Helping Science Teachers Experience Phenomena-based Science Learning and Understand the NGSS

Final Report of the Exploratorium Teacher Institute's NIH-SEPA Project

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MODULE 1
OVERVIEW AND TAKEAWAYS

> That is what I want a finding of this grant to be: There is no such thing as an NGSS aligned 'thing' that sits there by itself. [Teaching NGSS] is less a reliance on content and stuff and more a reliance on pedagogy.
>
> *- TI scientist-educator*

The story of the Teacher Institute's NIH-SEPA grant is about evolution and lessons learned in the time of NGSS. Teacher Institute (TI) leaders wrote the original NIH-SEPA proposal in 2011, prior to the publication of the Next Generation Science Standards (NGSS). Much in the world of science education improvement changed in the intervening years. The fact that California was an early adopter of NGSS placed the Teacher Institute in a position of leadership for the state's challenge of helping teachers make the shift. Over the course of the SEPA project, the Teacher Institute tested different kinds of resources and learned much about the kinds of supports that are (and are not) useful to teachers as they work to integrate NGSS into their instruction.

This report is in four modules. Module 1 provides background, a summary of key takeaways from the evaluation, and an overview of Modules 2, 3, and 4.

The NGSS

The Next Generation Science Standards (NGSS)[1] are K-12 standards that involve three equally important and interwoven dimensions of science learning: Science and Engineering Practices (SEPs), Crosscutting Concepts (CCs), and Disciplinary Core Ideas (DCIs). This three-dimensional approach to learning science and engineering represents a substantial shift from previous state science standards that laid out, in advance and in a more linear fashion, a sequence of discrete topics to be taught at each grade level.

The Teacher Institute at the Exploratorium

The Teacher Institute is staffed by a group of scientist-educators (Ph.D. scientists who have dedicated their professional lives to improving the teaching and learning of science in schools) and expert classroom science teachers. Their professional learning programs for science educators embody a pedagogy of phenomena-based learning and teaching. Over more than 30 years, the TI has formed an ever-growing community of practice. From the web site:

> *The Exploratorium Teacher Institute (TI) has been the professional development home for middle school and high school math and science teachers since 1984. TI's mission is to create and support a collaborative community of teachers, at all levels of their careers, through professional development that joyfully emphasizes the teaching and learning of science as a process for understanding the*

[1] https://www.nextgenscience.org/

world around us. Each year, more than a thousand teachers attend TI workshops and programs designed to provide opportunities for them to ask questions as learners, share expertise as practitioners, and develop as leaders.

The evolution of the Teacher Institute's NIH-SEPA project

The NIH-SEPA project was initially designed to produce "Digital Teaching Boxes" as web-based resources for teachers. The intent was to take the concept of Teaching Boxes that teachers have long created as part of the Teacher Institute (the physical box in which teachers file all of the resources, tools and materials needed to teach a particular unit), but instead produce digital resources readily sharable with other teachers. The idea was to leverage the broadest reach possible through the internet.

While the Digital Teaching Boxes proved to be useful for the teachers who created them, they were not feasible as resources for other teachers. TI leaders learned over time that what teachers needed was not "stuff"—neither fully sequenced curriculum units nor individual hands-on activities. Rather, in the age of NGSS, what teachers needed was, first, a deep understanding of phenomena-based learning and teaching, including how such an approach integrates the three dimensions of the NGSS; and second, resources and tools they could use to construct phenomena-based teaching sequences relevant for their classroom contexts.

The TI's NIH-SEPA project was also designed to involve working scientists, whose current studies could exemplify the Science and Engineering Practices of the NGSS as well as inspire science teachers to integrate cutting-edge science into their lessons. The TI staff became skilled at involving scientists in teacher institutes by making explicit the intersections of their work and interests, and by preparing scientists to participate alongside teachers as well as to present from the front of the room. Teachers and scientists alike benefited from new professional relationships and greater mutual understanding. TI staff discovered, however, that the nuances and variety of working scientists' practices did not map onto the SEPs of the new standards in a clarifying or helpful way.

Evaluation[2]: The takeaways

The TI's effort to unlock the door to the NGSS

Through cycles of developing, prototyping, and reviewing the design and utility of the Digital Teaching Boxes (DTBs), researchers and TI staff collectively noticed that the DTBs did not meet the feasibility criterion as a resource for teachers. Of further concern, the TI staff learned that the DTB *concept* was off the mark. DTBs did not help teachers teach with the flexibility and context-specific sensitivity that the TI staff see at the heart of the NGSS's three-dimensional approach.

The TI staff gained insight into what lies at the heart of NGSS by experimenting with how they designed phenomena-based learning for teachers. When they engaged teachers in phenomena, asked what they noticed, invited reflection, and asked what they wondered, the teachers' wonderings led the way to the next activity that the TI staff would facilitate. In this way, the TI staff came to see NGSS "storylines" not as prescriptions, but rather, as being composed through the interactions of teachers, students, and what they notice and wonder about phenomena. The teachers who experienced this form of science learning

[2] A summary of evaluation activities is included at the end of this module.

felt inspired, motivated, and informed. They came to understand NGSS through experience rather than by reading or observing.

The Teacher Institute remains vital in its role as an intermediary organization,[3] with its model culture of curiosity that is dedicated to teacher learning and agency. Its leaders continue to learn how to develop supports for teachers and to develop the teacher leaders that the school system needs to model NGSS in the classroom and support their colleagues' learning.

