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RESPONSE 2

"Where Is the Line?"

Brian P. Coppola

My titular question (*Where is the line?*) mainly elicits discomfort among my friends and colleagues who work in the area of teacher education and professional development: "Is there a line past which you will admit that the expectations set for teachers is simply unreasonable?" In my experience, the answers have been highly qualified "maybe" statements: no matter where the line is, it can be relocated, and then teacher education and professional development can provide the means to elevate teachers to any new level. I disagree. I not only think a line exists, but I think we have crossed it.

I am an outsider. By way of full disclosure, my last extensive involvement with precollege teachers was when I graduated from high school in 1974. I have collaborated with my science education colleagues for many years as the "science guy." I have taught organic chemistry in large course settings at the University of Michigan for almost 30 years, mainly to first-year students, and so I interact with many students who have just left the K-12 sector. Since 1989, my department has honored the prior experience of our students who have reasonable mastery of high school chemistry topics by eliminating university-level General Chemistry as a requirement (Coppola, Ege, & Lawton, 1997; Ege, Coppola, & Lawton, 1997). In the organic chemistry course, we promote strongly the value of developing scientific dispositions, particularly through the use of the primary literature as a resource, and built upon the contemporary, mechanistic model of the structure-reactivity relationship (Coppola, 2010).

Let me also say that I am not keen on the way contemporary US education uses the term Standards. I think of Standards as, well, actual standards. I want airplanes built and maintained to strict standards, and I want the expected compliance to meet these standards as 100 percent over the line (and so do you). Yet there are times when 100 percent is unreasonable, and so the line has to be drawn

somewhere. For instance, proofing construction in California, for earthquakes, specifies a 6.5 magnitude as an important threshold. As engineering improves, this line can be moved. But there is a point past which the expectation for no damage is simply unreasonable. When I hear my colleagues talk about the science education standards, I hear wishful thinking about theoretical goals that are disconnected from even a minimal set of considerations about the lived reality of *the diverse character and experience of millions of human beings who are teaching in science classrooms across the United States.*

In private conversations, I have heard that wishful thinking is exactly what our Science Standards are: a target, a statement of principle. Perhaps the disconnection from reality disturbs me the most. Pie-in-the-sky “if” statements are not reasonable to call standards: *If we lived in a world where countries satisfied the three pillars of freedom—from poverty, from war, and from prejudice—then. . . .* Is this a realistic statement of an achievable cultural standard? The NGSS, and the way my colleagues treat them, strike me this same way: *If we lived in a world where teachers construct science learning environments around the three pillars of science—inquiry through authentic practices, explicit and coherent understanding of interrelated cross-cutting concepts, and discipline-based core ideas—then. . . .* Is this a statement of achievable cultural standard? I think it is beyond reason.

I am equally skeptical that the architecture-du-jour (Learning Progressions) must be the key to the answers we are seeking. It is too premature. Learning Progressions are still too theoretical for me to bet the farm on them, and they still assume a level of skills and literacy about the average teacher that is unjustifiable. I have more to say about this later.

Teaching science as science is certainly a terrific goal, but we are not even asking scientists to do that at the post-secondary level. In the NGSS, and through Learning Progressions, we are imposing science on people who, by and large, understand science as an academic exercise, at best. This difference between authentic and theoretical teacher expectations is a simple fact that needs to be taken into account. Whether there is a blogger’s summary of rising anti-intellectualism (Williams, 2014) or the comparative criticism of rigid, standards-based systems (Coppola & Zhao, 2012), increasing the distance between the average skill of teachers and the average expectations on teachers makes no sense.

