Teaching Chemistry as a Story: Using Narrative Structure as a Framework for Science Education

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Abstract

For years science curriculum reformers have bemoaned curricula that are "a mile wide and an inch deep." The tendency for high school science to be "[content]-dominate and textbook centered" leads to science courses bloated with facts and equations at the expense of a deep understanding of science as a process and way of knowing about the world. One reason for the excess of content in US national science standards documents is a reliance on identifying the so-called core ideas of science. Core ideas do not provide constraining factors and so the favorite topic of everyone is included leading to the expanding of science content over the last three decades. Selecting and organizing science content based on a narrative framework suggests a way to constrain and organize content in a way that students, already prone to organizing new information in narrative forms, can more easily manage. This article will lay out the basic structure of the narrative framework and apply it to construct a scope and sequence for the first-year secondary chemistry course.

Keywords: Curriculum, Narrative, Chemistry, Standards, NGSS

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Introduction - That which tells a story is core

For years science curriculum reformers have bemoaned curricula that are "a mile wide and an inch deep" (NRC, 2012, p. 25). The tendency for high school science to be "[content]-dominate and textbook centered" (Klassen, 2006, p. 48) leads to science courses bloated with facts and equations at the expense of a deep understanding of science as a process and way of knowing about the world. Teachers tend to rush through to complete a curriculum that has been imposed on them (or sometimes by them) before end of term. *Good* students learn to keep up, plug the right numbers in the right equations, and get good grades. *Bad* ones get pulled under by the content tide and lost in the flood of often only loosely connected science facts.

This approach to science education suffers from two problems. First is the overload of content. The negotiations that lead to curriculum maps and course design produce what Klassen (2006) calls "the overcrowded curriculum syndrome in which the favorite topic of nearly everyone has to be included in the curriculum" (p. 32). The second problem is the lack of a conceptual framework, guiding content selection in a way that helps mitigate problem number one. The most common tool used over the last three decades to select content for standards and curricular documents is some reference to core ideas in science. The approach has lacked sufficient constraining power, causing the mile to grow and the inch to shrink. This paper is an attempt to change the dimensions of learning back toward the deep and narrow by introducing a narrative framework for science education. The narrative framework, with a focus on building a content story rather than labeling content as important or not, offers a more constraining rationale for content selection, thus avoiding the pitfall of content overload.

The use of the term framework here is meant to convey a broad conceptualization of how to select, package, and deliver content. It is an aerial rather than ground-level view, which offers a pedagogical lens to focus decisions about how and what to teach. The narrative aspect of the framework envisions using the typical science course content as a series of events that build a set of stories about the inter-workings of the natural world—stories that extend from the synthesis of elements in the cores of gas giants to the metabolic processes of a single cell. These science stories have common themes and their discoveries have histories that themselves reveal something about the nature of science.

I mean to use narrative framework in two broad ways. One is about teaching science content as a story, the other is teaching science using stories about science. In what follows I will focus more on the former, primarily using the tools of narrative modes of thought to build science curricula that help constrain content overload while providing more meaningful connections between bits of content and between the content and the stories of scientific discovery. By making content selection and delivery leaner and more palatable through narrative thinking—*teaching science as a story*—teachers and students will be afforded more space for *teaching (and learning) science using stories* and, already in a narrative frame of mind, a greater ability to engage with those stories.

To argue for the narrative framework approach to science curriculum design I will first explore both a brief history of the modern standards movement and then key features of recent national science standards documents. National-level science standards documents of the last few decades have moved in the right direction by including key features of the nature, practice, and process of science within the documents. However, these writings have done little to help scale back the amount of content that would provide the time necessary to explore these important dimensions of science education and the stories that model them. Next, I will present a survey of the research related to the various uses of narrative in science education. I will then lay out how to use a narrative framework to construct a standard first year chemistry course. Finally, I will conclude with future work needed to make the narrative framework sturdy enough to support a meaningful approach to science education.

This paper represents the development of an idea which I have partially implemented. It is an attempt to catalogue my thoughts which have become sufficiently developed to share and to elicit contributions from other educators/scholars. Learning and learning to teach are asymptotic goals. A complete, fully-realized pedagogy is of little use to a teacher as it will stagnate thought and creativity. I invite the reader to wrestle with the ideas, expand the narrative connection to teaching, resolve any errors or contradictions, and pose new questions that challenge both teachers and students to think in new ways—not just about what they are learning, but how and why. This kind of reflection and metacognition is an essential ingredient in the transformation of students and teachers into dynamic co-learners.

