grouping is the focus for this unit of the *Biology 30 Program of Studies* (Alberta Education, 2014a).

*Homeostasis* is a state of equilibrium and stability within a body. This state is necessary for all of the systems to perform their processes properly. The *nervous system* is the one to fight against changes in the internal and external environment and maintain homeostasis. It does this by regulating the body's responses to a variety of internal and external stimuli. "The human nervous system can regulate tens of thousands of activities simultaneously" (p. 367). It monitors and controls sensory input, integration, and motor output. The nervous system is divided into the

*central nervous system* (brain and spinal cord), then the *peripheral nervous system* (the nerves that connect them to the rest of the human body). Figure 6 outlines these divisions. Through *sensory pathways*, the body receives

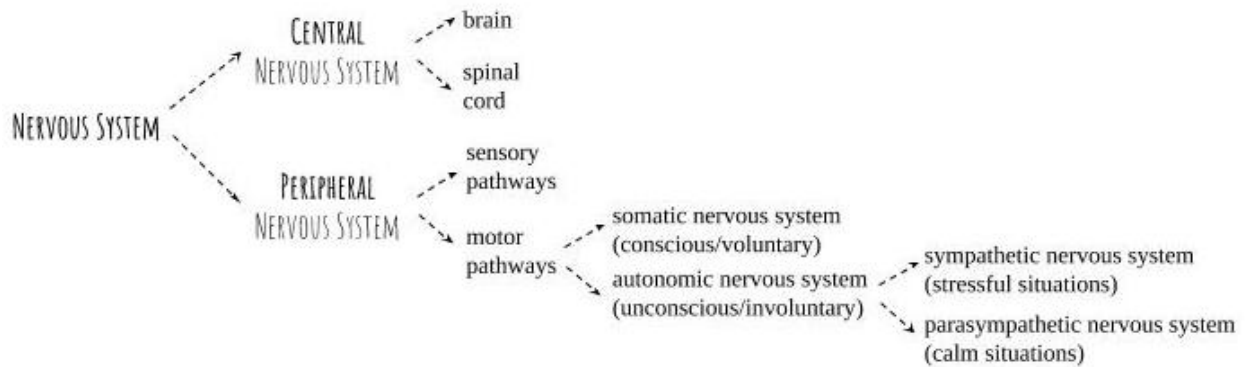


Figure 6. *Nervous system components, showing the hierarchy of the nervous system.*

Adapted from Figure 11.3 by Colbourne et al., 2007, p. 367. Copyright 2007 by McGraw-Hill Ryerson.

contextual information for the body and sends that data to the central nervous system. Once the data has been processed (*integration*) it is relayed through *motor pathways* of the peripheral nervous system for the body to respond to that information in either *somatic* (conscious and voluntary control) or *autonomic* (not conscious and involuntary control). Some neurons are equipped to rapidly protect the body from danger and threat. These sudden and reflexive responses are completely involuntary and certainly unlearned. They are simple connections of neurons or *reflex arcs* that move faster than pain receptors to move the information from sensory input to motor output, as such they demand no input from the central nervous system. Autonomic functions are regulated by the *sympathetic* and *parasympathetic* nervous systems; the former is typically activated by stressful situations (fight-or-flight), while the latter is activated when the body is calm (rest-and-digest). Like the gas and brake pedals in a car, though they often function in opposition to one another, both are necessary for a complete journey.



**2C: Literature Baseline — Hamlet by William Shakespeare.**

William Shakespeare's *Hamlet* centres around Prince Hamlet dealing with the death of his father, King Hamlet. Whether the title refers to father or son is moot; it may in fact refer to the legacy the latter inherits, which is not a throne but is in fact the rotten kingdom of Denmark. The play opens with a visit from a ghost resembling the late king. He refuses to speak with the guards or Horatio, the prince's closest friend, but he will speak with the prince, telling him of King Hamlet's murder at the hands of the incumbent king, King Hamlet's brother and Prince Hamlet's uncle Claudius, a man who not only sits on King Hamlet's throne, but sleeps in his bed with his wife Gertrude, the prince's mother. This twisted family tree has left young Hamlet grieving, angry, brooding, sulky, furious, and without an outlet to deal with these feelings. The ghost's revelation gives him a purpose that he quickly accepts and the rest of the play becomes his plot to expose Claudius' betrayal. Hamlet cannot be sure the ghost is indeed a spectre of his father and not the devil in disguise, hoping to tempt him into sin of his own. He must confirm guilt before he can exact revenge. He must also deal with his resentment of a mother he believes moved on too quickly from his father, resentment that infects his own relationship with Ophelia, daughter of Claudius' closest advisor, Polonius. Instead of pursuing frank conversations with all involved, he believes feigning madness is the best way to get his enemies to bring down their guard and to not suspect his attempts to expose Claudius' treachery.

Claudius recognises Hamlet's reluctance to accept the new status quo and worries Hamlet will disrupt what he has only just achieved. Claudius and Polonius work to understand Hamlet's motivation, the former believing there is more than grief at play inside of Hamlet. Polonius suspects the problem is lovesickness and recruits Ophelia to confirm the suspicion. Claudius and

Gertrude suspect the problem is grief and resentment over his mother's over-hasty marriage, and recruit two of Hamlet's friends—Rosencrantz and Guildenstern—to confirm their suspicions. Meanwhile, a troop of actors arrives at the castle, and Hamlet recruits them to confirm his suspicions, orchestrating a play to mimic the ghost's story of the former king's death such that Hamlet can see Claudius' guilty conscience exposed in recognition. So begins a whirlwind of investigation and spying, each party trying to catch the other in a reluctantly exposed truth. Rosencrantz and Guildenstern try to spy on Hamlet, but he sees through their guise and the attempt falls flat. Claudius and Polonius spy on Hamlet and Ophelia, where Hamlet rants and rages at a woman he suspects has betrayed him, not unlike his mother did his father. Watching Hamlet break Ophelia's heart makes Claudius realise that Hamlet is certainly not mad, but also represents an incredible threat to his security on the throne. Hamlet watches Claudius at the play and finds the confirmation he seeks when Claudius leaves the play distraught. Hamlet finds him in a church, where he believes Claudius is praying, and therefore cannot be killed because he would be sent to Heaven, a kind of reward for the most terrible of crimes. It turns out Claudius cannot pray in this moment, so impossible is it for him to repent for a sin of which he continues reap the rewards, but this irony is lost on Hamlet, who runs from the church and finds his mother to target with his anger. He yells at Gertrude, chastising her for choosing Claudius, a pale comparison to King Hamlet. Gertrude calls for help and a voice exclaims from behind the tapestry in her room. Hamlet believes he has found Claudius sinning and kills him to send him to Hell. As Polonius' body falls into the open, he realises his mistake. Claudius learns of the murder and feels even more threatened. He sends Hamlet away, securing a tragic end with a letter he

entrusts to Rosencrantz and Guildenstern. A pirate attack (!) allows Hamlet to escape and return to Denmark.

In Hamlet's absence, Laertes, Polonius' son and Ophelia's brother, returns from France to avenge his own father's murder. Claudius convinces him the blame lies solely with Hamlet and the two hatch a plan to kill Hamlet in a fencing duel. Laertes will poison the edge of his blade and Claudius will poison some celebratory wine: whether Hamlet wins or loses, poison will be his fate. Also in Hamlet's absence, Ophelia has been driven insane, in part because of Hamlet's actions in the first acts of the play, but also out of grief of her father's death. She commits suicide, an event Gertrude sees and reports to Laertes and Claudius, further sharpening Laertes' resolve to end Hamlet's life in retribution. During the graveyard scene, Hamlet and Laertes grapple in Ophelia's grave, each declaring the greater love for Ophelia. Claudius stops the fights and Laertes and Hamlet return to their figurative corners. During the match in the fifth and final act of the play, Gertrude mistakenly drinks the poisoned wine and Laertes strikes Hamlet with the poisoned blade. Hamlet then wounds Laertes with the same blade, and the latter reveals Claudius' plot. Gertrude is dead. Hamlet finally kills Claudius. Laertes and Hamlet forgive one another and then die. The Norwegian prince, Fortinbras, storms and takes the castle. Horatio is left to tell Hamlet's story.

The action of the play seems to unfold over four months. At the outset of the play, Hamlet remarks that it has been two months since his father died (1.2.138); in the third act, Ophelia says it has been four months since King Hamlet died (3.2.123); in the fourth act, Claudius tells Laertes that two months ago, Hamlet heard a great swordsman praise Laertes' fencing skill (4.7.81), so Claudius and Hamlet must have been together less than two months before Claudius

and Laertes have this conversation. Earlier in this scene, Ophelia names tomorrow as St. Valentine's Day (4.5.48) and later in the scene she turns up drowned. If Ophelia is accurate, then extrapolating backward means King Hamlet was murdered at the beginning of September, appeared as a ghost around Halloween, and Hamlet orchestrated the Mousetrap for Christmas and was sent to England to die around New Years. The play ends shortly after St. Valentine's day, perhaps on Shrove Sunday, a day of absolution.

### ***2D: Biology 30 Interrupting Hamlet.***

At the outset of the play, Denmark has clearly fallen out of homeostasis, the system losing equilibrium and stability, for "something is rotten in the state of Denmark" (Shakespeare, 1604/2009, 1.1.90), and until homeostasis is restored, the kingdom will be unable to perform its processes properly. "Denmark" is metonymy: Denmark is a people, a kingdom, but moreover, it is a single vision expressed by a single voice from the head of state. "Norway" is activated similarly, both a country and a "brother" (Shakespeare, 1604/2009, 2.2.59) to Denmark and uncle to Fortinbras (2.2.62), given ambition (1.1.64), "skirts" (1.1.100), "a stomach" (1.1.103), a "strong hand" (1.1.105). The state and the ruler are indistinguishable in this world: Hamlet is asked to "look like a friend on Denmark" (Shakespeare, 1604/2009, 1.2.69) after lashing out at Claudius; the ghost tells the story of poison, remarking that Claudius pouring hebanon into King Hamlet's ear (Shakespeare, 1604/2009, 1.5.61-73) is an act that makes "the whole ear of Denmark [...] rankly abus'd" (1.5.36-38). However, the head in charge (of the body of the country) is often at odds within itself: when Claudius addresses his kingdom to summarise the state of affairs, he uses the royal "we" throughout (Shakespeare, 1604/2009, 1.2.1-128), a practice that falters whenever Claudius is seeking his own personal agenda, either plotting

against Hamlet—with Polonius (2.2.1-58), with Rosencrantz and Guildenstern (3.1.162-175 & 3.3.1-26), with England [in apostrophe] (4.3.58-68), with Laertes (4.7.1-162)—or confessing guilt to the audience—his aside while spying on Hamlet (3.1.49-54), not-praying after he leaves the play (3.3.36-98). When Laertes warns Ophelia that Hamlet’s “will is not his own” (Shakespeare, 1604/2009, 1.3.17), it is because he will be next in line to the throne (1.2.109) and therefore “on his choice depends / The safety and health of this whole state. / And therefore must his choice be circumscrib’d / Unto the voice and yielding of that body / Whereof he is the head” (1.3.20-24). The play, therefore, is a conflict between two nervous systems, both vying for control, both attempting to anchor his single vision and his single voice for Denmark, both losing sight of the needs of the greater system, their kingdom, for the sake of opposing personal agenda: revealing and obscuring guilt. Homeostasis is impossible without the complete elimination of one vision, but this play ends with the death of both parties, leaving the kingdom without a nervous system and primed for Fortinbras to activate his own control system as the central nervous system of Denmark.

Many of Hamlet’s seemingly bizarre actions can be better understood by way of the nervous system analogy. There are times of incredible action and those of inaction, paradoxes that engender debates over the prince’s true state of mind. The action of the play seems to occur over about four months, a significant amount of time for Hamlet to be investigating Claudius’ guilt and not doing very much avenging. This criticism seems fair if considered somatic and therefore conscious and voluntary: Hamlet’s nervous system is stalled in the integration stage, unable to relay decisions to the motor pathways. But Hamlet’s somatic system is not able to activate in the face of a damaged autonomic system, taxing the central nervous system with an

overabundance of improperly processed data and yielding unregulated involuntary processes. Every institution Hamlet relies on has been shattered, starting with the most important one in Denmark and setting off a chain reaction through the rest. Hamlet's father is dead, a man second only to God in the Great Chain of Being, King "Fix'd on the summit of the highest mount" (Shakespeare, 1604/2009, 3.3.18) of Fortune's wheel "To whose huge spokes ten thousand lesser things / Are mortis'd and adjoin'd, which when it falls, / Each small annexment, petty consequence, / Attend the boist'rous ruin. Never alone / Did the king sigh, but with a general groan" (3.3.19-23). So begins the crumbling of the rest of the autonomic system, the series of social norms that regulate involuntary processes to maintain the status quo. The Danish people, instead of heeding "[their] better wisdoms [...] have freely gone / With this affair along" (Shakespeare, 1604/2009, 1.2.15): instead of considering the marriage incestuous as would be the social norm (Gill, as cited in Shakespeare, 1604/2009, p. 9) have freely allowed Claudius to wed Gertrude. Denmark is "disjoint and out of frame" (Shakespeare, 1604/2009, 1.2.20), and none of the neurons can deliver their messages; certainly the reflex arcs that depend on these structures cannot act rapidly and protect the body from danger and threat. Further evidence of this occurs when Ophelia, instead of committing herself to "the holy vows of heaven" (Shakespeare, 1604/2009, 1.3.114) that she exchanged with Hamlet, accepts her father's direction to "repel [Hamlet's] letters and den[y] / His access to [her]" (2.1.109-110). To these people, promises made by way of heaven should be unbreakable, yet break they do in the wake of King Hamlet's death. Furthermore, instead of being able to trust Ophelia as an organ functioning properly in his system, she betrays Hamlet's confidence and reveals all of their intimacies to her father (Shakespeare, 1604/2009, 106-127). Unable to rely on standard social

conduct and therefore autonomous response, the somatic response he generates to fix the system is its inverse: madness. He acts crazy with Ophelia, dismantling the costume that society means for him to wear (Shakespeare, 1604/2009, 2.1.75-100) and does the same with Polonius (2.1.171-214), here dropping his blank verse and speaking out of iambic pentameter, choosing standard prose in lieu of the rhythm of nobility, recognising that “to be honest, as this world goes, is to be one man picked out of ten thousand” (2.2.178-179). Nothing is behaving as it should. Rosencrantz and Guildenstern, Hamlet’s “excellent good friends” (Shakespeare, 1604/2009, 2.2.221) are spies hoping to curry favour with the king, not to support their schoolmate (2.2.1-32). Hamlet recognises the faulty system, “the beaten way of friendship” (Shakespeare, 1604/2009, 2.2.265-266), and repairs the damage with a somatic response, asking them pointedly whether they have been repurposed as spies. Finally they confess, and Hamlet begins a speech (still without blank verse) about “forgo[ing] all custom of exercises” (Shakespeare, 1604/2009, 2.2.292), and alluding to a false stage made to look real but actually filled with disease (2.2.295-298), inhabited by man, who is meant to be “noble in reason [...] infinite in faculties, in form and moving how [direct] and admirable [...] the beauty of the world, the paragon of animals” (2.2.299-303), but who achieves nothingness (2.2.304). Clearly, everything borne of a system so broken will itself be broken, as are both Hamlet’s sympathetic and parasympathetic responses. Of course it takes him an absurd two months to rest-and-digest before the Mousetrap is sprung, and of course his fight-or-flight is equally absurd when bates the audience nonstop through the stressful situation that is the Mousetrap’s springing. The gas and brake pedals in this car function absurdly because of the absurd rewiring of autonomic conventions that he can no longer fully trust. Likewise, in confronting his mother in her chamber,

Hamlet's behaviour is so extreme as to provoke a hiding Polonius into exposing his presence.