The idea that research-based findings are enough to change behaviors is delightfully naïve, even at the postsecondary level, where, arguably, the scientific credentials of the instructors is more certain (Coppola & Krajcik, 2013, pp. 634–35):

Singer acknowledges the same dilemma as we have . . . when it comes to the role of evidence in changing behavior. She states, “evidence is necessary but not sufficient to change undergraduate STEM education.” This is a critical point. Another apt scientific analogy might be to not confuse thermodynamics and kinetics. To get from A to B, it does not only matter

how much more favorable the thermodynamic destination is, because you always have to overcome the kinetic barrier (in fact, poor destinations with low barriers are often quite attractive pathways to follow). The futurist, Paul Sappho, says it this way (Sappho, 2013): "Never mistake a clear view for a short distance."

One prescribed solution—and an explicit outcome for this Waterbury Summit—is research, and yet more research, which sustains the professional lifeblood of those who study education from their university chairs, can involve working with a comparative handful of highly supported teachers on their well-funded projects. The research agendas do not come close to even acknowledging the problem of *the diverse character and experience of millions of human beings who are teaching in science classrooms across the United States*.

Finally, because not every child attends college and not every college student studies science, there is a long-standing desire for science education to turn out the near-mythical educated and informed democratic citizen, who makes good decisions, and has developed a shopping-cart's worth of social, psychosocial, and cognitive skills around science.

I get it. I agree with the principles, I really do; as have more than a few generations of scientists and science educators, particularly those in the mid-twentieth century, post-WWII environment of nuclear politics. I also understand that education is a system with lots of moving parts, including its incredibly important context—that is, the cultural perceptions of educators, education and intellectualism in the United States. But these iterations of alarm followed by pronouncements of change have me thinking that I am reading about solutions that are in search of a problem, because the real problems are so damned hard to solve. And if the statement of Standards are not actually standards that can be achieved, and are immediately understood as being so challenging that they cannot be achieved, then there needs to be a prioritization that begins with a set of minimum actual standards—true standards for which we aim for 100 percent achievement by *the diverse character and experience of millions of human beings who are teaching in science classrooms across the United States*. Otherwise, these iterations begin to look like the fresh coat of paint on an old wagon with broken wheels: going nowhere, still.

On the New Standards

Much to the dismay of some of my colleagues, I found myself unable to provide an enthusiastic endorsement of the NGSS, despite some general conceptual agreement I have with the larger goals. The short and long of it is that the expectations for teachers have now been set too unreasonably high in an absolute sense. This is because, and I freely admit it, the expectations are higher than what I think I can *generally* achieve in my own first-year university classes, even with the significant advantages I have compared with my pre-college teaching colleagues.

What is the problem being solved? Can any of the issues that the NGSS claim to address be attributed to a failing of the previous science standards (NRC, 1996)? The previous standards were created to set a vision, with the aim that the resulting practices would address certain identified inadequacies and/or make improvements. How did that go? What are the explanations that link to why these previous standards did not do their job? Do we understand how to link something like standards to whatever dissatisfaction drives the need for new ones? Is there convincing evidence that those previous standards, and their consequential results, is in any way related to anything that happened? And if so, what? Is there a differential hypothesis on how the NGSS can result in a system that does not simply go the way of the previous standards?

If we accept a system of standards, then I argue that we need to think of teacher education and professional development as an intervention, or treatment, in the same way that we do drug testing. One of the standards in medical treatments is the LD_{50} , that is, the median lethal dose: the amount of a drug, or other treatment, that kills 50 percent of the tested population. It is a benchmark against a simple standard: survival. We know that some can tolerate more, and some can tolerate less, but it creates a comparative scale of efficacy (well, terminal efficacy). If we have an educational standard that is coupled with a treatment such as professional development, then one of the things I would really like to know is its ET_{50} , what it takes to get an Effective Treatment (ET), hitting the standard, for 50 percent of a statistically meaningful test population of a given character, with whatever specified criteria are meaningful to understand a teaching context. I would like to know how the professional development treatment to get an ET_{50} varies according to—you can imagine it—a grid of as many critical variables that effect teaching that we know of.

And what about the proposition that Standards-based systems, and their inevitable high stakes testing, is a significant contributor to the real problem itself?