The Standards Movement in US Science Education

The US standards-based movement in science education began in earnest following the publication of *A Nation at Risk* in 1983 (Ames, 2014; Lawrence, 2011). The standards-based era (which continues to the present) has produced two national science standards documents; both have identified that science courses seem to be over-stuffed with content, yet neither suggests a remedy. A brief examination of these documents and their construction is warranted to understand the genesis of the “mile wide and inch deep” problem and why education reform has yet to get a handle on it.

The standards-based reform era hit its first peak within the sciences in the mid-nineties with the release of the *National Science Education Standards* (NSES) (NRC, 1996). Taking a cue from Rutherford and Ahlgren’s 1989 book *Science for All Americans*, The NSES pronounced scientific literacy to be the primary goal of good science education, emphasizing inquiry as the method to achieve that goal. Unlike later documents, the NSES seemingly does not distinguish between content knowledge (the facts and ideas of science) and science process (including history and nature of science), lumping both together under the heading of “Science Content Knowledge.” Within that heading, however, are eight categories which make the content-process distinction: four describing science content broken down by discipline[1], and four relating to science as a process. The chemistry content standards are embedded in the physical science standards. Of the six physical science standards three appear to be chemistry standards as it is generally taught, two overlap chemistry and physics, and one appears to belong primarily to physics. The six broad standards are each subdivided into four to six subtopics, producing twenty-eight distinct physical science content objectives. In addition to the content standards, the NSES recommends teachers of all sciences communicate unifying concepts and processes in science, science as inquiry, science in personal and social perspective, and history and nature of science. Within each of these categories are additional standards (also broken into subtopics), that when combined with the twenty-eight content standards described above, constitute the recommended physical science education every high school student should receive.

Effectively teaching the content according to the NSES means teachers must:

- Develop a framework of year-long and short-term goals for students.
- Select science content and adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of the student.
- Select-teaching and assessment strategies that support the development of student understanding and nurture a community of science learners.
- Work together as colleagues within and across disciplines and grade levels (NRC, 1996, p. 30).

Framework as used by the NSES is built with the standards already in mind and differs from its intended application with respect to the narrative framework—as a precursor and guide to the selection and organization of content standards. Later, the NSES describes the introduction to the

[1] The content knowledge is broken into four discipline areas: 1. physical science 2. life science 3. earth and space science 4. science and technology

chapter on content standards (chapter 6) as setting "the framework for the content standards, by describing the categories of the content standards with a rationale for each category" (NRC, 1996, p. 103) This second usage falls closer to what is intended here but misses some aspect of how the content might flow together into some coherent whole towards some overarching goal.

Part of the confusion over frameworks and how and when to use them comes from a lack of clarity over a key set of educational terms: standards, curriculum, and content. There exists some drift in the exact definition and hierarchical structure of the terms; here they will be used in the following way. Standards are the broadest of these terms and are best described as a concise written description of what students are expected to know at the completion of some span of learning, such as a chapter, unit, grade level, etc. A curriculum is the fleshing out of standards, providing the specific lessons, time lines, materials, and assessments that describes the approach to specific course or grade-level learning. Content is the particular facts and ideas of a course or subject: dates and artifacts of history, discoveries and laws of science, works of the great masters, the form of iambic pentameter, etc. A Framework should lie outside this hierarchy of terms, providing a guiding and hopefully constraining lens for building, selecting, organizing, and delivering standards, curriculum, and content.

The NSES uses two frameworks, one built by teachers to select content and build curriculum based on the content standards and another to justify the selection of content standards (although it is not clear if the writers built the second framework to select content or selected the content and then justified their decisions with the second so-called framework). There is an overlap between the two uses. By "select science content" the NSES can only mean examples of the topics described by the content standards, for the content standards are too specific to allow teacher flexibility in topic selection. The job of topic selection has been done by the latter framework, which justifies the content standards. In presenting the narrative framework below I will attempt to bridge both uses with an ultimate goal of constraining the amount of content and turning it into a tool focused on building science learning. In doing so, I will use content and content standards somewhat interchangeably as a means to describe the kinds and total number of topics to be taught.