Hamlet's culminating sympathetic autonomic response is involuntary: the reflex arc protects him from danger and threat as he instantaneously drives his rapier through the tapestry behind which Polonius hides. Still, Hamlet spends the next 80 lines continuing to drown in autonomic responses, his body (his Denmark) desperately trying to regain control of an unstable system.

Enter the Ghost, the missing fixture "on the summit of the highest mount" (Shakespeare, 1604/2009, 3.3.18), and suddenly the autonomic gives way to somatic, and Hamlet and Gertrude are finally able to have a sensible conversation, the voluntary control allowing Hamlet's brain and not simply his spine to weigh in on his decision making.

### ***2E: Pedagogical Extractions.***

My students are often relatively quick to judge Hamlet for his inaction. He spends months *not* avenging his father's murder, instead seeming to put all his efforts into rationalising all the reasons that now is not the time for action. He plays when he should be working. He mocks when he should love. He runs when he should stand strong. The "should" of it all is where they judge. Our discussion following this Biology lens was much more about how that "should" is broken *for* him, not *by* him, a shift which elevated a discussion of judgment to one of power and authority and control. One student summed it up best, suggesting that Hamlet's not a mess; Denmark is. Indeed, it is rotten, and Hamlet is the only one trying to restore homeostasis. Tragic hero indeed.

As the insights here seem to mirror those in other experiments, in lieu of repeating myself, I will instead take the opportunity to explore some of the pedagogical extractions beyond my classroom. One of the students in my English 30-1 class had Biology right after English, so



she would often have English books sitting on her Biology desk. One day she told me that on just such an occasion, she had her *Hamlet* text sitting in plain sight. Her Biology teacher gestured to it and said, “I don’t have any time for that.” I reframed his answer when she told me the story, explaining that there is lots of time in a day. “What he’s really saying is that he doesn’t believe *Hamlet* is worth allotting time to.” This man is in fact one of the teachers who has my giant roots/affixes posters in his classroom. You see, he was already teaching the roots and affixes; my resource made that easier. However, beyond language, he is clearly not ready for anything that would appear to add to his overburdened teacher-plate. I recognise this perspective in a lot of my colleagues who do not see a broken system. To be clear, they do not see a flourishing one either, but they do see a sustainable one, and that is often a more immediate and powerful motivator: survival. I recognise this feeling as the kind of teacher who would tell me to stay in my lane: something along the lines of “you teach English and I’ll teach Biology; don’t confuse the children.” And I understand that reluctance, but I also understand we are asking the same student to learn English and also to learn Biology: would connections not make that same student more adept at learning *everything*? Would connections not make that same student more adept at learning *anything*? Would that not free up time for all teachers? Perhaps more Biology teachers *should* make the time for *Hamlet*.

## **Chemistry Case Studies**

### **Experiment 3 — Chemistry 20: Diversity of Matter & Chemical Bonding.**

#### ***3A: Goals from the Alberta Education Program of Studies.***

“Students will: (1) describe the role of modelling, evidence and theory in explaining and understanding the structure, chemical bonding and properties of ionic compounds [and] (2)

describe the role of modelling, evidence and theory in explaining and understanding the structure, chemical bonding and properties of molecular substances” (Alberta Education, 2014b, p. 16).

### ***3B: Science Baseline — Diversity of Matter.***

Matter is observed and discussed at three levels: *macroscopic* (naked-eye), *microscopic*, and *molecular*. This latter observation is the focus of this unit, as it deals with changes in matter that can be observed at the atomic level. These changes fall into one of three categories: *physical*, *chemical*, or *nuclear*. Physical changes adjust shape and structure but not the chemical formula of a substance; these include phase changes (evaporation or melting), dissolving, and changes in appearance, all of which require relatively small amounts of energy. Chemical changes adjust the bonding within the substance (between atoms and/or ions) and therefore adjust the chemical formula to generate new substances with permanently different properties from the original, a process which usually demands a larger energy change. While chemical changes create new relationships *between* the atoms of that matter, nuclear changes happen *within* the nucleus of atoms to create entirely new atomic matter and demand incredible energy changes to break and create new nuclear bonds.

Because chemical reactions generate new substances, a simple diagnostic test is often enough to reveal whether this has occurred. Scientists look for colour, odour, state, energy changes that suggest the presence of new substances. The *law of conservation of mass* asserts that even in light of these changes, the total mass of matter present remains constant throughout the reaction. “The individual entities do not change, except in the ways they are associated with each other” (Jenkins, van Kessel, Tompkins, & Lantz, 2007, p. 48). This logic yields *balanced*

*chemical equations* in investigating the reactions of a chemical change: if mass comprises certain atoms or ions in the reactants, then the same total number of those atoms or ions will be found in

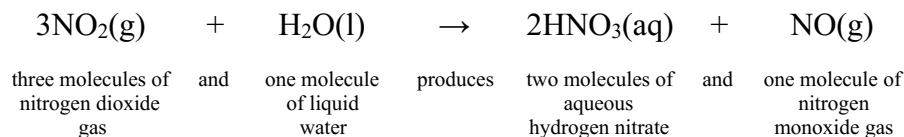


Figure 7. *Balanced chemical equation for the chemical reaction of nitrogen dioxide and water.*

the products following the reaction. In the example above (Figure 7), one molecule of nitrogen dioxide is not enough to react effectively with water to generate these products, Instead, they are *coefficient* and three come together for this reaction to occur. On the product side of the reaction, those three nitrogen atoms and six oxygen atoms are redistributed into the new substances generated by the reaction. And these ratios remain the same at whatever volume is used for the reaction, allowing larger quantities of matter to react in identical ways, provided the fundamental ratios are maintained.

Reactions come in many types and are categorised by the relationship between reactants and products. If elements come together to form a compound, it is a *formation reaction*. If the opposite occurs and a compound is broken down into its elements, it is a *simple decomposition reaction*. *Combustion reactions* occur when substances are burned to produce oxides (and heat). *Replacement reactions* occur when *solutes* (substance dissolved) and *solvents* (substance doing the dissolving) interact to create solution (the mixture) and in some cases *precipitates*. A precipitate comes to be when the capacity of the solution is met; it can process no further solute in the solvent and the excess settles to the bottom of the solution.

**3C: Literature Baseline — The Wars by Timothy Findley.**

The narrative of *The Wars* is assembled by a fictional historian, piecing together events over a year and a half that start with Robert Ross's enlisting in the army and end with terrible injury in June of 1916. She is hardly an unbiased narrator, moving between first-, second-, and third-person point of view as she assembles voices and artifacts to tell Robert's story.

Robert first enlists in the army following the tragic death of his sister, Rowena. She suffered from hydrocephalus and was wheelchair bound. The day she died, she fell from her wheelchair in the barn while Robert was busy masturbating in his room. Overwrought with guilt, he heads to training camp where he meets a war hero, Eugene Taffler. Robert heads to town with some of the other trainees and ends up at a brothel where he is unable to participate, having prematurely ejaculated in his pants. The prostitute instead shows him a peephole into another room where he spies Taffler having violent sex with another man. Confused and angry, Robert throws his boots and smashes a mirror and water jug. This cements the motif of an unhealthy understanding of sexuality and the pairing of guilt therein. There is also a scene in this part of the novel that echoes the demand his mother made to kill Rowena's rabbits after her death; when a lame horse needs killing on the boat, it falls to Robert, who struggles with the task. This cements the motif of animals in relationship with their humans.

Part two finds Robert in France where he nearly drowns in a sinkhole but manages to save himself. He and two of his men, Poole and Levitt, join three others — Devlin, Bonnycastle, and Rodwell — in a dugout where they will all live for the time being. Rodwell cares for injured animals, reminding Robert of Rowena's relationship with her rabbits. He and Robert become

good friends. This part of the novel ends with a huge explosion of landmines causing the deaths of tens of thousands of men without gaining any land in the process.

The next part of the novel tracks Robert's time in the trenches, with sanity weaving in and out of reality. The key scene is with Robert needing to put guns at the base of a crater. He and his men find themselves caught in a gas attack and improvise urine soaked cloth strips to hold over their faces and protect them from the gas. For hours, they lay in the mud, pretending to be dead. When they decide to leave, Robert realises they are being watched by a German soldier, but for some reason the German allows them to leave. As the German reaches for his binoculars, Robert thinks he is reaching for a gun and shoots first, later learning that the German had a sniper rifle and could have easily killed them all earlier, had he wanted. Robert is haunted by guilt.

Part four finds Robert in a hospital recovering from his wounds, where he meets Juliet d'Orsey; her family home is being used as an infirmary during the war. Again, he meets Taffler, who has lost both arms. Taffler attempts suicide but is saved. On another night, Juliet walks in on Robert and Barbara d'Orsey having violent sex, Juliet's misunderstanding and youth mirroring Robert's in his spying on Taffler in the brothel. This part ends with Robert leaving the d'Orsey home to return to the front.

Robert gets lost and arrives at a mental institution called Désolé, where he is brutally raped in the bathhouse by four men. Who he originally believed to be asylum patients turn out to be fellow soldiers, and Robert is horrified by this revelation. He burns his only photo of Rowena in an act to save her from the horrors of the perverse world in which he has found himself. When he returns to the front, the Germans are in full attack, and Robert realises that a nearby barn

could be hit, burning the horses therein. He asks a commanding officer, Captain Leather, to release the horses, but the man refuses. Robert and Devlin try to set the horses free, but Captain Leather shoots Devlin, tries to shoot Robert too, but misses. Three German shells land and consume everything in fire, including the barn where the horses indeed burn alive. Robert shoots Captain Leather dead and runs, knowing he will be courtmartialled for disobeying orders. He finds a dark horse and a similarly coloured dog near a stopped train, then realises that all the cars are filled with horses and decides to free them. (This is the scene captured in the prologue.) They all run along the tracks, free until soldiers surround them and back them into a barn. The soldiers try to smoke Robert and the horses out by lighting this barn on fire, but the doors are locked. The animals perish, and Robert is left with terrible burns. The final six pages of the novel are given to his convalescence. His incredible pain garners an offer of euthanasia, which he declines. Because prison is out of the question, he is allowed to live out his final six years at St. Aubyn's hospital. We learn that Juliet d'Orsey loved him, staying by his side until the end and inscribing the epitaph for his gravestone: "EARTH AND AIR AND FIRE AND WATER" (Findley, 2001, p. 217).

### ***3D: Chemistry 20 Interrupting The Wars.***

The matter of *The Wars* is assembled by a fictional historian who seems to piece together events at a macroscopic level. She tracks eighteen months of Robert Ross' life, starting the diegesis near his enlisting in the army and ending with the epitaph on his gravestone, which reads "EARTH AND AIR AND FIRE AND WATER" (Findley, 2001, p. 217) above his name and years of life. The novel indeed captures and showcases matter in all its diversity, and because she attempts to be an unbiased narrator—moving between first-, second-, and third-person points

of view to assemble voices and artefacts to tell Robert's story—the historian is able to assemble facts in such a way that she honours the molecular bonds of those pieces. Of the three changes in matter—physical, chemical, and atomic—only *chemical* is of import to Robert's journey. Physical is simplistic: surely his body is beaten and ravaged by war. Atomic is irrelevant: Robert remains true to himself throughout the story: for even in the face of incredible energy change, the nucleus of his self remains unaltered and new atomic matter is never generated. Chemical, however, is certain: the relationships *between* the atoms and ions of his matter are where we witness change, where we come to understand the new substances generated by Robert's interaction.

Robert's sister, Rowena, is hydrocephalic, a word that describes a build up of cerebrospinal fluid on the brain, and which literally means *water on the head*. This overabundance of water makes her wheelchair-bound, and therefore in need of her own reactant to live a productive life. With one, the other has purpose: she's the first human he sees; he believes her to be his mother; he becomes her guardian; he makes hutches for her rabbits; for her he learns to run. The day she died, she fell from her wheelchair in the barn while Robert was busy masturbating in his room. Therefore when Robert removes himself from their equation, tries to deconstruct the product into its constituent molecules, indeed tries to identify and flourish as an independent molecule, Rowena's coefficient molecules are without anchor and evaporate from existence. With the product side of their reaction no longer possible, all other new substances must also be rendered impossible. The rabbits were theirs, fed and cared for by only Robert-Rowena. With her death, "the rabbits had to die... because he loved her" (Findley, 2001, pp. 18-19). There is something poetically perfect about the fact that Robert learns from his





Of course, life cannot be given on both sides: water is absent and Robert is again acting in self-serving ways, forgetting that his humanity is coefficient. In contrast, during the coyote scene, the equation is perfectly balanced, all elements functioning in harmony: “the heat had deserted the day and the water sent a cool shock up the walls of the valley, striking at Robert as if a wind had risen” (Findley, 2001, p. 27). Fire and water and earth and air (respectively) all have their place, and finally the coyote can stop and revel in a completed reaction. Robert himself is not ready for coefficient, because he cannot understand a balanced equation without his sister. “He wanted no attachments yet. What he wanted was a model” (Findley, 2001, p. 24). He watches the coyote perform a successful formation reaction and finds solace; his own thirst disappears with the coyote’s. So satisfying is the balance that for the next two weeks, Robert longs for someone to howl (Findley, 2001, p. 28).