The pro-standards aphorism goes like this: if you do not have a destination, then every road gets there. Interesting. Because right now we have standards and (more or less) none of the roads get there, at least when we talk about *the diverse character and experience of millions of human beings who are teaching in science classrooms across the United States*. I am concerned, here, about the millions of teachers who are left on their own, or perhaps to whatever passes as professional development in their districts, compared with the relatively small handful of teachers who end up associated with highly funded, highly attentive professional development programs—funded by the NSF and directed by many of the participants in this Summit. My question to these professional development (PD) experts during our coffee breaks: do you think that your current PD program, with its teachers under your protective wing, achieves a 50 percent level for Effective Treatment? Can we expect this standard? All of the people I talked with were more comfortable with about a 5–10 percent level. Here, then, is the crux of my concern about why talking about “the line” matters. If the work of these highly funded,

academically-based PD programs is good to a (self-assessed) 5 to 10 percent level for a privileged class of teachers, what reasonable hope is there for teachers "in the wild" who find themselves already looking up as the bar is raised farther from where they are?

For two of the pillars, authentic practices and cross-cutting concepts, I think I would swap out for the three scientific dispositions that Camins (2012) suggests ought to characterize the precollege science learning experience: comfort with ambiguity, the search for uncertainty, and learning from failure. For the third pillar, I think that when you peel away all the layers in the new rhetoric, you still end up worried about how teachers and students in America's incredibly diverse educational settings are dealing with learning about phase changes, the Krebs cycle, analytical methods, plate tectonics, glycolysis, and objects rolling down inclined planes, among many others, and how these are constructed and used to explain observable phenomena.

I am worried that by upping the ante on the complexity of what a strained workforce, our teachers, is responsible for, it means that at some point (if not already) the system becomes so strained that it cannot function. What constitutes a responsible foundation for our teachers' understanding of the basic subject matter (phase change, Krebs, etc.) when, particularly, as a technological society we have been so successful in deepening our understanding of these things? And now, one level up, we are going to ask teachers to take their inadequate understanding and design instruction that gets students to understand the distinctiveness of scientific thinking through authentic practices and cross-cutting concepts. And, one more level up, we want teachers to design environments that assume this previous understanding, and tie it to the development of social, psychosocial, and cognitive skills. At some point, the demands on any system can become so severe that it either collapses or it is crippled (famously, at least in *Star Trek III*: the more you overthink the plumbing, the easier it is to stop up the drain).

On a recent trip to New York City, I met with a colleague who was running a summer program for high school students needing additional help in preparing for the Regent's Exams. My colleague was telling me about an experienced teacher who was assisting with the laboratory program, someone who had an undergraduate degree in chemistry from the University of Chicago. In addition to only being comfortable with using fill-in-the-blank worksheets and standing at the electronic balance to do the mass measurements for the students ("write down this number, here, and get out your calculators and enter the other numbers in this order . . ."), the experienced teacher was unaware that she was having them enter a non-sensible value in one of the spaces (mass of crucible = 35.50 g; mass of crucible + hydrate = 3.45 g . . . actually, she was unknowingly accounting for the tare of the crucible in making the measurement and did not realize that this did not match the sheet, or the manipulation of the values that she was directing). When one of the summer students began to ask about the negative mass and the discrepancy, the teacher was unable to do anything except repeat the order to

follow her directions. In the daily debriefing, my colleague, who had overheard most of this, asked the teacher about it. The teacher's reply, through tears, was that this was the way she learned how to do this and had no other options. As a faculty member in a department of chemistry, I am a complete stranger to this context, but it makes me believe that there might be some severe disconnects between the theory, implementation, and outcomes from teacher education and professional development.