Just over ten years after the release of the NSES, the National Research Council (NRC) retooled the approach to national science standards applying the idea that a well-constructed and coherent framework should precede standards writing. In the summer of 2010 they released for public comment a draft of *A Framework for Science Education.* After receiving feedback from "interested practitioners, researchers, and the public" (NRC, 2010, p. cover page), a final report was released in 2012 as *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (here after *K-12 Framework*). The *K-12 Framework* is described as "a broad description of the content and sequence of learning expected of all students by the completion of high school…" (NRC, 2012, p. 8) The report goes on to explain that it is not intended as a list of grade-by-grade or high school course content standards. Additionally, the *K-12 Framework* committee intentionally restricted the document "to a limited number of core ideas," so as to "avoid shallow coverage of a large number of topics and to allow more time for teachers and students to explore each idea in greater depth" (ibid., p. 11). A decade after the NSES, The *K-12 Framework* is still concerned that science courses are overstuffed with content but falls short of offering a corrective. The problem persists in part because, like the NSES before it, the *K-12 Framework* selects content based on what is deemed *core* in science.

The *K-12 Framework* was intended as a first step in a complete rewrite of the NSES. The process culminated with the release of the *Next Generation Science Standards* (NGSS) in April of 2013. The NGSS stuck with the *K-12 Framework* organization of carving science education into three broad areas: science practices, crosscutting concepts, and disciplinary core ideas—the framework of the NGSS. However, the NGSS does little to streamline content in order to allow time for the depth of teaching called for by the *K-12 Framework*. With respect to physical science, including the chemistry standards, the NGSS has five standards categories, which it breaks into twenty-four standards, which are again subdivided into thirty-eight disciplinary core ideas (DCI). In addition to the DCIs, each standard has a roughly equal number of subtopics that address science and engineering practices and crosscutting concepts. Furthermore, two additional standards categories, human sustainability and engineering design are embedded within all areas of high school science. While not beyond argument, it is hard to interpret the NGSS as anything other than a content increase over the NSES, even as the *K-12 Framework* continued to decry "miles and inches" more than ten years after the NSES.

What the NSES, *K-12 Framework*, and NGSS failed to do was recognize a limitation in their content selection criteria. All three select content standards on the criteria that they are *core* aspects of science and therefore important for students to know. Core importance, however, is a moving target over time and depends on who is sitting on a standards writing committee. Some items will be nearly indisputable. Atomic theory for chemistry and cell theory for biology are unlikely to be left off of any reputable science teacher's or educational authority's content list. Oxidation, on the other hand, was deemed of core importance in 1996 and less so in 2013. Given the ever-present risk of Klassen's overcrowded curriculum syndrome, what a particular group of experts finds core at a particular moment in time lacks a strong enough justification for why some content is included in a set of standards and others left out. Furthermore, core importance is a weak ligament for holding that content together and offers little in the way of suggesting a sequence in which core topics should be presented. Replacing core importance as a selection criterion with content in service to teaching science as a content narrative provides an alternative to selection and sequence that can better guide teachers and curriculum designers to keep content lean and offer students a narrative trail to follow in connecting one bit of content with the next.

In what follows we will leave core behind, or at least demote it, in favor of selecting content to build a more focused content narrative. In doing so we will let narrative structure make choices on what topics matter where expert opinion of core importance has made them in the past. A story still needs a teller and so there is still room for interpretation, discussion, and reimagining. However, the replacement of narrative for core promises to help constrain the experts' tendency to flood the novice with too much of a good thing. Drinking from a firehose of content rarely aids in quenching a thirst for knowledge.

Narrative and Science Curriculum

And Yet It Moves

"The story begins," Richard Feynman said in his now-famous lecture on the law of gravity, "with the ancients observing the motions of the planets among the stars, and finally deducing that they all went around the sun, a fact that was later rediscovered by Copernicus" (Feynman, 2013).