The next major battle (reaction) Robert faces is in a mental institution called Désolé. If family is where ethos gets its foundation and war is where one goes to protect ethos, a mental institution is where ethos has no home<sup>10</sup>. When Robert is raped in the bathhouse (water) by four men, he assumes they are patients and therefore without stable identity. When he discovers that they are fellow soldiers, nothing about the reaction makes sense and he burns (fire) his only photo of Rowena in a gesture to finally and ultimately save the rabbits from the unbalanced chemical equation in which he has found himself. This combustion reaction produces a heat that is now fully expressed and follows Robert through the rest of the story. It also produces an oxide, and in this case because he burns a hydrocarbon to generate reaction, they are most likely carbon monoxide and carbon dioxide, both toxic to humans. His symbolic gesture partners him hereafter

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<sup>10</sup> And seeing as Désolé is French for “sadness,” pathos will also be lacking here.

with animal-kind in lieu of man-kind: new coefficients. When he returns to the front, he sacrifices everything human to save a burning barn of horses. Robert ignores orders, shoots his commanding officer, finds a black horse and a black dog to run with. His efforts find him backed into a corner and himself burned by incredible fire. Burned and now blackened like the animals, like the photo of Rowena, he survives with a fraction of life, one marred with a useless body and incredible physical pain: a reaction that finally matches and therefore balances the guilt he felt for ever allowing his sister's death. For the majority of the novel, Robert sought replacement reactions, trying to dissolve himself in water to find solution. But Rowena no longer exists, and once he acknowledges this in burning Rowena's photo, he accepts his nature in combustion reaction. He is ultimately consumed, but also realised. If a tragedy occurs when the protagonist is unable to successfully overcome the central conflict, and a comedy occurs when he is able to, then *The Wars* is both tragedy and comedy. Robert has found himself, and the fictional historian has shown us how he realises everything in becoming nothing. This paradoxical solution is why she both starts (in prologue) and ends (in diegesis) her collection of the the artefacts with this ultimate symbolic gesture, because "people can only be found in what they do" (Findley, 2001, p. 3) and "the spaces between the perceiver and the thing being perceived can... be closed with a shout of recognition. [...] Nothing so completely verifies our perception of a thing as our killing of it" (Findley, 2001, p. 218). Robert Ross is not a solitary molecule; he is a reaction.

### ***3E: Pedagogical Extractions.***

I framed this interaction much the same as I did with my grade eleven class studying *The Crucible*: summary → science → "trust me" → marriage → thoughts? → now you. The differences were that my 30AP English students asked to open this up to Math and Music in

addition to the sciences (“Of course!”), and that they signed up for their non-English lens right near the beginning of our novel study. These students articulated the same excitement *and* the same concerns as the other class did. Most students told me they were excited: they were allowed to use strength from somewhere outside of my classroom to feed understanding within it. Some students told me they were concerned as this was a completely new experience, concerned as English was their strength and they felt they might be diluting it with science. In all cases, everyone was willing to give it a try.

Once we were on the other side of the novel, we ran it as a science-English fair, where students needed to make a poster (or two or three) that could explain the logic of their lens(es) without their needing to stand next to their poster to explain. This meant that students could use diagrams, flowcharts, equations, drawings to supplement the written word in whatever way they saw fit. What resulted was a classroom filled with some of the coolest observations about *The Wars* that I have ever encountered. Students were asked to grab their notebooks and tour the room—the fair—writing down every insight they discovered about *The Wars* that was particularly resonant. I walked and wrote with them.

Physics students used forces and fields to explain why Rowena’s death affected Robert more than Rodwell’s suicide, and discovered that many people moving in the same direction create a strong magnetic field, such that the fronts and efforts in WWI become a series of magnetic fields forcing people to act in odd ways, especially when these fields encounter one another. Calculus students used the “point of discontinuity” in graphing to explain the archivist’s struggle to create a linear narrative around the life of Robert; they used the “point of inflection” to unpack Robert’s sinking into previously unknown depths of despair when he acts contrary to

his nature under the rule of commanding officers. Biology students used genetics to access the evolution of Robert Ross throughout the novel, suggesting his chromosomal makeup had been altered by way of meiosis and other mutations: as such, the alleles donated to his makeup from his parents manifest either dominantly or recessively as his *context* shifts its demands on his *self*. One of my students took my Chemistry discussion in a new direction, focusing on the *incomplete* combustion reactions she could identify, a notion that I had definitely missed in my examination. Other Chemistry students used redox reactions to understand the transfer of power that generates negative and positive charges: during Robert's rape, the soldiers took Robert's sense of autonomy to build their own, a realisation that elucidated all the times those in the novel took power from others to give themselves a semblance of control over *something*; Robert is the one who learns to take power from those who do not deserve it and use it to protect the weak, to share his power with them. Music students used chord theory to demonstrate Robert's import as protagonist and therefore the tonic chord, where Robert's life changes are represented by the addition and removal of notes, which contributes to the overall manipulation of chord balance and harmonic alteration. There were viruses and diseases, ramps and collisions and vectors and pulleys, circulatory and digestive and excretory systems, stoichiometry and conservation of mass, ecosystems and food chains. Nervous and endocrine systems became interpersonal relationships. Circular motion became the repeated wars throughout the novel, the centre of each becoming that toward which Robert is accelerating. One group wrote an equation explaining the weight of emotion as a compound of Robert's constant mass encountering ever fluctuating acceleration due to gravity, and brought me to tears with the poignancy of their explanation.

Before the students really started their leg of this journey, I did an informal (Google form) survey of the 34 students, asking who was excited, neutral, concerned. After they had worked with this lens for a couple of classes, I asked again. When we were finished the novel, I asked a third time. A summary of my findings of this informal survey can be found in Table 4. Students were also given the opportunity to document their thinking. As this

Table 4. *Informal survey of student reception*

Timing of survey	Concerned	Neutral	Excited
<b>Before</b>	7	7	20
<b>During</b>	3	10	21
<b>After</b>	1	0	33

degree of interdisciplinarity in my English classroom is still a relatively new process, one which is sure to cause anxiety simply because it is unusual, I wanted a place where students could give me feedback on what was and was not working so I could adjust accordingly<sup>11</sup>. Looking solely at their work was not going to provide this insight, as *every* student was incredibly successful in marrying an alien discipline with *The Wars*. Still, I believe education only really works when students feel that they belong, that *they* are never the aliens. Though those were certainly a minority, the students who were concerned throughout the process needed to know that this was not meant to be a trap into which they would fall and fail, but an opportunity to find new things about the novel we were studying *and* of themselves as learners. That one student who remained in the “Concerned” camp even after the process became my own concern for any process like this. When I asked him to articulate his concern, he said that he felt he was pushing a square peg

<sup>11</sup> This is, afterall, their classroom, even when I call it “mine.”

through a circular hole and that things that seemed clear were becoming unclear. As we unpacked these concerns, it came back to the strength/weakness component. English has always been his strongest subject, never any of the sciences. When I asked him if English in his Science classes would work better, he told the class that would be amazing.

#### **Experiment 4 — Chemistry 30: Thermochemical Changes.**

##### ***4A: Goals from the Alberta Education Program of Studies***

“Students will: (1) determine and interpret energy changes in chemical reactions [and] (2) explain and communicate energy changes in chemical reactions” (Alberta Education, 2014b, p. 42).

##### ***4B: Science Baseline — Enthalpy, Activation Energy, Catalysts.***

“The study of energy changes (that is, energy produced or absorbed) by a chemical system during a chemical reaction is called *thermochemistry*” (Jenkins et al., 2007, p. 485). This study demands an isolated system to contain the energy and matter before, during, and after the reaction. It also demands precision measurement or *calorimetry* to show that the thermal energy transfer is a product of the mass of a substance, its specific heat capacity, and the temperature change suffered during the reaction. If kinetic energy is produced by moving electrons or vibrating atoms or rotating molecules and potential energy is stored in covalent or ionic bonds and intermolecular forces, then *enthalpy* is the sum of all of that energy within a chemical system. The *law of conservation of energy* tells us that any change in enthalpy is equal to the change in thermal energy (Jenkins et al., 2007, p. 491). Therefore, if the temperature between reactants and products does not change during the reaction, then the energy forms have not changed: the kinetic and potential energies remain identical. If there is an energy loss by the chemical system, it will become an equivalent energy gain in its surroundings. This energy gain

is an *exothermic reaction* and is represented by negative enthalpy change. If the opposite occurs and the reaction absorbs (in lieu of producing) energy, an *endothermic reaction* has occurred as has a positive enthalpy change. Once the enthalpy change is calculated, it can be included as a term in balanced equations. In the case of endothermic reactions, the enthalpy change is considered a reactant and recorded to show it is absorbed as part of the reaction. In the case of exothermic reactions, the enthalpy change is considered a product and is recorded to show it has been released as part of the reaction. Enthalpy can be expressed in terms of a standard unit, like a *mole* ( $6.02214179 \times 10^{23}$  atoms) to generate a value called the *molar enthalpy*. Enthalpy can also be expressed in terms of a standard context, or *standard enthalpy of formation*. These standards allow us “to compare the stabilities of compounds” (Jenkins et al., 2007, p. 510), and understand that some compounds are more stable than the elements used to build them. *Thermal stability* refers to the ability of a compound to resist decomposition in the face of heat. A low standard molar enthalpy of formation suggests a higher thermal stability.

Reactions are possible because of effective collisions, which require proper positioning of the molecules in question such that bonds can be broken and formed as needed. In some cases, simply introducing reactant entities to one another is enough to generate reaction as they already have the required minimum energy. In other cases, elements do not immediately react as soon as they encounter one another. For instance, a spark is needed to start the combustion process, to ignite the reaction that will cause the elements to form more thermally stable products. This energy threshold for this is called the *activation energy*, which must be reached before a reaction occurs. Once an exothermic reaction begins, it often continues until it exhausts the reactant molecules (or fuel). After that initial energy is supplied, the energy generated from a resulting

exothermic reaction is enough to transfer to other molecules needing their own activation energy, continuing the reaction throughout the medium without further aid from external energy sources. If activation energy must be supplied externally, it may be in the form of heat, light, or electricity. At a molecular level, this activation is being used to separate the bonds between atoms or ions. The stronger the bond, the more energy is required to separate them, a value called *bond energy*, which is the same energy that is released in the formation of that bond. In endothermic reactions, more energy is required to break the bonds in the reactants than is generated in the product. In exothermic reactions, the opposite is true.

A catalyst is something that makes a chemical reaction occur more readily, but is not consumed itself as part of the reaction. It reduces the activation energy necessary and therefore accelerates the reaction to produce a greater yield in an otherwise similar context. Because of this, the reaction can often occur at much lower temperatures without affecting the net enthalpy change of the reaction. Catalysts generate efficiency. The theory is that instead of the bonds having to be broken and formed in only one way, a catalyst provides “an alternative pathway with a lower activation energy” (Jenkins et al., 2007, p. 541). In the case of the decomposition of methanoic acid, instead of the energy needed to move a hydrogen atom from bonding with the carbon atom to bonding with the oxygen atom in the molecule, an additional hydrogen ion acts as catalyst, easily creating the oxygen bond first and allowing an easier release of the carbon bond, an alternative pathway to the same end.

#### ***4C: Literature Baseline — The Great Gatsby by F. Scott Fitzgerald.***

*The Great Gatsby* by F. Scott Fitzgerald finds Nick Carraway in New York ready to bask in the Roaring Twenties and the Jazz Age. Nick moves to New York from Minnesota during the



summer of 1922, fresh out of university and looking to make a name for himself socially. The suburbs of New York are divided into East Egg, where old money lives, and West Egg, where the *nouveaux riche* live. Nick rents a house in West Egg, from which he can commute to New York City to work as a bond salesman. When worlds collide, Nick (and therefore the reader) witnesses the impermanence of Gatsby's efforts, crumbling under the pressure and permanence of old money.

For the first two chapters, the titular character remains largely absent, save for a moment at the end of the first, late one night, when Nick sees Jay standing on his balcony, arm outstretched across the bay toward a green light on a dock on the opposite shore. These first chapters are spent introducing us to the “sinister contrast between [these suburbs]” (Fitzgerald, 1925/2004, p. 5), “East Egg condescending to West Egg” (p. 44), showing the connections and abundance and privilege specific to old money, of generations of money as opposed to Gatsby's “three years to earn the money that bought [his house]” (p. 90). These counterpoints are established first in the Buchanan house with Tom (Nick's former classmate at Yale) and Daisy (Nick's cousin), and then in Tom's mistress' apartment in the city. Tom's mistress, Myrtle Wilson, hails from a place between the Eggs and New York City proper, called *The Valley of Ashes*. Myrtle desperately wants out of her world of lack and is willing to do whatever she can to realise one of abundance, including putting up with Tom breaking her nose if it means an NYC apartment and parties therein. This sets the foundation of contrast for Nick's meeting Gatsby at one of a series of what can only be described as the most absurdly extravagant parties known to man, where drinks seem to float out of the ether and buffet tables groan under the weight of food, where people dance and drink for an entire weekend without really learning one another's names,

where servants spend all of Monday repairing the damage of the days before. Upon his arrival at one of these parties, Nick cannot seem to find Gatsby, nor can he find anyone else who knows the man. But Gatsby finds Nick, and they connect over a common past in the war effort and, as Nick will learn, Gatsby's desire to be reunited with Nick's cousin Daisy. It turns out Gatsby and Daisy know one another from before the war, and everything Gatsby has become since then has been an attempt to catch her attention and woo her anew. Nick arranges a meeting, and so begins the affair.

An affair, however, is not enough for Gatsby. He wants all of Daisy, and contrives a confrontation with Tom so Daisy can tell him that “[she] never loved him” (Fitzgerald, 1925/2004, p. 109, 132), to “obliterate four years with that sentence” (p. 109). The day starts at the Buchanan house, but then Daisy moves them to neutral territory in New York City, where they rent a sweltering hotel room in which they can drink and pass the day. On their way into NYC, they pass through the Valley of Ashes for fuel at the Wilsons' garage, where Myrtle sees Tom driving Gatsby's yellow car with a woman she assumes is his wife and is overwhelmed with jealousy and missed opportunity. Daisy and Gatsby, meanwhile, drive Tom's car. Once in the hotel room, Gatsby forces the issue and tries to compel Daisy to erase the past years with Tom, who balks at this attempt, exposing Gatsby as a bootlegger and criminal, amassing the kind of fortune that is dismissible and nonthreatening to the likes of old money. Daisy struggles, and Gatsby cracks, while Tom confidently asserts his place in the world. They drive back to the suburbs, Daisy and Gatsby sharing Gatsby's yellow car, so unthreatened is Tom by the hotel revelations. The narrative follows Tom, with Jordan and Nick in his car as they again encounter the Wilsons' garage, where they discover Myrtle has been hit and killed by a yellow car. It seems

Myrtle thought it was Tom driving and ran into the street to stop him. Tom thinks Gatsby a coward for hitting Myrtle and driving away. We discover later that it was Daisy driving and therefore Daisy who killed Myrtle. George Wilson is convinced the driver was Myrtle's lover and seeks retribution. Tom fingers Gatsby, who Wilson shoots and kills. Nick arranges a funeral, which is largely unattended, save for Gatsby's father and one regular party guest—old Owl Eyes, who once marvelled at the completeness of the charade Gatsby has amassed. Ultimately disgusted with the lack of humanity his summer has exposed, Nick moves back to Minnesota, deciding that Gatsby's relentless pursuit of "the orgastic future" (Fitzgerald, 1925/2004, p. 180) is what made him great.