We do not need to teach everything that we know, and a well-considered approximation is always tied with the need-to-know for any group of students in any given environment. I have been in the audience a few times when Craig Nelson, an evolutionary biologist at Indiana University, poses this question: "What is the shape of the Earth when you teach Architecture 101?" The answer is that, in this situation, we use a flat-earth model. We know, on the curved surface of our planet, that two plumb lines separated by any distance are not ever parallel. However, on the scale of building most buildings, the variation is outside the limits of the needed precision. Courses are like this. While my expertise gives me, say, 10th decimal place precision in my understanding of organic chemistry, one of the terrific challenges in teaching the introductory course is deciding what precision is needed, perhaps 2nd decimal place, and another, greater challenge is constructing a coherent and consistent 2nd decimal place version of the subject. Some faculty instructors have a hard time with these approximations because it seems like they are promoting incomplete heuristics in lieu of "telling the truth." But there is no need-to-know in the 10th decimal place knowledge, in the context of the class, so it does not serve any useful purpose. And as Nelson is quick to point out, my 10th decimal place understanding is not the truth, anyhow, it is just the latest iteration of the flat earth model.

In his essay about the AP Biology upgrade, Benson acknowledges the need to find the expectation boundaries when it comes to the depth of subject matter for which the course is responsible. But even if that expectation for mastery is exactly where a teacher is at, it is not adequate. My level of knowledge and expertise needs to be higher than the instructional boundary in order to be able to bring perspective, alternative entry points, and so on, to instructional design and to the day-to-day challenges of working with students. And subject matter mastery relatively easy compared to things like social, psychosocial, and cognitive goals.

On Learning Progressions

I am worried that tying the NGSS to Learning Progressions (LPs) is jumping the gun. I like the LP concept, but if this were a new drug, we would barely be in the Phase One clinical trials. We really do not know enough about how LPs interact with a wide diversity of subjects (students and teachers alike) who are drawn from the diverse array of settings that exist in our country.

Assuming we have a well-constructed and understood LP, LPs still have a pair of coupled weaknesses. First, the details about a LP come from some aggregate, average behavior of the student population(s) that was used to construct it, which means that information about an average is being used to predict the character of individuals. If it is the 4th grade, then this is what you should be able to do. Second, the concept of a progression begins to more formally create expectations that can never be based on the actual experiences of any given set of students. That is, not only is this what we are supposed to be doing in 4th grade, but we also need to be able, in a highly formalized sense, to expect the mastery of the lessons from grades 1 to 3. What are the error bars on what students at any given level should and/or should not be able to do, and how does the absolute placement on this LP depend on the school, the teachers, the setting, and so on. Without advancing to the Phase Two and Three clinical trials, we cannot know how this LP treatment interacts with all the different clinical features of the wide array of "subjects" on which it is supposed to act.

In an essay on the distinctiveness of both disciplinary expertise and embedded understanding of disciplinary dispositions, when comparing the expertise of pre-college and post-secondary educators, this difference in what can be expected emerges (Coppola & Krajcik, 2013, p. 628).

Discipline is a continuum of increasing focus as one moves through education. Although the distinction is fuzzy-edged, one characteristic of post-secondary science education is the shift from introductory survey classes with multiple topics (e.g., High School and General Chemistry) to classes that specialize according to a more specific disciplinary expertise (e.g., Organic Chemistry, Physical Chemistry, Cellular and Molecular Biology, or an Organismal and Population Biology) and the increased chance that the instructor is also a person who is versed in the art of that specific area (an Organic Chemist, a Physical Chemist, a Molecular Biologist, or an Organismal Biologist). The common impression from survey classes, and one that is never a goal, is that scientific knowledge reduces to a bundle of facts. Ideally, disciplinary context provides an integrated understanding, where the "thinking, feeling, and behaving" part of understanding is an indispensable feature of the story. Progressing through the K-20 spectrum, the larger cross-disciplinary ideas about science, as a way of knowing, become highly contextualized through the more detailed study through the lenses of disciplinary focus.