The law of gravitation was one of Feynman's favorite ways to illustrate the nature of physical laws and the most basic principle and point of science as an ever changing field of study. Feynman, dubbed by his intellectual contemporaries as the great explainer*,* understood that one cannot teach physics, "by just giving the basic laws on page one and then showing how they work in all possible circumstances" (ibid.). To learn physics one must understand its history, its relationship to the other sciences and to nature. To learn physics, is more than knowing some equations, it requires placing physics in context. In short, to teach physics is to tell its story. To disentangle the story of physics and the physics itself is to lose something in the telling.

Employing stories in the service of teaching science neither began nor ended with Feynman. The great explainer's innate tendency towards a narrative of science exists elsewhere in popular and academic writing in more overt approaches. Peter Atkins (1995), chemist turned historian of science, has created an elegant and instructive chemistry narrative in *The Periodic Kingdom*, while science writer Sam Kean (2011) has written several engaging books about scientific discovery. With respect to more formal research, narrative is employed in various modes. One corner of that research tends to focus on engaging more with the history and the philosophy of science in science teaching and in teacher education (Erduran, 2001; Gooday et. al., 2008; Mathews, 2015; Metz et. al., 2006; Monk & Osborne, 1997), including the fully-integrated history and physics program of Holton and Rutherford's *Project Physics*, which itself has an interesting history (Holton, 2003). Others have been primarily concerned with using stories about science in the science classroom to more fully engage students and to bridge everyday experiences with academic ones (Avraamidou & Osborn, 2009; Conle, 2003; Gilbert et. al., 2005). Still others write about building theories for integrating narrative approaches into science instruction extending so far as to suggest that "[n]arrative could well form the basis for entire science curricula" (Mott et. al., 1999, p. 79; See also Bruner, 1986; Egan, 1986; Klassen, 2006, 2010; Norris, 2003).

What many of these arguments rely on is a sense of the universality of story, both across cultures and time, and that story is a natural feature of how humans organize their world (Fuchs, 2013; Doyle & Carter, 2003).[2] Science, on the other hand, in an effort to remain objective and dispassionate, has cordoned off a tract of thinking and learning where reason and logic have primacy and story is little considered. Psychologist Jerome Bruner (1986) has bifurcated such modes of thought into *paradigmatic* (logico-scientific) and *narrative*. Many of the scholars cited above accept some form of Bruner's two modes of thought, claiming broad swaths of science education rely excessively on a paradigmatic approach even as students, novices in science, more readily structure thought through narrative organization.

One fairly thorough attempt to counteract the imbalance in modes of thought employed in science teaching comes from Kieran Egan, an educational philosopher. In *Teaching as Story Telling*, Egan claims that "In nearly all teacher preparation programs students are taught that in planning lessons and units they should first identify and list their objectives, then select content and material, then choose methods, and then decide on evaluation procedures." Egan worries that the result is lesson planning that is "inappropriately mechanistic," and offers in its stead a model which sees "lessons and units as good stories to be told rather than sets of objectives to be

[2] See Also Creath's (2009) discussion of the role of history in science especially the narrative structure of the science lab book; Gottschall's (2013) description of the story-telling animal; as well as the paradigm's of Thomas Kuhn (1974, 2012) which act in part as a common story for paradigm adherents.

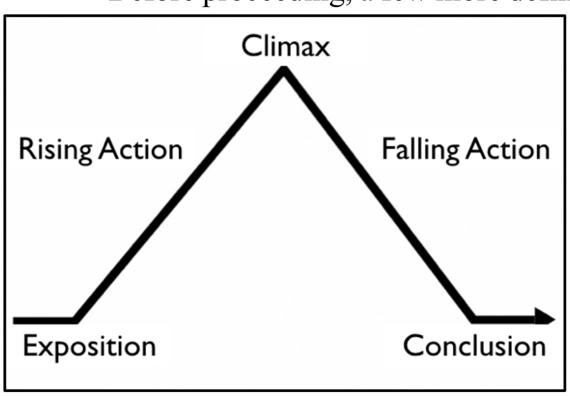
obtained." Egan targets all subjects in elementary education, but at several points singles out mathematics and science as being in need of his story telling treatment for they "suffer most from being stripped of the affective association" as well as an over-reliance on Bruner's paradigmatic approach (Egan, 1986, p30).