#### ***4D: Chemistry 30 Interrupting The Great Gatsby.***

*The Great Gatsby* is indeed a study of energy changes, ones that take place in a number of systems which are all part of the greater isolated system of Nick's summer out East. There are the Eggs of Long Island Sound, the Valley of Ashes, and New York City itself, all of which work to contain energy and matter before, during, and after the reaction that is Fitzgerald's novel. Though characters in the novel believe that "he's just a man named Gatsby" (Fitzgerald, 1925/2004, p. 48), it is Nick Carraway who makes him *Great*, recognising that "there was something gorgeous about him" (p. 2), believing that a death does not circumvent his "turn[ing] out all right at the end" (p. 2). Though it is indeed an isolated system, at the outset of the novel and at its conclusion, Nick is able to pass through the boundaries of that system without affecting enthalpy because of his position as spectator, a camera or lens by which the reader can access the circumstances, the "privileged glimpses into the human heart" (Fitzgerald, 1925/2004, p. 2) because "life is so much more successfully looked at from a single window" (p. 4). Nick is a

catalyst, not consumed himself as part of the reaction, but his sheer presence makes the reaction occur more readily. Historically, Nick's old money background grants him access to the likes of Tom and Daisy Buchanan; geographically, his new money summer home grants him access to the likes of Jay Gatsby and his parties. "If personality is an unbroken series of successful gestures" (Fitzgerald, 1925/2004, p. 2), then Nick circumvents the break and guarantees the success. Nick generates efficiency. Before his arrival, Gatsby's efforts to catch Daisy's eye fall flat. Before his arrival, Tom would never deign to set foot in West Egg. Though he doesn't seem to live a life unto himself, Nick does bring interactions to a head for the people around him, often simply by seeing and understanding and exposing their true nature. Tom Buchanan is physically dominating, often catching people by their arms and compelling them with his physique into place in his world (Fitzgerald, 1925/2004, p. 7, 11); Daisy is emotionally dominating, catching people by their desires and compelling them with her voice into place in her world (p. 9, 14). Nick's autonomy is stripped, not an entity unto himself, certainly not dominating, acting exactly as those around him need him to act: "a dozen people send their love [to Daisy] through [Nick]" (Fitzgerald, 1925/2004, p. 9); "[Nick] had no desire to meet [Myrtle]—but [he] did" (p. 24), nor is he allowed to leave when he would like to (p. 28, 35); of course Nick would be of "the last of Gatsby's guests [to leave]" (p. 52); Gatsby "absolutely" (p. 89) needs Nick to join him and Daisy after their reunion, "[his] presence mak[ing] them feel more satisfactorily alone" (p. 94). There are glimpses of Nick's own life, but the detail of the diegesis is only present when it comes to involvement in *others'* lives. Nick is "within and without, simultaneously enchanted and repelled by the inexhaustible variety of life" (Fitzgerald, 1925/2004, p. 35). Occasionally this makes him "uneasy, as though the whole evening had been a trick of some sort to exact a

contributory emotion from [Nick]” (Fitzgerald, 1925/2004, p. 17). Though Nick labels these occasions “casual events in a crowded summer [which] absorbed [him] infinitely less than [his] personal affairs” (Fitzgerald, 1925/2004, p. 56), he dedicates the vast majority of the novel to their exposition. Though the novel is only nine chapters long, chapter IV includes three pages simply listing the “names of those who came to Gatsby’s house that summer [...] who accepted Gatsby’s hospitality and paid him the subtle tribute of knowing nothing whatever about him” (p. 61), then plays out an entire day where Nick first hears Gatsby’s false past, then meets Gatsby’s current shady business partner, then sits down with Jordan to hear Daisy and Gatsby’s shared truth and proposed future. With so many *thens*, it is apparent that when Nick is not acting simply as a catalyst, he is a calorimeter, precisely measuring the energy change or transfer as a product of specific substances in specific contexts, the meter who can track and calculate difference, see that a person “had changed since his New Haven years” (Fitzgerald, 1925/2004, p. 7), or spot that a “personality had also undergone a change” (p. 30); it is Nick who marvels at how “groups change more swiftly, swell with new arrivals, dissolve and form in the same breath” (p. 40), watches scenes reinvented “before [his] eyes into something significant, elemental and profound” (p. 47); it is Nick who notices “a change in Gatsby that was simply confounding” (p. 89), who tracks when people have “passed visibly through two states and [are] entering upon a third” (p. 91), and marks “the hour of a profound human change” (p. 95). Nick sees.

The first four chapters of the novel is the left side of a chemical reaction, Nick assembling the reactants and asserting his position as catalyst; the last four chapters of the novel are the right side of the chemical reaction, Nick demonstrating just how exothermic this reaction is by examining its products. The centre chapter (V) provides the effective collision that makes

the reaction possible, a collision that does not occur in Daisy's or Gatsby's houses, but in Nick's. Though Gatsby helps set up the house and yard, he cannot be waiting inside for Daisy's arrival. Instead, he arrives *as* she does, moments after she does through the *same* door she uses, welcomed by Nick *as* Daisy is. Nick is crucial to positioning the molecules in question such that the bonds can be broken and formed as needed. But simply introducing them to one another is not enough to generate reaction. When Nick makes an excuse to leave them in the room alone, Gatsby tries to leave with him. Indeed, it is Nick that gets Gatsby back into the room with the realisation that Daisy feels *as he does*, that they are properly positioned. Indeed, if activation energy must be supplied externally, in this case it takes the form of light, illumination of the truth of Gatsby's behaviour: Nick tells Gatsby that he is "acting like a little boy [...] rude [leaving] Daisy sitting in there all alone" (Fitzgerald, 1925/2004, p. 88) and provides the compulsion, the spark needed to start the combustion process, to ignite the reaction. This divides the bond between Tom and Daisy and reunites the latter with Gatsby: Daisy-Gatsby exists anew. The rainy weather turns to sunshine and there is "a change in Gatsby that was simply confounding [...] he literally glowed [...] a new well-being radiated from him and filled the little room" (Fitzgerald, 1925/2004, p. 89). Post-reaction, Nick is no longer necessary as catalyst, being "forgotten" (Fitzgerald, 1925/2004, p. 96) by the reactants; they acknowledge him only "remotely, possessed by [their own] intense life" (p. 96).

Nick spends the remainder of the novel fixed in his calorimeter role, taking stock of the enthalpy of formation, tracking the energy that has been generated in the product of this reaction. For it is indeed exothermic, first evidenced by the sunshine that emerges in its immediate wake and culminating in the broiling heat the day Myrtle dies. Nick-the-calorimeter examines the

thermal stability of the compounds to resist decomposition in the face of heat, and reveals that Gatsby's lies are unstable compounds, "founded securely on a fairy's wing" (Fitzgerald, 1925/2004, p. 99). It seems that Gatsby could have hailed from old money, but his inheritance was interrupted by corruption, so corruption was what he inherited instead: unstable compound indeed. Pre-reaction, Gatsby exists in a state of growth, of expansion; post-reaction, the new Gatsby compound is vulnerable to decomposition in the face of heat. Nick watches Tom and some old money friends arrive and further decompose Gatsby's persona, the "cool nod" (Fitzgerald, 1925/2004, p. 103) belongs to everyone who is not Gatsby. When Daisy and Tom attend the latest of Gatsby's parties, Daisy is not simply disenchanted by Gatsby's wealth, but is "offended [...] appalled by its raw vigor [...] and by the too obtrusive fate that herded its inhabitants along a short-cut from nothing to nothing. She saw something awful" (Fitzgerald, 1925/2004, p. 107) and not because she understands it, but because Nick understands her in this world, and therefore the reader can see her susceptibility to being used as a reactant for a new bond opportunity. Gatsby doesn't yet see this, nor does Daisy tell him. Instead, Gatsby wants to "repeat the past" (Fitzgerald, 1925/2004, p. 110) for his mind to "romp again like the mind of God" (p. 110), not realising that this relationship is a new reaction with new reactants, in a new context, demanding a new catalyst, and generating new products. Nick, however, sees the compounds for what they are: Gatsby's thermal stability post-reaction is so low that his desires are futile, he will be unable to resist decomposition. Daisy, meanwhile, will rebond with Tom to maintain her thermal stability as Old Money. Daisy-Tom will survive this novel, but Gatsby's greatness will not survive beyond Nick, beyond the story he keeps bound here.

Once an exothermic reaction begins, it often continues until it exhausts the reactant molecules (or fuel). Chapter VII tracks the culmination of this reaction, closing with Gatsby “watching over nothing” as Daisy has returned to her marriage. The chapter is intended to be the confrontation that will anchor their bond, but the contextual thermal energy is so incredible, there is no energy left to maintain the intermolecular bonds. Indeed, the world at the beginning of the chapter seems to be “simmering [...] hover[ing] on the edge of combustion” (Fitzgerald, 1925/2004, p. 114), “too hot to touch” (p. 115), “too hot to fuss” (p. 119). Daisy tells Gatsby that “[he] look[s] so cool” (p. 119), recalling a cool autumn night five years ago, when they had first joined (p. 110); here they are products of a reaction that excludes Tom, who cannot find the fuel necessary to bond Daisy to himself, so Daisy-Gatsby takes Tom’s car into town. Tom stops for literal fuel at Wilson’s garage and finds figurative fuel in Wilson’s suggestion that he and Myrtle are leaving town. The chance that could lose both of the women in his life is enough to push Tom to secure the most important woman, Daisy. Tom always exists in a state of complete activation energy, ready to snap and explode given enough fuel in the room. Now that he is refuelled, he, Nick, and Jordan join the other two in NYC, primed to reposition Gatsby and Daisy’s relationship as reactants in a secondary reaction, one of his own design, one which will consume and exhaust Gatsby. Daisy confesses that she hasn’t erased Tom or their past; Tom confirms that “there’re things between Daisy and [him] that [Gatsby]’ll never know, things that neither of [them] can ever forget” (Fitzgerald, 1925/2004, p. 132); and “the words seem to bite physically into Gatsby” (p. 132), to decompose his cool and allow “panic” (p. 133) into his being, so that Nick can see he is defeated, “snapped out, made accidental, isolated, like ghosts” (p. 135). This new reaction is endothermic, consuming the thermal energy of the day and the kinetic energy of



the car as Myrtle dies, and using it to break the bond energy as Daisy-Gatsby is separated and Daisy-Tom returns to existence, “an unmistakable air of natural intimacy about the picture” (Fitzgerald, 1925/2004, p. 145) of Daisy-Tom. “[Daisy] vanished into her rich house, into her rich, full life, leaving Gatsby—nothing” (Fitzgerald, 1925/2004, p. 149). And Tom, for his part in the Daisy-Tom compound makes this figurative nothingness literal in setting Wilson on Gatsby and securing Gatsby’s complete decomposition, “the holocaust complete” (Fitzgerald, 1925/2004, p. 162). At Gatsby’s funeral, only three men stand in attendance: his father Henry C. Gatz attends to mourn the child that was James Gatz; Owl Eyes attends to mourn the fallen charade that was Jay Gatsby; Nick attends to complete his calorimetry, “compelled into an aesthetic contemplation [that humans] neither understood nor desired, face to face for the last time in history with something commensurate to his capacity for wonder” (Fitzgerald, 1925/2004, p. 180).

#### ***4E: Pedagogical Extractions.***

Though I have always used relationship and dynamic and threshold words cross-curricularly, this was the first time that I had the explanation above in my back pocket as I was doing so. Seeing *Gatsby* as a manifestation of catalysts and calorimetry and enthalpy provided me with a network for those words that anchored my own understanding more firmly, and therefore made it more readily available in situ.

Often, I start the study of the novel with a close reading of the contextual clues of chapters one and two. My thinking is that though Nick sees Gatsby reaching out toward the bay at the end of chapter one, Nick does not truly meet him until the third chapter of the novel. These first two chapters are therefore about the context in which these characters exist, about

understanding how primed the circumstances are for the greatness the reader has been promised. Students, therefore, examine the elegance of the first chapter that precedes the ashes of the second. From this, they develop an aphorism, an epigram, a truth from which they will build their thesis for the essay that will culminate our study. As we read the novel, they craft a robust foundation and collect evidence for it with every turn of the page. This year, my 30-1 class struggled with this first step in ways that they should not... for a graduating class of students finishing their English Literature education, even if this was the first month of this course. I have always wondered if this is because they were not taught the craft of thesis writing before sitting in my classroom, or simply that the lesson they did learn did not find purchase in any permanent way. I suspect the latter is more likely the case, seeing as some of these students I have had the pleasure of teaching before; there is not a world where I would not have covered that *every time I teach*. So, if I presuppose the fact we are all teaching thesis-writing at every level in high school English, how are those lessons only being learned for a portion of time and never to long-lasting effect?

My answer seemed to come this year.

As the students work through these first steps, I move around the classroom assessing their efforts, offering everyone the chance to get an *Excellent* on our essay scale (Figure 9). If

	THOUGHT AND UNDERSTANDING	SUPPORTING EVIDENCE	FORM AND STRUCTURE
<b>FOCUS</b>	When marking <b>Thought and Understanding</b> , the marker should consider <ul style="list-style-type: none"> <li>• how effectively the <b>student's ideas</b> relate to the assignment</li> <li>• the quality of the <b>literary interpretations</b> to show <b>understanding</b> of the text relative to the topic</li> </ul>	When marking <b>Supporting Evidence</b> , the marker should consider <ul style="list-style-type: none"> <li>• the <b>selection</b> and <b>quality</b> of evidence</li> <li>• how well the supporting evidence is <b>employed, developed, and synthesized</b> to support the student's ideas</li> </ul>	When marking <b>Form and Structure</b> , the marker should consider <ul style="list-style-type: none"> <li>• the manner in which the student <b>focuses, arranges, and shapes</b> the discussion in response to the assignment</li> <li>• how well a <b>unifying effect</b> or a <b>controlling idea</b> is developed and maintained</li> </ul>
	<b>Consider ideas presented in the <i>Personal Reflection on Choice of Literary Text(s)</i>.</b>		
<b>Excellent</b> <b>E</b>	Ideas are insightful and carefully considered, demonstrating a comprehension of subtle distinctions in the literary text(s) and the topic. Literary interpretations are perceptive and illuminating.	Support is precise, and astutely chosen to reinforce the student's ideas in a convincing way. A valid connection to the student's ideas is efficiently maintained.	A judicious arrangement of ideas and details contributes to a fluent discussion that is developed skillfully. The unifying effect or controlling idea is effectively presented and integrated.
<b>Proficient</b> <b>Pf</b>	Ideas are thoughtful and considered, demonstrating a competent comprehension of the literary text(s) and the topic. Literary interpretations are revealing and sensible.	Support is specific, and well chosen to reinforce the student's ideas in a persuasive way. A sound connection to the student's ideas is capably maintained.	A purposeful arrangement of ideas and details contributes to a controlled discussion that is developed capably. The unifying effect or controlling idea is coherently presented and sustained.
<b>Satisfactory</b> <b>S</b>	Ideas are relevant and straightforward, demonstrating a generalized comprehension of the literary text(s) and the topic. Literary interpretations are general but plausible.	Support is general, adequate, and appropriately chosen to reinforce the student's ideas in an acceptable way but occasionally may lack persuasiveness. A reasonable connection to the student's ideas is suitably maintained.	A straightforward arrangement of ideas and details provides direction for the discussion that is developed appropriately. The unifying effect or controlling idea is generally presented and maintained; however, coherence may falter.
<b>Limited</b> <b>L</b>	Ideas are superficial or oversimplified, demonstrating a weak comprehension of the literary text(s) and the topic. Literary interpretations are incomplete and/or literal.	Support is inadequate, inaccurate, largely a restatement of what was read, and/or inappropriately chosen in relation to the student's ideas and thus lacks persuasiveness. A weak connection to the student's ideas is maintained.	A discernible but ineffectual arrangement of ideas and details provides some direction for the discussion that is underdeveloped. A unifying effect or controlling idea is inconsistently maintained.
<b>Poor</b> <b>P</b>	Ideas are largely absent or irrelevant, and/or do not develop the topic. Little comprehension of the literary text(s) is demonstrated.	Support is irrelevant, overgeneralized, lacks validity, and/or is absent. Little or no connection to the student's ideas is evident.	A haphazard arrangement of ideas and details provides little or no direction for the discussion, and development is lacking or obscure. A unifying effect or controlling idea is absent.