K-12 and post-secondary instructors generally differ greatly in both the time with, and depth of, their prior experiences carrying out work in the discipline. An educational environment designed and implemented by a scientist whose expertise involves years of first-hand generation of data in the discipline carries the possibility, at least, that contextual, practical, epistemological, theoretical, and experimental issues are part of the knowledge

and cannot be easily separated from them. As we have said, this is a fuzzy-edged distinction, in that there are certainly K-12 teachers who understand and can convey disciplinary insights from having only limited experiences; and there are post-secondary educators whose Ph.D. does not guarantee that they are aware of, or capable of conveying, the deeper understanding from their fields.

Designing Learning Environments around Model-Based Reasoning

Two of the six articles in the August 2013 Special Issue of the *Journal of Research in Science Teaching* include excellent examples of how model-based reasoning can be used to re-conceptualize the traditional introductory course at the university level. In one case (Dauer, Momsen, Speth, Makohon-Moore, & Long, 2013), a group of biologists took a specific system, the “Gene to Evolution” model, and used it as a framework to link concepts from molecular-level processes to population-level outcomes. The subject matter in this class spiraled around the development of this model. In the second case (Ding, Chabay, & Sherwood, 2013), an introductory physics course in Mechanics is described and studied. In this program, all of introductory physics is handled through learning how to identify and apply one of three principles (the Momentum Principle, the Energy Principle, and the Angular Momentum Principle). The vast landscape of endless equations that introductory physics classes are known for collapses to the judicious use of these principles.

In 1989, my colleagues and I undertook a large-scale revision of the entire undergraduate chemistry curriculum at the University of Michigan. The centerpiece of this change, and one that still thrives, is the elimination of General Chemistry for the vast majority of the non-engineering students. Based on an adequate high school background, first-term first-year students begin their study of college chemistry with organic chemistry, and, in particular, a re-thought version of the organic chemistry subject matter, based on a modern model of relating structure and reactivity. In fact, just to make the distinction clear at every turn, we do not even call the course “Organic Chemistry;” we call it “Structure and Reactivity” (Coppola et al., 1997; Ege et al., 1997).

The types of assessments we use in this class have driven the instructional design. Because the structure/reactivity model in this subject area is so well behaved, and because organic chemistry does not rely on numerical/mathematical representations, we are able to use the most up-to-date journal articles as the basis for writing examination questions. The power of the contemporary structure/reactivity model in organic chemistry means that hundreds of thousands of new and unfamiliar examples and observations can be understood by the application of a handful of principles (structure: connectivity, stereochemistry,

conformational analysis; reactivity: four transformations involving polar sigma and pi bonds—complexation, substitution, addition, elimination). Exam questions, which usually carry the citation (once again, to signal as clearly as possible that recognition and recall of specific examples is meaningless), present students with data or other pertinent structural or experimental information. As opposed to recognizing and recalling a specific factoid, we ask students to make sense of new and unfamiliar data and to provide an explanation that is based on making meaning from this evidence. Perhaps not surprisingly, "Don't forget to read the question" becomes a familiar admonishment for those who struggle with what we are doing. Up to 30 to 40 percent of the time, exam problems have more than one answer that is completely consistent with the data that are given. Do not for one moment believe that our students are automatically comfortable with this level of uncertainty and ambiguity; they are not. But it is something they learn over the year. Enrollments in the fall term are approximately 1500, and the Drop/Fail/Withdraw (grades of "D" or "F," or those who withdraw) rates are exceptionally small (about 6 to 8 percent).

At every turn in the design and implementation of these classes, my colleagues and I are drawing from our own deep and connected understanding of the subject and its principles. As stated explicitly previously (Coppola & Krajcik, 2013, p. 628): "disciplinary context provides an integrated understanding, where the 'thinking, feeling, and behaving' part of understanding is an indispensable feature of the story. . . . An educational environment designed and implemented by a scientist whose expertise involves years of first-hand generation of data in the discipline carries the possibility, at least, that contextual, practical, epistemological, theoretical, and experimental issues are part of the knowledge and cannot be easily separated from them."