Egan claims that a pedagogical framework ought to precede and drive lesson, unit and curriculum development and that framework should make better use of the narrative modes of thought. This idea of frameworks preceding standards would seem to have been followed in the case of the *K-12 Framework* and the *Next Generation Science Standards* but falls short in light of the current discussion in two significant ways. One, although history and nature of science find their ways into both documents, no clear method is presented for how to embed both ideas in the course of teaching. To be fair, this is a much larger problem than can be addressed by a set of standards documents, and in large part, belongs in a discussion of science teacher education. The second flaw, already mentioned, is that content selection lacks a structured approach, relying on a committee, heavily biased by adherents to paradigmatic teaching and thinking, to determine what *core* ideas are necessary for students to learn. Thus we return to Klassen's syndrome and content bias as to what constitutes good science teaching.

I wish to expand on Egan's prescription—extending it to secondary education and focusing on the standard first year chemistry class. What follows is a fleshing out of the first part of the narrative framework, namely *teaching science as a story*. The aim is to provide a guide for selecting and organizing chemistry content and a sieve to keep the content sufficiently lean to finally burrow down below that first inch.

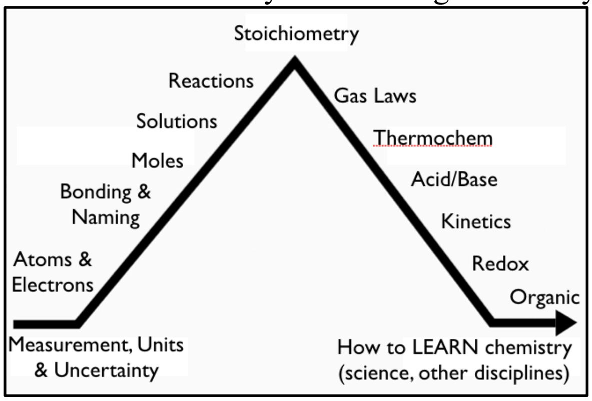
A Narrative Framework for Chemistry Curricula

Before proceeding, a few more definitions are in order. Narrative theorists have made clear distinctions between certain terms that have some overlap in their common usage. Among these terms are narrative, story, and discourse. Narrative has been described as being composed of story and discourse, where the story includes events, characters, setting, etc. and the discourse is the mode of telling the story (Gudmundsdottir, 1995; Bal, 2009). In the present discussion, the discourse can be considered the act of teaching and here we should be wary of constraining the art of teaching by overly scripting science content narratives. Story is most analogous to the idea of curriculum as described above, where the discrete events, setting, and characters become the methods and context of scientific discovery and the concepts and ideas that make up the collection of scientific knowledge. To connect these into a narrative structure, I wish to employ a diagram of narrative arc familiar to many high school students and language arts teachers. (Fig 1)



One form of the standard narrative arc begins with exposition, in which one is introduced to characters and the initial setting of the story. Then, a sense of rising action moving towards a narrative climax, followed by the falling action which wraps to a final conclusion. This is but one version of narrative structure. Some narrative forms are more complex variations of this simple structure while others take on different forms altogether. Elsewhere, Klassen (2010) uses a common linear story model to argue for story forms in science teaching.

Fig. 1



Chemistry is an excellent candidate for a narrative approach, as content naturally flows from one idea to the next. Atomic theory establishes the basic unit of chemistry. The type of atom predicts how its electrons will interact with other atoms. Interactions with other atoms predict bonding and the type of compound it will form. Type of compound guides naming and formula writing. Naming and formula writing are precursors to writing balanced chemical equations. And on it goes. It is not enough for teachers to recognize a narrative sequence to content, they must also be explicit in presenting it as such. Part of the effectiveness of a narrative approach is in letting students peer behind the curtain of how and why content is sequenced in a particular way and what goals the teacher hopes to accomplish with the story; all the while using narrative language as each new topic is introduced. Teachers must also be aware that because chemistry content knits together well it is easy to tell too much of the story when abridgment is called for. Abridging the tome of chemical knowledge comes from first identifying an appropriate climax for the framework and taking care to not overload the structure or include ill-fitting features to the frame.