Figure 9. *English Language Arts 30-1 Critical / Analytical Response to Literary Texts Assignment Scoring Criteria*. This figure shows the first three categories/criteria used to score this essay on the Diploma Examination. There are two other categories for writing skills, but they are not relevant to the discussion here.

they have not achieved enough insight, or calibrated the layers precisely, or opened the door to revealing interpretations, I provide feedback and return the work to them for further tinkering. If they have, we enjoy a shared high five and me saying something to the effects of “that will make for a fascinating essay.” My goal with a lesson like this is that every year, all 35–40 brains have the healthy starting point they need to make the next steps land securely and confidently.

This is one of the most difficult lessons for me to navigate, so diverse are the demands of my students at this point. I often find myself juggling dozens of distinct sets of needs and degrees

of understanding, carefully calibrating feedback to aim students toward their next successful efforts. In moments when I realise trends in these needs and understandings, I draw the class' attention back together, where I offer an impromptu clarifying lesson; then we return to the assessment dance. Back and forth, we move and shift and adjust, until the 80 minute block and all I have inside of me are spent.

Gatsby's world comprises a fractured reality: the poor live in the ash heaps while the rich (new or otherwise) live in elegance. This year, as I tend to, I started to speak in terms of analogy with a math equation. Id est, if all the aphorism achieves is *Elegance + Ashes = New York*, they can look forward to a *Limited* on the essay scale (Figure 9), for that is an equation that is not particular to F. Scott Fitzgerald's *The Great Gatsby*; it could work for any novel set in New York and dealing with class-distinction. If students create a specific relationship between these elements, they climb the scale in *Thought and Understanding*. Perhaps they write that *Ashes* and *Elegance* each have their own relationship with this New York, and they sneak into *Satisfactory*. Layering the thesis to illuminate subtle distinctions is ultimately our goal. Students often tell me they feel as though they are grasping at straws. One told me he felt he was 'bullshitting' some kind of saying that belongs on a poster beside a kitten hanging from a tree. These students do not feel as if they are getting closer to understanding the human condition. These students believe they are jumping through an arbitrary hoop that only English teachers and people who read poetry in bubble baths can understand.

This year, for the first time, I spoke about the equation in terms of enthalpy, which meant that each side of the equation was beholden to certain natural rules. This single adjustment moved our conversation from the ephemeral and ethereal to the enduring and empirical. For

these 30-1 students, science gave my lesson *street-cred*. Nothing about *The Great Gatsby* changed, but the way my students considered it sure did. The change was actually palpable in the room: students seemed to sit a little taller, stare at their pages a little longer before calling me over. At first, it got quiet, and then students started to ask about whether they were restricted to Chemistry if they saw another subject's relationship would work better. I gave them my best, "what do you think?" rhetorical gaze and received enough smiles paired with variations of "I think I get it" to make me feel like this had been a raging success.

With the foundation built, when (in a later lesson) I gave them a Diploma style topic and asked them to weave the two together, students readily secured *Excellent*. After a couple of other chapters, when I asked them to write me an explanation of how their thesis was *evolving* through the text, students were primed for moving into a lesson on *Form And Structure*. One student saw *The Great Gatsby* as a solar system, with each character a planet or satellite fixed in orbit relative to the others. She was able to talk about the tensions as a kind of gravitational pull, an unavoidable compulsion within the novel. As she explained her logic to me, I took notes. When she was finished, I showed her my notes: "you started here, and then you talked about this and then this and this," pointing at each of the points *she* had made. It looks like you have a seven-body paragraph essay, one for each planet as you approach the sun, finishing with the supernova. She then asked when she could talk about the solar system concept, so we talked about how integral that concept was to her thesis until she realised that she should explain it when she explained her thesis, in the intro. Best yet, she realised she had already written that, pointing at the evolution explanation the students had written earlier that day. Perfect.

It took me a few days to work in enough time to sit down with each student and take them through this same process. While I was busy working one-on-one, the rest of the class was reading and finding specific evidence that worked with the scaffolding that was taking shape. This meant that the first students I spoke with had a firmer grasp of their Form and Structure *before* looking for evidence, and the later students who sat with me used more evidence to explain their evolution. I am not sure either was superior, as I still stripped the evidence in my note-taking before providing each student with their explanation. Often one-on-one conferences are avoided because teachers worry what the rest of the class is doing while those are taking place. In this case, the accountability was built into the task I had left for everyone, especially seeing as I told the class that everyone could bring in all of this foundational work when it came time to put pen to paper on the essay writing day. Each student handed their work in to me the class before that day, and I rearranged the foundation in the steps they had experienced, hoping the lessons would all build to their essay. The next day, I distributed these packages beside Chromebooks logged into a secure essay writing portal. It was silent in that room for both days of writing, and not because they were scared, but because they knew exactly where they needed to stand and see this novel.

These were some of the best *Gatsby* essays I have ever marked, and they were each unique to the reader who penned them. Best yet, my time was not spent covering the essays in comments. Those had already been provided to students back when they had opportunity to respond to the feedback, back when they were *crafting* arguments. When it came time to evaluating, I was able to flag and highlight simply, finding the score that best suited the student response. I easily cut my marking time in half, a significant boon to an English teacher. And

when I returned the essays, students were certainly able to understand their grades and how they could move forward. No one complained that feedback was lacking or that mystery shrouded their achievement.

## Physics Case Studies

### Experiment 5 — Physics 20: Oscillatory Motion & Mechanical Waves.

#### *5A: Goals from the Alberta Education Program of Studies.*

“Students will: (1) describe the conditions that produce oscillatory motion [and] (2) describe the properties of mechanical waves and explain how mechanical waves transmit energy” (Alberta Education, 2014c, p. 33).

#### *5B: Science Baseline — Oscillatory Motion, Mechanical Waves.*

A motion that repeats at regular intervals — a flying bee or a bouncing ball or a vibrating guitar-string — is *oscillatory motion*. Each complete interval is called a *cycle*; the time for the cycle to occur is called the *period*. Inverting the *period* reveals the *frequency* of the motion, a measurement in hertz (Hz), which represents the number of oscillations per second. These oscillations may be revolutions (a car piston) or a vacillations (a clock pendulum); in any case, it is motion where the movement extends as far from the origin as possible and then returns to that origin. In the case of vacillations or back-and-forth motion, the object being tracked stops for a mere moment at its extreme and reverses direction to return to its origin, where it again stops for the slightest of moments to repeat the expression of motion. This distance of travel is called the *amplitude*, and the *simple harmonic motion* (SHM) therein is possible due to *non-zero net force* which demands that the *restoring force* be directly proportional to the *deforming force* (*Hooke's Law*). In clocks, these two types of oscillation (revolving and vacillating) work in tandem, the

latter helping the former to achieve accuracy, a fact that Christiaan Huygens exploited when he introduced the pendulum clock:

Up until [the mid seventeenth century], clocks were very inaccurate. Even the best clocks could be out by as much as 15 minutes a day. They used a series of special gears and weights that didn't always produce a uniform rate of rotation — a necessity for an accurate mechanical clock. Huygens recognised that if he could take advantage of the uniform oscillations of a pendulum, he could produce a much better clock. [...] Pendulum clocks became the standard in time keeping for the next 300 years. (Ackroyd et al., 2009, p. 359)

Any object that can vibrate has a natural frequency of vibration, or its *resonant frequency*. It was this feature that Huygen's tapped into to circumvent friction stopping his pendula from swinging,

design[ing] his clocks so that the pendulum was given a small push at just the right moment in its swing. The timing of these pushes coincided with the resonant frequency of the pendulum. By doing this, Huygens could make the pendulum swing for as long as the periodic force was applied. (Ackroyd et al., 2009, p. 381)

Changing the length of the pendulum changes its resonant frequency and therefore the push must be adjusted. Often, clocks have adjustable weights on their pendula to artificially adjust the resonant frequency to match the unchanging push being provided by the clock mechanism.

Using water as a starting point for wave theory, one can easily picture a wave and its parts. The flat surface of the water is the *equilibrium position*. When a *point source* interrupts that flat surface, the water either rises above this equilibrium position (*crests*) or falls below (*troughs*). Beyond water as a medium for wave forms, crests and troughs simply refers to opposite sides of the equilibrium position. In any case, the greatest displacement from the equilibrium position is the *amplitude* of the wave. A complete interval of crest followed by trough (or the *cycle* of this kind of oscillation) is *wavelength*, symbolized by the Greek letter lambda ( $\lambda$ ); a half-cycle (isolating just the crest or just the trough) is a *pulse*. A series of waves is



a *wave train*, and if they stay consistent throughout their journey they are said to be *in phase*, whereas those that spread out the further they move from the origin are said to be *diverging rays*. In the case of the latter, the amplitude is shared across more space and therefore decreased. In terms of sound, the larger the travel, the quieter the effect. In an ideal, isolated system, one can readily couple this theory with that of oscillatory motion: waves are simple harmonic motion when the wave train remains in phase. As such, the rest of the terminology from SHM can be employed here, with frequency, period, amplitude all having the same meanings. Ultimately, the velocity of a wave is the product of its frequency and wavelength ( $v = f\lambda$ ), the *universal wave equation*.

Moving this waveform logic outside of ideal, isolated systems presents opportunities for interference with barriers or other waves. In the case of a wave encountering an immovable barrier. If a wave train is moving toward a barrier, it is called an *incident wave*, while those moving away are called *reflected waves*. Should a wave encounter a straight barrier, it will be reflected identically, as if there were an imaginary source equidistantly positioned on the other side of that barrier. Should a wave encounter a more complicated barrier, the reflected waves will be affected in equally complicated ways.

When a wave encounters another wave, the pulses interact: they *interfere* with one another, and this *interference* generates a pulse shape different from either of the original pulses. When two crests or two troughs interfere, they generate a *superposition* of displacement that is categorised as *constructive interference*, whereas a crest and trough would generate *destructive interference*. If the amplitudes of the interfering pulses are equal but opposite in magnitude, the sum of their displacements is zero where the pulses disappear at the moment of overlap and then

reappear as they move beyond one another. It is entirely possible that the same waves can interfere in a number of different ways depending on when they interact. If their crests or troughs occur at the same point in the medium, they are *in phase* and therefore generate constructive interference, whereas *out of phase* waves generate destructive interference. Furthermore, depending on the wavelength of each wave train, the interference could be constructive at some points and destructive at others, shifting in and out of phase throughout their interaction. As with SHM, providing interference in phase with the natural resonance of the wave is crucial to adding to its energy and increasing amplitude. Missing this timing and pushing out of phase generates destructive interference that will soon cause the wave to return to equilibrium.

***5C: Literature Baseline — The Accidental Tourist by Anne Tyler.***

*The Accidental Tourist* by Anne Tyler follows a man named Macon Leary as he tries to deal with the grief in his life. Still undone by the tragic death of his son, Macon's wife Sarah decides to leave him in the first chapter of the novel. Macon's ultimate struggle, however, isn't with the things that have happened to him, but in how he learns to process that suffering instead of shutting it out and thereby succumbing to it. Even in the face of incredible potential for suffering and despair, Macon emerges victorious by his own terms. Through external antagonism, Macon comes to appreciate and ultimately attend to his internal antagonism. He begins this journey isolated and unaware of self, but ends the novel in a community wherein he finds self. At the outset of the novel, he expresses obsessive compulsive tendencies and demands systems to organise his life. Though at times he wonders whether "he'd defeated his purpose" (Tyler, 1985/1992, p. 45) or if his systems "might be sort of silly" (p. 46), as far as he could see in life, "everything seemed so complicated" (p. 55) and "he was falling apart; that

much was obvious” (p. 56). His systems are the only simplicity he sees, and the only way through impossible days. These come to such a debilitating head that he actually ends up winded, on his back, in the basement, with a broken leg, his dog Edward sitting on his stomach and the cat Helen stuck in a dryer tube. Helen, represents the static, incapable of change, the antithetical effect of Macon’s systems: “wailing and protesting, she has nonetheless clung to her course. What persistence!” (Tyler, 1985/1992, p. 57). Though she emerges from the dryer debacle unscathed, she catalyzes the beginning of change, at this point where he has gone too far, sunk too low, he is alone; even his systems have failed him. As Helen “scurried past the other window, [Macon] drew a breath and began the *long, hard trip* up the stairs for help” (Tyler, 1985/1992, p. 57, emphasis mine). Tyler then moves Macon through a number of communities, the first of which is his family, helping him convalesce in his childhood home where his siblings now live. This regression exposes the foundation from which Macon hails, the interactions at home that became the interactions he would manifest in life. Just as the broken leg gets Macon into this context, his broken dog pulls him into another. Macon hires a dog-trainer, Muriel Pritchett. Edward misbehaves, biting and growling and barking at his world, embodying all of the anger Macon bottles up and is unable to express. On the surface, our protagonist is just fine and coping well enough with each speed bump the world seems to throw at him, but underneath it all, his identity is fractured and he must resolve that internal conflict. Edward’s therapist, therefore, is truly Macon’s therapist, able to temper and regulate worldly interactions and give Edward and Macon a new frame of reference for the interactions they would manifest in life. Macon and Edward therefore move into a new home, Muriel’s, to learn the new foundation from which they hail. Tyler, however, does not provide a simply linear progression away from pain toward

pleasure. Macon's process of healing needs him to return to previous definitions of home to recognise the importance of his new definition. She therefore moves him in and out of these contexts, using visits to his siblings' home, a flood in his marital home, flashbacks to his childhood, and business travel around the world to complicate his journey and flesh out the new foundation he is building with Muriel. He even returns to a new chapter in his marriage with Sarah, seeming to rebuild their lives anew. But Macon is properly equipped to recognise the absence of colour in life with Sarah and the presence of it in not only Muriel, but his life with her.