Conclusion

My first-hand experience, drawn from over 30 years of teaching tens of thousands of students, tells me that model-based reasoning is as powerful in designing learning environments as it is in the normal, everyday practice of working with it as a scientist. Indeed, I cannot work without it.

In the classroom, my young colleagues have often reflected on their first experience teaching in the *Structure and Reactivity* courses this way (paraphrasing): *I think what we are doing is simply teaching the science, and not teaching how to do a set of chemistry problems.* Comparatively speaking, we provide a great deal of support (some might call it professional development) for the instructors who are teaching these classes for the first time, including materials and being part of an experienced team that talks regularly with one another about teaching these classes.

There is another side to this coin: What we do is not easy. And it is worthwhile noting that we are in no way under the illusion that we are asking students

to actually construct a new model on which to do model-based reasoning! *This is really hard.* We are aiming at developing students' abilities to understand, use, and apply an actual model with new and unfamiliar, yet authentic, data in both lecture and laboratory settings.

I have a difficult time, then, knowing what I know about my one hard-earned and deeply understood authentic model, understanding how a group of middle school children can both learn the science *and* construct *and* use a scientific model that has deep, lingering, and meaningful effect. Hypothetically, at least, achieving any level of sophistication with model-based reasoning—in classroom practice, scaled up, and in diverse settings—relies on a level of discipline-centered literacy and experience with experimental science that, to the best of my understanding, is not held by the majority of school science teachers. I worry that it becomes the straw that could break the back of that teacher in the New York City program I mentioned earlier, and I am absolutely sure she is not alone.

I understand that this is a provocative statement and let me be clear: I am NOT beating up on teachers. I also understand that there are teachers out there with excellent backgrounds who could approach this, or who could be trained to do this. But if we are going to make this expectation a national standard—a real standard—then a certain degree of realism has to accompany this declaration. This clear view not only lacks a short distance to its resolution, but the mountain of challenges sitting in the way is high and non-trivial. I am looking at the expectations in the NGSS, and I am wondering if I achieve them in my own teaching, or rather, what it would take to do so.

I wish that all of my clever friends and colleagues who worked so long and hard on the NGSS had taken all of that time and thought through about a hundred paradigm-breaking ways for the United States to improve the situation for education in our country. Just to stir the pot a bit more, Yong Zhao and I suggested (2012), for instance:

Incentivize the teaching profession. Even in this era of budget austerity, we need creative, strong, visible, compelling, and cost-effective ways to make the teaching profession more appealing. One drastic measure would be to make primary and secondary teaching an income-tax-free profession.

Reintegrate the disciplines and teacher education. While the United States will never return to the Normal school system, some way of putting teeth into the requirement for our disciplinary and education faculties to work together on this problem is needed. To this end, we should simply require, as a condition of accreditation, a meaningful collaboration between college disciplinary units (chemistry, physics, and so on) and schools of education in the early identification, recruitment, and preparation of future teachers, including programs for engaging precollege students and putting them on this path.

Resist any temptation to standardize and overly regulate higher education in the name of accountability. There is an increasing effort to impose government regulations and external standards upon colleges. These seemingly responsible actions will inevitably bring more regimentation, standardization, and testing, ruining what has made American higher education the envy of the world.

The United States is not Finland, where things are so culturally uniform, and the level of diversity is so low, that it is Finnish citizens who speak a different dialect who are considered the chief minority group. Implementing change is easier, there, than here. The United States is not China, where so many high school teachers are the product of their Normal Universities, in which their teacher preparation is integrated with graduate level research in the discipline. Although China has been the poster-child for Standards-driven education, its experience ought to serve as a warning buoy for the United States: one of the reasons they are starting to scoot ahead of us on measures of technology and innovation is because they have begun to abandon some Standards-based practices at the same time, ironically enough, that we have been moving in that direction. Historically, I think that the absolute level of disciplinary expertise held by their teachers has ameliorated some of the intrinsic problems with standardization, precisely because the teachers could default to their deep understanding of science and experimental practice.