Fig. 2

Stoichiometry, mathematical application of balanced chemical equations, is an ideal climax event for a first-year chemistry course (Fig 2). Students who are proficient in stoichiometric analysis are capable of applying those skills to numerous extensions of chemical thought and practice. A narrative structure with stoichiometry as the climax goal now guides the teacher and curriculum writer to select only the content that fits as meaningful event tokens in a stoichiometry content story. With this climax in mind the rising action are those topics that contribute to a meaningful understanding of basic stoichiometry—introduced using narrative language by explaining how each bit of new content connects to previous material and foreshadowing how that content will lead to the next part of the story and towards stoichiometry as the primary content climax of the course. This type of narrative driven content selection offers a stronger justification and constraint than has been offered in the past while remaining open to multiple tellings and organizations of critical events with a goal of any number of thorough but concise content stories that provide a clear narrative map for learning chemistry.[3]

Having identified the peak, let us descend back to the trailhead. Despite worries about rank empiricism in the teaching of science, science is primarily an empirical endeavor. A strong case

[3] Figure 2 is intended as a sketch of a chemistry narrative map and not a definitive arrangement. Addition, subtraction, and/or rearrangement are encouraged, provided one can present a justification for the narrative value of such a move. The work of filling in Figure 2, including identifying a learning climax for a course, could be done by teachers, schools, districts, or larger curriculum writing entities depending on the level of coordination desired at each level. My personal bias is towards teacher autonomy and would recommend that the further away this work gets from the classroom the broader should be the strokes used in building the narrative, leaving teachers or groups of teachers working closely together to work out many of the finer details of particular science stories.

exits for the exposition of our story to be a lesson on the nature of observation and the theory and application of scientific measurement and calculation.[4] From there students are equipped to understand the various qualitative observations and quantitative data that govern scientific processes and that led to key discoveries: Dalton's atomic theory, Rutherford's gold foil experiment, the development of quantum mechanics, etc. Much of the literature on using narrative approaches in science teaching is focused on using stories within the history of science to make science more engaging and to explore the nature and process of doing science (Klassen, 2009; Metz et. al., 2006). The rising action toward stoichiometry is replete with such stories which makeup the second aspect of the narrative framework—*teaching science using stories*.

In the falling action one finds the topics which tend to come after stoichiometry in most US chemistry courses—gas laws, thermochemistry, kinetics, equilibrium and the like.[5] Placing them here provides extension and texture to the first part of the story. Thermochemistry, for instance, can be taught as an extension of stoichiometry with an inclusion of energy as part of the balanced equation. Gas laws, kinetics, and equilibrium allow further discussion of the idea of theoretical approach, adding kinetic and collision theory to the atomic theory that drives most of the first part of the story.

If one of the goals of the narrative framework is to limit the total amount of content in the first-year chemistry course, the falling action topics are the place to make the necessary content cuts in order to achieve the oft-repeated call for depth. But history suggests that these negotiations will never produce a stable chronicle of chemistry on the downward slope of the arc. Gas laws, a favorite topic of many chemistry teachers, appear on neither the NSES or the NGSS as a chemistry standard. Oxidation-reduction is considered core within the NSES but absent in the NGSS. Conversely, equilibrium appears in the NGSS but is omitted in the NSES. The next iteration of national standards will undoubtedly identify new topics of core importance and leave others that were previously selected.

Unfortunately, a narrative structure does little to resolve the selection of falling action topics since all provide some additional texture and insight towards the main narrative. One way out would be to embed them in the framework as optional topics. Each is valid and has merit as a means of expanding student understanding of the reach of chemical knowledge. For the first-year student there is, however, a law of diminishing returns, and more texture can become abrasive. Furthermore, the overstuffed curriculum on the back side limits the time needed to create clarity on the positive slope of the narrative. Here we can mitigate Klassen's syndrome, by including an excess of topics in the framework but not requiring all. The falling action becomes a kind of choose your own adventure, where curriculum writers determine an acceptable number to be taught and teachers pick and choose, potentially even including students in the decision process.[6]

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[4] This story has recently taken a turn with the introduction of new SI standards on May 20, 2019, See Davis 2018.

[5] Because it is generally considered foundations to first year chemistry, stoichiometry is sometimes the first topic taught. See for instance the International Baccalaureate chemistry course which is heavily influenced by a British approach to teaching chemistry. This opens up a larger discussion of different cultural approaches to telling the story of chemistry, including the relative importance of organic versus inorganic chemistry for the first-time chemistry student.

[6] Additionally, district and state level assessments could easily be written so that schools or classes could choose from a menu of topics to be included on formal common assessments. Common topics on the positive slope would be on all assessments, but only those falling action topics studied by a particular class or school would appear on the test.