***5D: Physics 20 Interrupting The Accidental Tourist.***

Macon's childhood foundation can be viewed in terms of incident and reflected waves. Macon's initial reluctance to interact with complicated barriers is ultimately his refusal to deal with the complicated affection of the reflected waves. Straight barriers and therefore predictable reflection do not demand much calculation. This is the Macon who protects himself against interference by flying with a 1,198 page novel in his carry-on (Tyler, 1985/1992, p. 29), by teaching people to "see as little [of a city as possible]" (p. 33) because "going with the *Accidental Tourist* is like going in a capsule, a cocoon" (p. 251), by sleeping in a "Macon Leary Body Bag" (p. 9) and revelling in being "unconnected" (p. 65). Macon is a dynamic character when he comes to help a taxi driver with parenting (Tyler, 1985/1992, p. 152), or gets Edward to save Alexander from bullies (p. 255), or soothes Mrs. Daniel Bunn in her anxious flying experience (p. 292-296), whenever he welcomes complicated interference. Truly, "some lived careful lives and some lived careless lives, and everything that happened could be explained by the difference between them" (Tyler, 1985/1992, p. 254). This realisation is only possible,

however, because he learns to be in phase with his world, to position himself relative to potential interference such that his crest interferes with the crest of the incoming wave (not its trough), such that the interaction generates a superposition through constructive interference. Macon's fear of interference at the outset of the novel is due to his inability to match pulse shape, seeing only subtraction through destructive interference. For this reason, it is only *after* the party or the outing or the phone call that Macon can reappear as himself; *during* the event, the sum of the displacement is zero, both waves nullified and the interaction seemingly futile.

Though the study of mechanical waves clearly exposes some of the structure of Macon's motivation, I found far more purchase in the study of oscillatory motion, especially in terms of the routine of Macon's life and the disruption provided first by his broken leg and then his broken dog. Macon's existence indeed comprises *motion that repeats at regular intervals*. Sarah invokes this truth as one of the reasons she leaves, citing that "[Macon] just go[es] on [his] same old way like before. [His] little routines and rituals, depressing habits, day after day" (Tyler, 1985/1992, p. 4). Macon's period is the duration of a day, enough time for the cycle to be renewed by the placement of the sun. In this same conversation, she curses his "systems" and promises to leave him their house, recognising his reluctance to change. But Macon's period is also the duration of a trip. What at first seem to be oscillations through his day in a life that revolves, are in fact vacillations across the planet in a job that moves him to and fro: Macon writes travel guides for the reluctant traveller, a job that demands an extension as far from home as possible and then a return to that origin.

Macon hated travel. He careened through foreign territories on a desperate kind of blitz—squincing his eyes shut and holding his breath and hanging on for dear life, he sometimes imagined—and then settled back home with a sigh of relief to produce his

chunky, passport-sized paperbacks. *Accidental Tourist in France. Accidental Tourist in Germany. In. Belgium.* (Tyler, 1985/1992, p. 10)

Macon stops for a mere moment at an extreme distance from home, then reverses direction to return to his origin, where he again stops for the slightest of moments to repeat the expression of motion. This is not life; it is mechanics. Planes vacillate Macon all over his planet, the amplitude determined by a boarding pass, guaranteeing a non-zero net force of a *directly proportional restoring force to undo the damage of the deforming force*. Unlike the theory in the Physics unit, however, the vacillation is not physically identical — he is not always travelling to Germany or always to France — but it is figuratively identical. The individual qualities of these countries do not matter; they may as well be one in the same for the way Macon responds: “organizing a disorganized country, stripping away the inessential and the second-rate, classifying all that remained” (Tyler, 1985/1992, p. 10). Macon so clearly defines his being in these systems and routines, these repetitions to achieve simple harmonic motion, that he imagines this is enough to fulfil his existence, to encourage a natural frequency of vibration. Macon’s resonant frequency seems to be the “pleasurable hours” (Tyler, 1985/1992, p. 10) he spends rewriting countries, where outside of his own mind, “no one could have guessed how much he was enjoying himself” (p. 10).

In his return to home, Macon should find a return to the self of his origin and therefore safety and security. His home with Sarah does not function that way, however. Macon’s marriage with Sarah falls apart because “they’d seemed more like rivals [...] Sarah, haphazard, mercurial [...] Macon, methodical and steady” (Tyler, 1985/1992, p. 15). To reach Sarah, he must still extend himself in extreme ways, as must Sarah to reach Macon. This function of opposite

momentum is enough to act like the friction that slows and eventually stops a vacillating pendulum from completing its cycles. Sarah and Macon pull at one another without fail. Their early marriage represented a stage of “things they had learned to ignore in one another” (Tyler, 1985/1992, p. 15), things that resurface with the birth of their son and resonate in the empty chamber of their house when Ethan dies and then even louder when Sarah leaves Macon and he “[begins] to view Sarah as a form of enemy” (p. 66). Macon craves connection in lieu of opposition, confirmation that he is not alone, that others are struggling: a light on in the middle of the night at a neighbouring house (Tyler, 1985/1992, p. 18), “a cat to sleep on your bed at night, or a dog [...] to act pleased when you come in” (p. 155). Touching Muriel’s caesarian section scar tells him “we’re all scarred [...] you’re not the only one” (Tyler, 1985/1992, p. 199). In his return to his childhood home, Macon hopes to find connection, but discovers only reflection, identical pendula. Likewise, his broken leg allows him to simply “settle down safe among the people he’d started out with” (Tyler, 1985/1992, p. 61), feeding a craving he has to be “sealed away from himself” (p. 58). In his attempts to rekindle his marriage with Sarah, he does likewise, recognising “his oldest friend [...] embedded in his life” (Tyler, 1985/1992, p. 132), “the best of all of us” (p. 146), “the centre of [Macon’s] life” (p. 146), thinking that she is his constant. But, she is not the Sarah he married. She has lost the haphazard and the mercurial from her life and found herself giving into Macon’s pull, becoming methodical and steady like him, “something like accidentally glimpsing his own reflection in a mirror” (Tyler, 1985/1992, p. 129). While Sarah used to be a force to pull Macon away from his point of origin, she now simply mimics his reversed direction—“retreating [...] withdrawing [...] shrinking [...] turning into a Leary” (Tyler, 1985/1992, p. 138-139)—yet another redundant pendulum in his life. Sarah

classifies Macon as “ossified [...] encased [...] something in a capsule [...] a dried up kernel of a man that nothing really penetrates” (Tyler, 1985/1992, p. 140), and as she leaves him again, he now recognises that “inside [...] he was crumbling” (p. 142), and desperately wants “someone to help him” (p. 142), not simply echo what he is. During Macon’s panic attack at the restaurant in New York, Macon’s calls people in Baltimore to anchor him; Sarah and the other Learys cannot save him from this incredible amplitude, stopping the movement’s extension so it can return to its origin. Muriel can, however, redefining his fear as bravery (Tyler, 1985/1992. p. 162-163), and thereafter helping him see pride and amazement in the mundane. Muriel thinks as a Martian would (Tyler, 1985/1992, p. 177), finds opportunity for strength even on her back beneath a growling dog (p. 112), “could raise her chin sometimes and pierce his mind like a blade” (p. 209). With Muriel in his life, Macon feels “more [him]self than [he has] been [his] whole life” (Tyler, 1985/1992, p. 247). Macon, it turns out, does not need a contrary force to initiate the return to origin; that has always been in his nature. Instead, the system of his clock and pendulum needs “a small push at just the right moment in its swing” (Ackroyd et al., 2009, p. 381). Muriel’s pushes perfectly coincide with Macon’s natural frequency of vibration, and his purpose continues to swing as long as this periodic force is applied. It is for this reason that he chooses Muriel in the end. Certainly, he returns to his life with Sarah, but this vacillation exists only to remind Macon how an echo does not push him: he hears his words come out of Sarah’s mouth, and watches them fall flat, witnesses their not matching his true resonant frequency. Finally, he realises agency in committing an act “of his own accord” (Tyler, 1985/1992, p. 349), to anchor Macon’s belief “that people could, in fact, be used up—could use each other up, could be of no further help to each other and maybe even do harm to each other. [...] that who you are



when you're with somebody may matter more than whether you love her" (p. 315), because with Muriel, his *simple harmonic motion* remains *in phase* and Macon is a well-calibrated clock who knows that "the real adventure [...] is the flow of time" (p. 352).

### ***5E: Pedagogical Extractions.***

Teaching *The Accidental Tourist* to my 20AP class a couple of years ago provided me with one of the most vivid successes with using science to interrupt the study of literature. Students seem to really struggle with the ending, frustrated that Macon would choose Muriel, all sharp angles and aggressive colours and refusal to be anything but herself, in lieu of Sarah, with her curls and flowers and willingness to fit back into Macon's life and ultimately bury the hatchet of their broken marriage. During a work-period where students were designing their essay approaches, I remember a discussion with a student who insisted Sarah *complemented* Macon far better than Muriel ever could. I drew two diagrams on the board, (reproduced in Figure 10). The

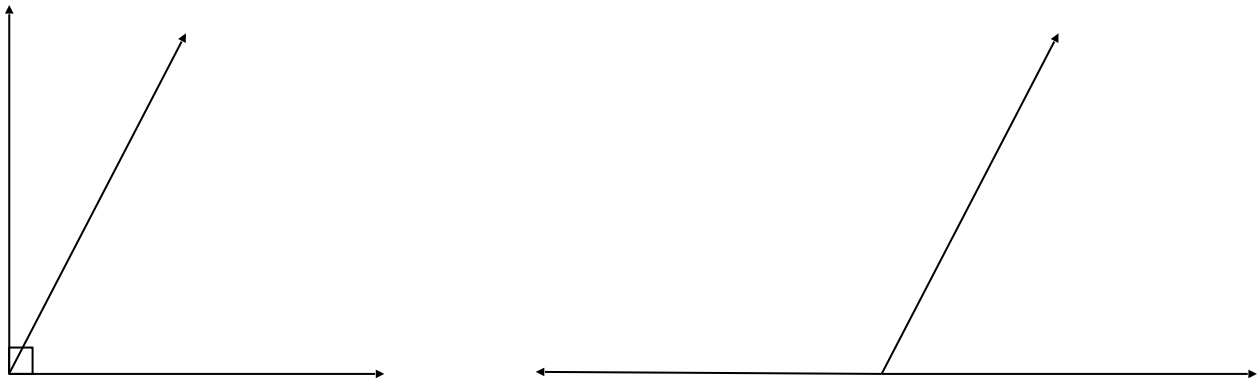


Figure 10. *Reproduction of the angle diagrams I drew on my whiteboard.* Macon + Muriel are represented on the left, while Macon + Sarah are on the right.

first was two angles that comprised  $90^\circ$  and two angles that comprised  $180^\circ$ . The left-most angle in each was identical; I labelled these "Macon." Then I asked, "Are you sure she complements him perfectly?" The student marvelled, realising that Sarah is too much for Macon: it has to be

Muriel, finally appreciating that everyone thinks Muriel isn't enough, but she is. Sarah, the student could now see, had *supplemented* Macon, not *complemented* him: she flattened him out and left him lifeless. Muriel's sharp angles offered a partial completion while still leaving space for life: their life, together.

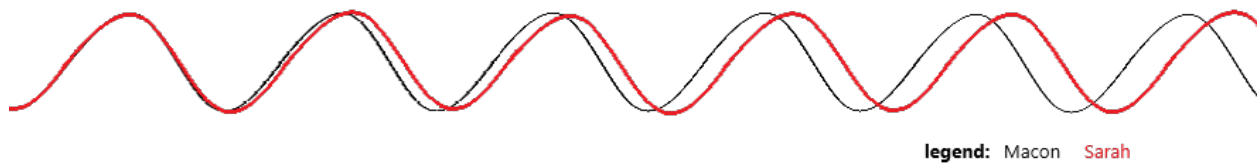


Figure 11. *Reproduction of the waveform diagram I drew on my whiteboard.* Macon and Sarah are labelled appropriately, showing the increased distance between them as time passes.

I then drew a second diagram on the board (reproduced in Figure 11), involving two waveforms, which I labelled Macon and Sarah. Sarah's and Macon's waves seemed to begin similarly: at the outset of their marriage they matched fairly closely, but because their periods were subtly different, the difference became more pronounced over time, drifting further away from one another as time passed. I excused my art and asked them to imagine more repetitions and subtle changes. I asked them to appreciate that, eventually, those periods would again realign, only to drift away anew. A student exclaimed that Macon is screwed if he stays with Sarah. "Exactly," I said, and pointed at the student. "Now draw me Muriel's wave."

At this point, there were a handful of kids who had wandered over to our discussion, eavesdropping and weighing in in small ways. I upped the ante and invited them to grab some board space with the first kid and argue it out. Then I got out of their way. "Tell me when you've cracked the case," I called, as I took a spot in a desk at the back of the room. For ten or fifteen minutes they argued and discussed and built together. I watched a number of perfectly *Proficient* concepts appear and disappear on the board, before finally they settled on the coolest one as the

one ready for my return. One of the students was a music kid, wave theory was sound and therefore opened us up to some layers with harmony. The students had decided that Muriel, seeing as she is extreme and indeed more aggressive in her journey through life had a greater amplitude, but her period was still matched to Macon's. In the reproduction provided in Figure 12, it is apparent that, despite their differences, at regular intervals they will always overlap perfectly, creating harmony, a chord of notes that function perfectly together. By this point, the rest of the class was focused on the wave conversation with us, and when I asked why it could never be Sarah, they decided that it was never about amplitude, only period, that society only notices amplitude.

Yup.

There it is: *Excellent*.

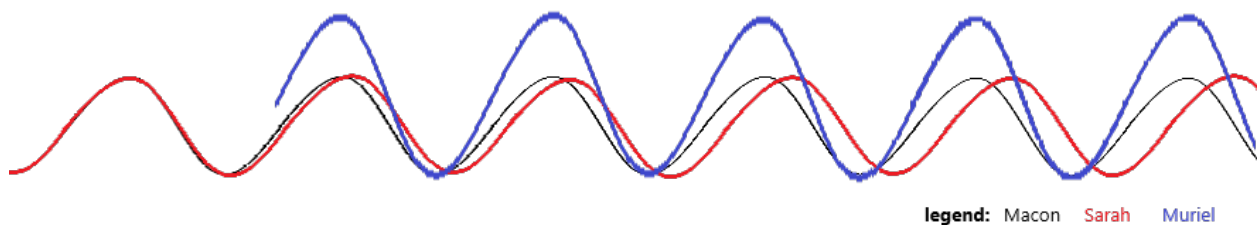


Figure 12. *Reproduction of the waveform diagram students created on our whiteboard.*

Though Sarah matched Macon more closely in the beginning of their relationship, they continue to drift further apart. On the other hand, while Muriel joins Macon's journey later, the regularity of their matching period makes her a far more dependable partner.