And so I am disheartened when the challenges-cum-strengths of education in the United States are not automatically taken together when I read in this area, because it usually seems to be solutions that are simply disconnected from the real challenge, again and again, *of the diverse character and experience of millions of human beings who are teaching in science classrooms across the United States.*

If I were to set a research agenda for those interested in science education, I think I would aim at the following targets:

- (1) Clump, cluster, and/or prioritize the NGSS into a rational, accessible, nested set of ideas, a subset of which constitutes an actual minimum standard that is rationally accessible by 100 percent of teachers. I think this is a critical exercise in Reality. Call them the *Reality Standards*.
- (2) Think about the ET_{50} measurement, and start thinking in terms of what it takes to get 50 percent of some given test population to an absolute level of success on the *Reality Standards*. We can then learn, I think, how the treatment needs to vary wildly, according to the given population, in order to achieve the same outcome (this is the anti-magic bullet principle). In a sense, this is a statement of the pedagogical content knowledge for effective professional development.

Poster Presentation II

Cultivating Systems Thinking and Engagement through an Intercollege Minor in Sustainability Leadership, August 2013

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Sustainability

Definitions of sustainability are varied and personal. Also, sustainability is broadly interdisciplinary.

Sustainability Leadership Competencies

Sustainability Competencies

- Ability to formulate, articulate, and revise one's own working definition of sustainability, and apply its concepts in multiple settings
- Capacity for systems thinking in sustainability – ability to identify system connections and boundaries
- Proficiency in using sustainability measures and metrics in analyses and decision-making
- Ability to articulate and apply in context the ethical dimensions of sustainability

Leadership competencies

- Ability to articulate a defined self-concept, including one's connections to community and to place
- Ability to implement and facilitate effective interdisciplinary and collaborative approaches to problem solving in sustainability
- Proficiency in describing and responding to different styles of leadership and group dynamics
- Effectiveness in facilitating change toward sustainability in multiple settings

Essential Elements

- Systems thinking and practical leadership
- Opportunity to practice addressing sustainability problems in a non-academic setting
- Both key elements are emphasized in the Sustainability Leadership minor

STEM in Sustainability Leadership Minor

- Includes STEM concepts, social sciences, humanities, and arts.
- Includes the three dimensions in the National Research Council (NRC)'s science education *Framework* (NRC, 2012): *crosscutting concepts* is prominently featured; *practices and core ideas* are also addressed.

Program Design and Requirements

- Program basis can be found in Frank Rhodes's words: the "concept of sustainability could provide a new foundation for the liberal arts and sciences." (Rhodes, 2006, p.1)
- Flexibility built in to ensure the program is accessible to students in any major, on any University campus.
 - Student may focus to varying degrees on the science or mathematics of sustainability, depending on the student's interests, or on the strengths of the campus.
 - All students have exposure to these topics and opportunities to apply knowledge in a practical situation.

Requirements: the 18-credit minor has three parts.

Part 1: Prescribed Coursework [3 credits] - Foundations of Leadership in Sustainability.

Part 2: Elective Coursework [12 credits]

(at least 3 credits at the 400 level; at least 3 credits from leadership courses.)

- 9 credits in sustainability coursework; 3 credits that provide immersive* sustainability experience

Part 3: Capstone Coursework or Project [3 credits]

- Complete a capstone course in sustainability or an independent study approved by minor committee,
- which includes an applied or research experience in sustainability leadership.
- At least 9 credits of the minor degree program must come from *outside* his/her major department.

**Immersive sustainability experiences provide opportunities to engage and learn in depth about sustainability challenges and solutions. Courses meet the requirement for an immersive sustainability experience when they involve:*

- a) the investigation of a sustainability challenge facing a community,*
- b) an inquiry process that helps define a sustainability challenge and/or assess implementation of a proposed solution,*
- c) structured opportunities for student reflection and self-assessment, and*
- d) regular contact with a faculty member to facilitate integration of scholarly content with the immersive experience.*

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