Having adapted the basic narrative form to a narrative of chemistry, a few more alterations are worth considering. With the sequence of the chemistry content story in mind, we turn now to the discourse or how the story should be presented, i.e. taught. The first alteration is from equilateral to isosceles (Fig 3). If stoichiometry is to be the climax of the chemistry story, it should be temporally shifted toward the end. How close to the end will depend on how much falling action is deemed necessary, but a climax half-way through a novel is certainly too soon. Second, I have offered a justification about how to select and arrange the narrative events for our story and now wish to place those events in context to provide a setting for the story of chemistry. That setting is science, or perhaps more accurately learning science, for there needs to exist a distinction that is often lost. Aiding the student in her climb up the rising action of the chemistry narrative is a current of thought that places teaching and learning in the context of the practice of science, the nature of science, and the nature of learning.

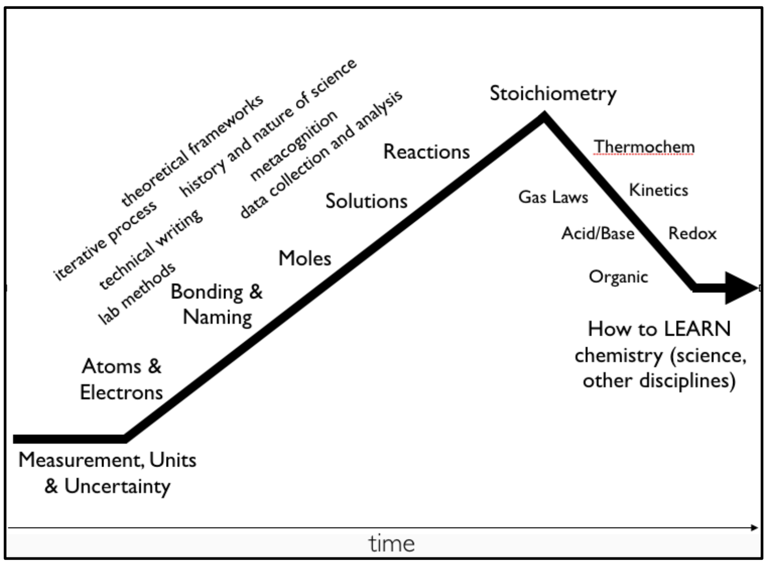

Fig. 3

Figure 3 lists a collection of the ideas that ought guide the chemistry narrative and be the drivers of learning. Here we have a departure from the national standards documents described above. Both the NSES and the NGSS attempt to put the content of science and the process and nature of science on equal footing. That said, content continues to be the primary driver in the classroom. I wish to go one step further and place content hierarchically below process, not because content is less important than process but because identifying the *right* content is less important than using content (any content) to teach process. The narrative framework deliberately layers the structure such that the conceptual features of science and learning are the focus of teaching the course; the content is used to transmit to the students the themes of thinking and learning in science. Both are important, but when content is placed in service to teaching the themes of science and learning, the stakes of identifying the right core content are much lower since multiple arrangements of content can tell a coherent science story.

I do not wish to address all of the learning themes listed on Figure 3, but a few require some exposition. Learning to learn requires a bit of reflection as the process unfolds, a process known as metacognition (Bransford & NRC, 2004). If the narrative framework is used, then Figure 3 should be explained to students, so they can reflect on the justification of the sequence as each event unfolds. Likewise, an articulation of theoretical frameworks in science (atomic theory, collision theory and the like) help students to see how explanations work in science and how they might be different than in other disciplines.

The intellectual stream running throughout Figure 3 combines to offer a conclusion to this science narrative. Having completed a first-year chemistry course, how should a student be different than when they first entered the classroom? Rather than saying they know a set of chemistry facts, the goal should be that students understand how they learned chemistry, furthermore that knowledge should be reflective of previous science learning and applicable to future scientific endeavors as well as learning in other disciplines. The goal of good secondary science teaching should not be to make new scientists, but to create better learners of science and better learners in general. A way towards this goal is to get students to see science as a story and perhaps even get them to imagine themselves as participants in that story—either as produces, consumers, or both.