These kids wrote some cool essays about *The Accidental Tourist* that year. They did not get bogged down about theses. They did not panic over textual support. They did not worry how to organise their essays. Once the science had granted them access to the machine of author's purpose, they unpacked it readily. It was never an end point, our waveform discussion, only a

framework on which to stand, a vantage point from which the keys could fit into the locks, a pair of glasses that brought *harmony* into focus.

**Experiment 6 — Physics 30: Momentum & Impulse.**

***6A: Goals from the Alberta Education Program of Studies.***

“Students will: (1) explain how momentum is conserved when objects interact in an isolated system” (Alberta Education, 2014c, p. 42).

***6B: Science Baseline — Momentum, Collision.***

Momentum is a product of the *mass* and the *velocity* of an object. Measurement can be either scalar (like *mass*) or vector (like *velocity*); the latter of which occurs when direction is a component of the measurement. Because momentum is calculated using a vector measurement, it retains the direction of that original vector. However, because any real world medium includes friction to slow down moving objects, constant momentum cannot really exist. Instead, what this measurement illuminates is *instantaneous momentum* of an object. Any change in momentum is called *impulse*, a tendency that can be made less severe by increasing the time for the object to suffer that change. In many cases momentum is halted when the object encounters a barrier. By adjusting the surface of impact, one adjusts the time allocated to distribute the force of impact to the object. To minimize the force needed to stop an object, one needs to maximize the time in play. This is the way safety devices in vehicles are designed, such that interaction time is maximized to reduce the average net force. A crumpling front end and collapsing steering column and deflating air bag all work together to provide the car with time to absorb the impact of a crash. They also distribute the force of impact over a greater area to reduce the average net

force at one point on the driver's body. This is the same logic that goes into the design of sports padding and explains why a catcher uses an oversized mitt instead of his bare hand.

*Collision* is the term for the kind of interaction where an impulse is provided to each object. Any time objects interact, they can be said to be in *system* with one another. An *isolated system* exists when mass is constant and there is no external force (like friction) to act on the system. Systems should involve the impulse of external friction in addition to that of the actual collision, but friction needs time to act. Because of the instantaneous nature of collision, the force of friction is negligible in one-dimensional collisions and the momentum is considered constant. In these cases, the momentum that moves between objects is conserved within the system, and therefore the total energy of the system is also conserved. This is also true in a vacuum where the force of friction remains negligible regardless of the duration of impulse. When unilateral collisions distribute the initial kinetic energy form to only kinetic energy after the collision, it is said to be *elastic*. When the initial kinetic energy becomes other energy forms during the collision — like sound or light or heat — it is said to be *inelastic*.

Most collisions in reality occur in three dimensions, but momentum is still conserved even when distributed multi-dimensionally. For the sake of instruction, this unit uses two dimensional collision to build on the understandings of uni-dimensional collision. Identifying the centre of mass exposes the core location at which momentum acts on an object and simplifies the vector being studied. The goal is not to track the translational motion of each piece of what could be a very complicated object, but to track its average, its centre. Interestingly, “depending on the distribution of mass, the centre of mass may be located even *outside* the object” (Ackroyd et al., 2009, p. 492). Again, for the sake of instruction, this unit employs perpendicular interaction so

the velocities can be resolved as x and y components. The components also stick together following collision; therefore their momenta interact to close the triangle, allowing Pythagorean theorem to provide the solution — quarterbacks and linebackers are locked together in a tackle; cars are welded in a crash; two balls of putty become one.<sup>12</sup>

***6C: Literature Baseline — Macbeth by William Shakespeare.***

The play starts with three witches, speaking in riddle and rhyme, and orchestrating something nefarious. This scene is brief, however, and we quickly find ourselves watching the conclusion of a great battle, one in which Macbeth stood out as particularly valiant and noble, protecting the interest of Scotland from the Norwegian invaders. This is particularly impressive considering another nobleman, the Thane of Cawdor had taken the inverse path and was actually helping the invading armies. That nobleman is killed, and Duncan decides to reward Macbeth by giving him the traitor's former title. Elsewhere, Macbeth and his friend Banquo come across some witches who name Macbeth Thane of Glamis (which he is already), Thane of Cawdor (which he does not yet know is his title), and King hereafter (which seems absurdly beyond his grasp). They also name Banquo's descendants as kings. Neither of the men believe the witches, but when Macbeth indeed becomes the Thane of Cawdor, he immediately imagines killing the King to make the third prophecy true. When Duncan names his eldest son, Malcolm next in line to the throne, Macbeth realises a threat to his prophecy, and he and his wife decide to act.

Duncan comes to Macbeth's castle, Inverness to celebrate the recent victory, and Macbeth and Lady Macbeth conspire to kill the King as he sleeps. Macbeth has moments of pause, but Lady

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<sup>12</sup> Presumably, non-perpendicular interaction generate more complicated triangles and necessitate different theorems for the resulting calculations. This unit is clearly about building blocks and has been simplified to show the fundamental relationship in momentum. The inverse is also true, where fireworks explode from stationary positions due West and due South, again providing two of the three sides of the triangle.

Macbeth questions his manhood and shames him into acting courageously and taking what should be his, ultimately killing Duncan and framing the guardsmen sleeping outside his room. The next morning, MacDuff arrives to awaken the king, and finds him dead. Macbeth, under pretence of rage, kills Duncan's guardsmen. Malcolm and his brother Donalbain believe they are next and flee to England and Ireland (respectively). Their running away "puts upon them / Suspicion of the deed" (Shakespeare, 1623/2009, 2.4.26-27), and without an heir in Scotland, also allows Macbeth to take the throne.

Banquo knows the prophecies and is suspicious of Macbeth, but Macbeth knows the prophecies cite Banquo's sons as heirs to the Scottish throne and therefore perceives a threat in Banquo and his son, Fleance. The new king hires murderers to eliminate the threat, but they are only able to kill Banquo; Fleance lives, as does the final prophecy. At the next feast, Macbeth sees Banquo's ghost and his behaviour makes everyone else uneasy. Macbeth gets more and more tyrannical, and his subjects more and more worried. Macduff refuses to attend Macbeth's coronation, instead heading to England to support Malcolm. Macbeth perceives this as a great betrayal and heads to find the witches for more information. He receives three riddled apparitions: (1) "beware Macduff, / Beware the Thane of Fife" (Shakespeare, 1623/2009, 4.1.70-71), (2) "none of woman born / Shall harm Macbeth" (Shakespeare, 1623/2009, 4.1.79-80), (3) "Macbeth shall never vanquish'd be until / Great Birnam Wood to high Dunsinane Hill / Shall come against him" ((Shakespeare, 1623/2009, 4.1.91-93). He also receives a fourth vision which confirms the prophecy that Banquo's sons will be the future rulers of Scotland. Believing that the first two prophecies counteract one another and the third is an impossibility, Macbeth leaves the witches feeling confident in his position, but to cement his

security, he sends murderers to kill Macduff's family. Macduff, in England, hears of this ultimate betrayal and vows vengeance.

Meanwhile, Lady Macbeth is sleepwalking and having visions of blood on her hands. Macbeth taunts his men and mocks reports of deserters and of threats. When Lady Macbeth commits suicide, Macbeth hardly feels anything, a vast contrast to the incredibly emotional response Macduff had in learning of the deaths of his loved ones. Malcolm prepares to attack Dunsinane Castle, but devises a plan to hide the size of the army by cutting down and hiding behind the trees of Birnam Wood. When they begin their attack, it indeed appears as if Great Birnam Wood is coming to Dunsinane Hill. Malcolm's forces infiltrate Dunsinane and Macbeth begins killing soldiers, taking out England's best and quoting the second apparition to validate his invincibility. Macduff reveals that he "was from his mother's womb / Untimely ripp'd" (Shakespeare, 1623/2009, 5.8.15-16) and therefore not "one of woman born" (5.8.13). Macbeth falls by Macduff's sword and Malcolm is crowned king.

#### ***6D: Physics 30 Interrupting Macbeth.***

At the outset of *Macbeth*, the diegesis is already founded on the difference between scalar and vector measurements. King Duncan arrives on the battle scene after the vast majority of the action has concluded. The fanfare and attendants indicate the immensity of Duncan's scalar substance, but the trumpet's call to arms is not for the king, but for his soldiers, the masses that move in battle. One such soldier imparts a story of the immense vector that is Macbeth, outlining the direction of his actions as a crucial component of measurement. This is especially true when juxtaposed with the momentum of Cawdor, whose cowardly and traitorous vector Macbeth collapses with his own brave and valorous one, the former helping the invading armies while the



latter protects the interest of Scotland from the Norwegian invaders. At this point, Macbeth's momentum of bravery and valour seems set. But this instantaneous momentum is only set until Macbeth collides with another mass, shifting his vector accordingly. Until this meeting, Macbeth was valiant in the face of cowardice and loyal in the face of treachery: opposition is not enough to shift his momentum. Like any tragic character, his centre of mass is his hamartia, and identifying that as *hubris* exposes the core location the witches must hit to act on this object in motion. The witches, however, understand and exploit his hubris: just a taste of glory is enough to cause shift, because the target at the centre of Macbeth's mass is so exactly struck. He quickly contrives to remove any obstacles that might interfere with this new vector: the king and his sons are cast out of his path. He also binds his vector to that of Lady Macbeth, who shows Macbeth how to think on his newly exposed core. As momentum is a produce of mass and velocity, Lady Macbeth's velocity echoes that of Macbeth's, securing a greater momentum by combining their vectors. However, the shift to this new state is so dramatic that Macbeth questions all of the other pieces that comprise his mass — his valour and honour and decency — which makes them fracture and fall away. Unlike the Macbeth that started the play, with his core so exposed, King Macbeth fears anything with which he interacts, including Banquo and Fleance, Macduff, and his own future. He returns to the witches to again clear his path of collision, but their prophecies merely reinforce his current path.

Macbeth was first knocked off course in his initial collision with the witches. It is therefore only possible to counteract this momentum in collision with a mass moving in vector contrary to theirs. Shakespeare writes this in Macduff, a man who cannot be bated into behaving in any way except his own. His King is murdered and Macduff flies to the aid of the rightful heir;

his wife and babes are murdered and Macduff feels his grief passionately; his country is betrayed and Macduff undoes the betrayal. Because Macduff's centre of mass exists outside of himself — in Malcolm, in his family, in his country — it is not one that can be easily targeted or dodged. Macduff is neither a puppet for the witches, nor a victim for Macbeth. Macbeth might be the quarterback, in prime location to score, but Macduff is the linebacker he cannot predict. Because Macbeth cannot fathom a momentum that derives outside of self, Macduff arrives from a blind spot, adheres to Macbeth's momentum, closing the triangle to return Scotland to its proper course.

***6E: Pedagogical Extractions.***

Students often reduce *Macbeth* to a cautionary tale, that Shakespeare is writing to tell them not to be seduced by delusions of grandeur, but to live honourable and respectable lives, secure in lot and position. This moralistic reduction yields end points, conclusions, bottom lines, but rarely insightful discussions, openings, ambiguities. In some ways, this is fine because I have long suspected that the current *Program of Studies* (Alberta Education, 2003) includes Shakespeare as mandatory for what it offers students in opportunities with language decoding (p. 7). That is, students are meant to unpack context clues in word usage, poetic design, and moments of figurative language, not necessarily overarching themes. Still, if one can decode Shakespeare, one can decode anything. This would also explain why the study of Shakespeare is mandatory only in 20-1 and 30-1 courses, while 10-1, 10-2, 20-2, 30-2 do not need the elevated language game that William Shakespeare's players play. Still, it feels like a missed opportunity, to simply disassemble the machine and stare at its pieces, not to marvel at and understand the relationships and dependencies they build.

This exposes a conundrum that I have often struggled with as an English teacher and as a Department Head of English teachers, a conundrum that manifests in the very front matter of the *English Language Arts Program of Studies* (Alberta Education, 2003), where a kind of line has been drawn between Language and Literature (p. 1), discussing their importance separately and independently. Furthermore, I have always found it curious that *Metacognition* is relegated to the “Importance of Studying Language” section and not the “Importance of Studying Literature” section that precedes it. It seems to me that the writers of this *Program of Studies* (*POS*) are suggesting that *Metacognition*, like *Language*, is a tool that translates to all contexts, a tool that will continue to help its user, whereas *Literature* is only important when one is in high school. I believe that both *Language* and *Literature* are more than simply tools or means to an end; instead, I believe they can become internalized ways of being and thinking and seeing. I am certain these lines would be more effective if they were erased, but perhaps their existence says more about 2003 when the *POS* was last updated.

No. That is not it.

I can pretend the issue exists largely because our *POS* (Alberta Education, 2003) is 16 years old (at the time of this thesis-writing), and is therefore born of an old misunderstanding. But, I cannot convince myself that that is entirely accurate. It seems that people are never truly certain what it is that English teachers are meant to do, or what can happen in English classrooms. Even my own parents — readers and interdisciplinary masters — are often taken aback to hear me speak pedagogically. *Teachers just didn't think this way when I was in school. We didn't have these discussions in our English classrooms. Your students are lucky to have you.* But, it cannot be *that* strange, this teaching of English Literature. I can appreciate that other

subjects are naturally more accessible: the *content* of mathematics and sciences is readily identifiable; those teachers need simply teach the material. The same logic is often imposed on English classes, which leaves students, parents, teachers asking, “Why do students have to learn [insert author’s name]?”

But students are not learning Shakespeare or Tyler or Fitzgerald or Miller or Findley. Students are learning what authors *can do*. And how they can *do it*. And what combination has evoked which response in the reader. The study of *English Language Arts* is the study of the manipulation of ideas and vessels for those ideas, of the ways vantage points shift meaning, of the ways perspective becomes authority. Once again, it is the *Arts* component that gets dissolved. That the dissolution is happening within the English discipline itself is most upsetting. It seems to me that teachers — English and non-English alike — have imposed a pedagogical approach that works in other disciplines in an attempt to legitimize their efforts: a focus on content, not on skill. A line is certainly firmly drawn between *Language* and *Art*: “We’re teaching Shakespeare because the curriculum says we have to, which means students have to learn it.” This causes teachers to administer *Macbeth* unit tests that ask how Macbeth came to be Thane of Cawdor and not how (and why) that choice comes to resonate so ironically with the audience; that ask students to know Duncan and Macbeth are not brothers, but never to unpack the greater obligation of subject, soldier, and host; that ask students to decode “barren sceptre” as an allusion to Macbeth not having heirs to a throne, but not to deal with his ignorance of other legacies he might leave, instead fixated temporally on present security.