Conclusion and Extension

The standards movement resulted in an overemphasis on science content as a driver of science curriculum, relying on a justification for selecting the content for high school science courses based on some form of what was believed to be a core and important feature of a particular scientific discipline. To be fair, in the latter part of the twentieth century content knowledge was difficult to access, leaving experts and teachers as the primary resource. As a result, there was some justification for teachers to maximize content delivery in the time they had with their students. The digital age has made even the most complex of scientific facts and ideas readily available. Once maximizing content delivery is no longer seen as critical, identifying the exact right core content is likewise less critical and perhaps counterproductive. Core importance as content selection justification is only broadly constraining, fluctuating based on the whims of particular research groups and curriculum committees and tends toward courses over-stuffed with content. The narrative framework described above aids in focusing content selection toward a particular narrative climax, emphasizing the process, nature, and story of science over teaching the right core content. This approach places the narrative framework as the next move away from science classes based primarily in the efficient memorization of facts and solving of equation in order to get on to the next chapter and towards those that teach a more coherent understanding of how science works and how it is likely to impact student's lives.[7]

I have given the science narrative framework shape and primarily offered it as a tool for selecting, constraining, and sequencing content, in order to help present science teaching as a story. However, the framework is far from completed. Among the issues that require additional construction are narration, characters, and a theory of assessment. Within the study of narrative there is much talk about the role of the narrator in stories. What point of view does the narrator take? Is the narrator inside or outside the story? What are the distinctions between narrator and author? Responses to these questions may provide the framework with clearer application with respect to the role of the curriculum writer, the teacher, and the student. Additionally, definitions of story often include some requirement of human or human-like agents. Some writers of narrative in science teaching have extended this definition and granted agency to nature and natural objects as the characters of the science story (Fuchs, 2013). Following this trail may provide another useful facet to the narrative framework and hence a clearer way forward in good science teaching and learning. Finally, no approach to teaching will be given much credence without addressing

[7] Do not read conceptual science only. To learn how science works, students will need to learn some facts, do labs, collect data, and solve an equation or two.

assessment. If students are unable to demonstrate some desired cognitive change, then the science story is fraught. The goal of the narrative framework is to move a student toward learning science as a way of knowing and as a tool for addressing certain types of problems. At a wider zoom, students who have engaged reflectively with the narrative framework model should have a better understanding of an approach to learning. Such goals do not make for straightforward and easily quantifiable assessment. They are worthy goals and assessing them is likewise worthy. However, assessment and the other extensions of narrative and science are beyond the scope of the present paper, yet represent fruitful areas for further study.

Chemistry has here provided a model of the construction of a science curriculum narrative, but other sciences await the same treatment. Biology, whose pursuit extends from the cell to the ecosystem, holds a plethora of possible stories. The history of physics, particularly the kinematics and dynamics of motion, presents particularly fertile ground. As mentioned above, the Harvard Project Physics program offers a model of teaching physics using its history as the organizing feature. For the high school student, arranging the curriculum as a narrative from Aristotelian to Newtonian thought would be a promising approach, primarily because it helps reveal student bias towards Aristotelian modes of explanation (just ask the beginning physics student about the motion of an object that has two equal but opposing forces acting upon it and the overwhelming response is that the object's speed—not it's acceleration—must be zero) (Monk & Osborne, 1997, p. 413). To arrange these stories, good pedagogical climaxes must be identified. From there possibilities are numerous across all branches of science. Pick the climax and tell an engaging story—no more, no less. What is edited out will no doubt be interesting to both student and teacher. Students captivated by the story will seek out other science narratives and will have the tools to engage with the tales.

One more area of future extension requires addressing. Applying a narrative framework to science teaching beyond the superficial will be most effective when science teacher education asks preservice teachers to spend more time outside science, studying the humanities. This should go beyond taking more non-science classes, [8] but taking courses that study the humanities' relationship to science and courses that compare disciplinary approaches to solving problems. Science is a human endeavor. To convey this effectively science teaching needs the humanities. It is in the humanities that they will discover that science has a story, and perhaps through that lens they will be able to see teaching science as a story worth telling.

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[8] Here many will claim that science teachers are already deficient in the number of required science courses. Finding and perhaps creating the courses that expand knowledge of humanities without producing deficiencies in scientific knowledge is a challenge for creators of teacher preparation programs.

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