I am certainly not suggesting that understanding content is useless. I too administer content assessments in my English course, but they are not significantly weighted into the

students' averages. This demonstrates a divergent assessment model between content-based and skills-based courses. Those scores are there on the report, showing which piece of the foundation had been fulfilled. Yet, I have seen some English teachers who take the content piece and make it the whole, and I have corrected many students, teachers, parents, administrators who mistakenly impose content-based rules on our skills-based paradigm. I tell my students that I do not care if they can remember that it was Lady Macbeth who pretended to faint when King Duncan's murder was revealed. I do, however, care who can *use* that piece of evidence, who can show me that this was one of a series of moments that Lady Macbeth used to show the world she was non-threatening, fulfilling expectation as a weak and therefore insignificant woman, while behind the scenes she plotted and pulled as many strings as the witches, that when she asks to be unsexed, she is speaking to a greater social commentary in Shakespeare's purview. I do not care *if* they can remember, but *how* they can remember, the *Art* in their remembering. That *Art* is a skill that they are learning and we are meant to be teaching. I suspect that *Art* is missing from many English classrooms.

## Chapter Five: Metacognitive Dissonance Fostering Allegoresis Matrix

### Analysis

When I did the giant English Science-Fair project with my 30APs in their *The Wars* study, Biology was by far the most popular choice, with Chemistry coming in second, Physics third, and Math fourth. Biology has always struck me as a sensible place to start these efforts with metacognitive dissonance. Biology is a discipline of systems and interrelationships, much like the study of English Literature. However, the kind of teacher from my anecdote in Biology 30 is firmly stuck in the first half of the metacognitive dissonance matrix I built at the end of my Literature Review. That teacher engages with English Language Arts simply as a lingua franca<sup>13</sup> to access the Biology. As T. Paxson (1996) suggests, the disciplines indeed merely sit near one another, but do not challenge one another and certainly do not modify one another, encapsulating Kuhn and Dean's (2004) "Realist" and "Absolutist" stages where assertions are facts to represent reality. Such interdisciplinarity fulfills Thagard's (2011) notion that binds understanding to surface qualities and appearances. When his students emulate a clearly associated model (Neuenhaus, 2013), they have satisfied the course requirements. That said, I know that his own *Biology Program of Studies* (Alberta Education, 2014a) asks students to consider not only "a knowledge of science," but "its relationship to technologies and society" (p. 1). I suspect, therefore, that there is more interdisciplinarity afoot than he is willing to admit in an offhand

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<sup>13</sup> A language that two parties agree to use when their native languages are significantly diverse.

comment that relegates literature as something lesser and insignificant<sup>14</sup>. Furthermore, Biology's

*Program of Studies* (Alberta Education, 2014a) goes on to say that

[students] also need to develop the broad-based skills required to identify and analyze problems; to explore and test solution; and to seek, interpret and evaluate information. To ensure relevance to students as well as to societal needs, a science program must present science in a meaningful context — providing opportunities for students to explore the process of science, its applications and implications, and to examine related technological problems and issues. By doing so, students become aware of the role of science in responding to social and cultural change and in meeting needs for a sustainable environment, economy and society. (p. 1)

This directive appears in the front matter for each of the Science Programs of Study (2014a, 2014b, 2014c). This is promising, as it certainly moves not only beyond the first level, but has great potential to move well past the second level, where the disciplines engage one another without growth in theory or subject (T. Paxson, 1996). It also circumvents Kuhn and Dean's (2004) recognizing the absence of deep-processing of an opponent's arguments. "Meeting the needs for a sustainable environment, economy, and society" (Alberta Education, 2014a) is hardly possible when the only goal of interaction is to be the owner of the prevailing argument (Kuhn and Dean, 2004, p. 270).

Still, I worry that Science teachers fall victim to the same plight as English teachers, and become stuck at the second level, one which comes naturally to adolescents anyway. Why fight it? Science and Math and Social and English teachers alike are seduced by the clarity of discourse that is possible because of the target and base are easily recognizable as similar, consonance in lieu of dissonance. This yields students who are comfortable only "executing

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<sup>14</sup> I also suspect that a comment like his is more about social posturing than it is about actual beliefs. I have found myself occasionally compelled to do likewise, insisting that my subject is the most important: instead of fostering a balanced respect for all, we are each desperately trying to carve out a space where our own subjects can be given undivided attention. I do not have judgment for these compulsions, but it does behove us to attend to them.

strategies under structured conditions” (Neuenhaus et al., 2013, p. 219). Everything about these first two levels speaks to an easy day for both teacher and student: the teacher nurtures learning via “telling, delivering, and directing, and being a sage on the stage” (Klein, 2005, p. 10), asking students to find associational similarities, routed in task and procedural knowledge (Neuenhaus et al., 2013, p. 215); the student attains processes that are autonomous, default, habitual, and fast (Thompson & Johnson, 2014, p. 215-216).

What then of critical thinking?

Seeking, interpreting, evaluating information are skills crucial to critical thought, but they do not happen without “a great deal of tending by those wishing to scaffold children’s development [...] especially if it is this progression that provides the necessary foundation for intellectual values” (Kuhn & Dean, 2004, p. 272-273). Accessing the third level allows students to ask meaningful questions about complex issues and problems, to locate multiple sources of knowledge, information, and perspectives (Klein, 2005, p. 10). And, seeing as the Science Programs of Study hope “to ensure relevance to students as well as to societal needs [by situating science] in a meaningful context” (Alberta Education, 2014a/2014b/ 2014c, p. 1), it seems to me interdisciplinarity founded in metacognitive dissonance is exactly what all teachers should have time for, Science and Math and Social and English teachers alike.

From what I have witnessed, our students have proven themselves more ready for this approach than their teachers. All of my students, even the reluctant ones, were certainly capable of the third and fourth levels of interaction. In grade eleven, as they worked with *The Accidental Tourist* and *The Crucible*, students paired cognitive functions to their allegories, achieving metaknowledge, “creativity and innovation, problem solving/critical thinking, and



communication/collaboration” (Mishra & Mehta, 2017, p. 8), allowing the structures of the argument to become the structures for thinking; as each group in each class argued what the lens was exposing, their assertions became judgments that could be evaluated and compared, and thinking was demonstrated “in terms of issues or claims, with facts summoned in their service, rather than the reverse—storing up facts with the idea that some conclusion may emerge from them” (p. 270). Students indeed demonstrated integrative interdisciplinarity by comparing and contrasting concepts to reveal patterns and connections (Klein, 2005, p. 10), allowing illumination because of the dependence of one discipline on principles of the other (T. Paxson, 1996, p. 83). Students were not simply controlling themselves, but regulating themselves: using and adapting strategies flexibly in response to changing contextual demands (Neuenhaus et al., 2013, p. 214). In my grade twelve classes, the two disciplines became “one more comprehensive discipline” (T. Paxson, 1996, p. 83), demonstrated by students’ ability to create an integrative framework and more holistic understanding in their work with *The Wars* and *The Great Gatsby*. Weaving the literary and the real, the imaginary and the symbolic indeed ultimately engenders insightful knowledge into life, including ethical awareness, cultural competence, and conditional knowledge and values (Mishra & Mehta, 2017, p. 8).

### **Recognizing Affect**

Thomas Paxson (1996) makes clear that we should “be more conscious of the various levels of interaction [...] and more intentional in providing students opportunities to explore such levels of interaction” (p. 93). There are certainly places for all kinds of interdisciplinarity. However, our current efforts at interdisciplinarity seem to haunt the first half of my comprehensive matrix, and rarely the second half. Those last two levels are nurtured through

“[teaching] models of mentor, mediator, facilitator, coach, and guide” (Klein, 2005, p. 10), where similarities are cognitivist, based not in task but in “principle [...] attention [...] motivation” (Neuenhaus et al., 2013, p. 215), and founded on processes where students “actively choose and evaluate strategies, consider resources, receive feedback [...] allocate their resources and assess their readiness” (p. 220). These processes are slower because they actively intervene the autonomous, default, habitual processes of lower level interactions; they engage deliberate cognitive processes like probability and logic, hypothetical thinking, and/or conflict resolution (Thompson & Johnson, 2014, p. 216). In this way, teachers can *see* and therefore appreciate the interruptions to doing that affect changes in the student. As James Kelly (1996) suggests,

It is by taking the *affective* very seriously that a new epistemological model can be brought to bear. By understanding the affective in general, and the emotions in particular as analogous to our sensory powers, we obtain a thicker concept of the person by imbuing the person with additional epistemic abilities. (p. 106, emphasis mine)

This “thicker concept” is how students *and* teachers come to understand the learning and not simply stand near it. Without understanding how different analogies function differently, we are unable to match classroom context and student need, specifically selecting and then cultivating cognitive processes to push our students to new ends (Harris & Tolmie, 2011; Lancor, 2014; Tendahl & Gibbs, 2008).

I think about my school, a relatively large high school in a relatively large city, average in its students and teachers and context. We have people who are stuck, and we have people who can hear and see and invite opportunity, and therefore change. Once upon a time, when I was delivering the giant Roots and Affixes posters and making arrangements to print more for those who needed them, one of our Chemistry teachers approached me and asked if they were

mandatory. “I don’t understand your question,” I responded. He explained that it seemed the decoration of his classroom walls were his prerogative, and my foisting these posters on everyone was compromising his autonomy. He wanted to know under whose authority these posters were going up. I let him know that I had the support of administration, but quickly shifted our conversation to help me understand how he felt this was an obstacle and not an opportunity. He returned to the prerogatives and the autonomies, again using words like *decoration* where he might have considered *education*. I quickly recognised the lost cause, told him that I was not trying to take anything from him, and apologized that he felt his world was being threatened by some interdisciplinary tools for his students. He and I have not really had another conversation since. *I do not know how to live in his world.*

Conversely, on a separate occasion, one of our Physics teachers told me that he loves it when I speak science. Some students were presenting their posters as a major project for their AP Capstone Research course, and had invited all of their teachers to join them before the research leg of the journey unfolded. We would again be invited post-research to see how their journey had evolved and what the students had learned; then these students would write their findings into 5000 word AP papers. This Physics teacher and I stood before the same poster and student, a study about sibling relationships mitigating the impact of divorcing parents. I marveled at how the student had chosen a really cool position and vector for his study, and wondered how collisions with unanticipated obstacles would shift his trajectory. There was a pause as the student considered before responding. It was here that my Physics buddy interjected with his comment. We all laughed good-naturedly. Then the student responded flawlessly, my metaphor of vectors and collisions and obstacles not a roadblock, but a way for him to anticipate and

understand obstacles he might encounter elsewhere in his research. Nothing taken; everything gained.

The biggest problem with the goals laid out in the current *Programs of Studies* (Alberta Education, 2003/2014a/2014b/2014c) is not necessarily their wording. The biggest problem that I can see is the way those goals are manifesting in classrooms, where teachers think there is only *more work more work more work* to fit onto an ever-crowded and ever-shrinking plate, a condition that is never a carrot for change to happen. However, nurturing interdisciplinarity through allegoresis-fostering metacognitive dissonance does not demand teachers being experts in every discipline. The “more work” concern becomes a non-issue when we appreciate that our students are the ‘experts’ in the other disciplines: teachers need only provide opportunity for them to *be* interdisciplinary and for them to know what *that* truly means.

Each of these scientific models are systems that mirror a complex literary understanding. I definitely hear and see and invite opportunity there. I know our students do too. I have heard and seen and invited that opportunity with them, to great success. In modelling that success here, my hope is to make the work something that teachers could mimic in their own classroom environments to expose the existence of the allegoresis they endeavor to foster. Peeling back the label of Science or Literature and exposing the dynamics of those inner workings is how we can ask students to better use the ‘space’ in their brains. No longer are there silos and lines of division, but more solid and more dense connections, consonance where once there was dissonance. This opens up the academic discussion insofar as the implications of creating connections in these ways — are those connections longer lasting? When a learner becomes

practiced in allegoresis, how will that skill translate to other circumstances in their complex and connected lives?

## Chapter Six: Conclusions and Future Considerations

I believe this kind of pedagogical shift is the next major adjustment to our classrooms. I understand that this hope demands a significant change of current teachers, teachers born of the system they now foster. I believe, however, that it is certainly not asking too much of students, instead allowing them to see and therefore know themselves in their study. Students are crucial *to* the experience, and not simply sitting *near* the experience. In talking with my colleagues throughout the district, simply because I was excited about what I discovered in crafting this thesis, I was pleasantly surprised to learn that some of them are eager to learn more about this approach. The Assistant Principal (from *The Crucible* case-study) and I will regularly bend one another's ears about what this means intellectually and practically for the evolution of classrooms, excited to do more for students *and* lead more fulfilling professional lives in our schools. A colleague in my department opened this door recently and had students analyzing Alden Nowlen's "The Glass Roses" by way of DNA characteristics. Remembering very little about DNA himself was hardly an obstacle; he simply moderated the discussion, asking the right questions, and priming the conversation where needed. The students' knowledge of DNA was already in their tool-box; David just gave them permission to use it. One student told him she felt like they were getting away with something they should not, like these were two worlds that were not supposed to collide (D. Wasmuth, personal communication, February 27, 2019). An English teacher colleague at another high school in the district informally spoke with some of his students to help them work through some characters in the short stories they were studying. He relayed a tale of their eyes lighting up before one dug into a virus analogy to reveal the interdynamics of character and the other discovered a sine function to deal with the protagonist's

narrative arc. One student told him “he thought he was never allowed to mix the subjects” (R. Piazza, personal communication, December 14, 2018). Clearly, we currently chase cognitive consonance and the inherent comfort therein. We should be chasing this kind of metacognitive dissonance and the collisions and discomfort that evoke new thinking and new connection, that nurture innovation and inspiration. Life is about connection.

Sam Lipsyte, a novelist and short story writer suggests (as cited by DeWitt, 2019) that our connecting skills can become impaired:

[Western] thought is, of course, steeped or even founded in metaphor, but there is also a moment when you kind of see how metaphor can both illuminate and obfuscate, sometimes at the same time. [...] Our problem with metaphors is when they get calcified and we can't conceive of our reality another way because certain constructions hold such enormous sway. (para. 8)

Our current pedagogical models are calcified in much the same way. Our current metaphors just are not enough. In constructing any balanced and effective argument, Aristotle spoke of the three rhetorical appeals available to human kind: *ethos*, *logos*, and *pathos*. *Ethos* suggests the ethical weighing of human nature, an examination of who and what and why in relationship. *Logos* employs logic and reason, irrefutable facts and therefore authority. *Pathos* asks us to examine the evocative nature of a thing, how it resonates inside of our hearts. In our divide and conquer model, we have relegated *ethos* to humanities, *logos* to the sciences, and *pathos* to the arts. Obviously, I would be a proponent of reuniting these three modes of persuasion, but seeing as science and therefore *logos* have been repurposed in this thesis as a lens of interruption for literature, let us look a little closer at *logos*. From the Greek, meaning “word, statement, discourse [and also] computation, account, reason” (“Logos,” n.d.) *logos* seems well suited to this interdisciplinary

metacognitive dissonance discussion. Best yet, it derives from the root “leg [...] to collect, gather [...] to pick out.” Solvitur ambulando indeed. We better get walking if we hope to solve this.

Finally, there is an ultimate notion our Greek ancients contributed to the rhetorical conversation:

*kairos*, which indicates a readiness in circumstance, a time ripe with opportunity. That time, methinks, is now.



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