The question of schools' "fit" with NGSS

The lessons learned from this project cause us to wonder about NGSS in the context of real schools. The NGSS are ambitious, calling for an approach to teaching science that is highly responsive to students' interests, sense-making, and questions. This approach asks that teachers have the time and space to reflect on students' work and learning, deliberate with colleagues about next steps, and design the necessary materials and supports. Even experienced professional development providers such as the Teacher Institute educators sometimes scrambled to provide the resources to support investigations sequenced from what *emerged* during a workshop, as opposed to a sequence that was *predicted or prescribed* in advance. One TI leader envisioned this form of teaching in school: "Even for a teacher who has four periods with a similar student population, period one is still different from period three."

There is much concern in the field about whether teachers, as individuals, have the capacity and will to make the needed shifts in practice. As much as we share that concern, we have even greater concern about the extent to which system elements—specifically, the structure of school days, teachers' jobs, and districts' resources and commitment to professional learning—have the potential to adapt such that teachers have a reasonable chance to shift their practices toward NGSS. In the great majority of districts and schools, the embedded structures of teaching work and student work appear to be counter to the vision of NGSS. For example:

- Within a 9-month contract that includes few or no release days, it is hard to imagine how to provide professional learning opportunity adequate to the changes expected.
- Given the typical workday in which secondary teachers and students "do science" – in one of six 50 minute periods devoted to different disciplines, with each teacher responsible for 100+ students—it is difficult to imagine either the student sense-making or teacher flexibility that NGSS call for.

Then there is the prospect of high stakes state science assessments. All of those involved in this project assume that the test that is under construction in California will have a powerful influence on how districts prioritize science and how teachers will be expected to teach science. The question is whether the assessment will influence science teaching toward the vision of NGSS or away.

[3] Intermediary organizations operate at the boundaries of the education system, creating opportunities for teachers and others to act as "boundary spanners," gaining access to multi-organizational networks, specialized knowledge, and resources that they can use to enrich their schools and districts. (Honig, M. I. (2004). The new middle management: Intermediary organizations in education policy implementation. *Educational Evaluation and Policy Analysis*, *26*, 65-87.) NGSS is an example of a policy that school systems cannot feasibly implement without the contributions of intermediaries such as the Teacher Institute.

The following sections serve as executive summaries of Modules 2, 3, and 4.

Lessons learned from the Teacher Institute: Adapting to the emergence of NGSS

Module 2 summarizes why and how the Teacher Institute's NIH-SEPA work evolved away from the proposed vision. It emphasizes the lessons TI scientist-educators learned about NGSS, about supporting teachers in addressing NGSS, and about the involvement of scientists in this endeavor.

About NGSS

Many stakeholders have had a hand and voice in shaping the vision for the NGSS. What one makes of NGSS "depends on where your connection to the [science education] ecosystem is." Meanwhile, teachers await state assessments, which they fear will dominate the conversation: "It comes down to a test. It inevitably will. Unfortunately."

NGSS does not involve teaching a predetermined sequence of topics. "It is not cookie-cutter, it is not conventional at all." There is a good deal of local discretion involved in implementing the standards in real contexts. This is a double-edged sword.

About supporting teachers

Professional development providers and teacher leaders are still (and will continue to be) making sense of NGSS. The wide range of familiarity in the field presents challenges for the design of teacher learning.

All teachers can learn to teach NGSS; however, teachers need differentiated supports. A teacher's first step is to assume that students can figure things out from studying phenomena using SEPs.

Phenomena-based learning helps teachers understand phenomena-based teaching and how to engineer it for their students. Sequencing phenomena-based activities helps teachers integrate the three dimensions of NGSS. The TI has developed a tool that enables teachers to sequence activities at a feasible grain size that is larger than a lesson and smaller than a curriculum.

Teachers need to engage in conversation and meaning-making as they address NGSS.

About working with scientists

The TI staff learned to become more deliberate in scaffolding the scientists' involvement to better contextualize their work for teachers and for students.

While "the idea of focusing on the science and engineering practices rang true," working scientists tend to engage in a vast array of science and engineering practices that are either not what NGSS emphasize or are not appropriate for a secondary science class.

Attending the entire workshop allowed the scientists to engage in the work alongside teachers as well as to interact with them informally so they could better grasp the teacher and student context.

A teacher's lens on the Teacher Institute's SEPA project and NGSS

Module 3 portrays the trajectory of a teacher's professional learning over the period of the SEPA grant. Darcy started her high school biology teaching career with support from the Exploratorium, participated in the early years of the SEPA workshops, served as a teacher-in-residence at the TI where she continued to develop resources for educators, and returned to her district with responsibility for leading NGSS implementation in biology. Her development parallels the Teacher Institute's evolution, beginning with the discovery that pre-designed curriculum units (even those made by teachers) are not very helpful in the age of NGSS, and then working to create tools that can better help teachers shift their practices to align with NGSS.

Darcy's case opens a window onto the realities that districts face as they attempt to address the NGSS in their districts. Even well-informed science teachers are challenged to actualize the NGSS's three dimensions with their students. For administrators—few of whom have science or science teaching backgrounds—awareness of the nature of the NGSS and what they demand of teachers remains elusive. Some steps the district took toward implementation inadvertently created more obstacles and resistance. Further, the district's habitual curriculum development practices and teachers' jobs are not structured to provide the amount and kind of supports that teachers need to shift toward NGSS.

Three profiles of phenomena-based classroom teaching

Module 4 includes accounts of how three experienced TI alumni anchor their science teaching to phenomena. All three teachers' use of phenomena-based approaches emphasize their efforts to make the science learning not only engaging but deeply relevant to the students.

Profile 1 is of a teacher who uses the phenomenon of coral bleaching—relevant to youth in the time of climate change—to teach matter and energy cycles involved in cell respiration and photosynthesis. Her approach emphasizes the scientific practice of modeling.

Profile 2 is of a teacher who uses the phenomenon of identity to explore the question of "nature *vs*. nurture" with respect to genetic traits that form who we are. This teacher, who works in a continuation high school, wants to explore with his students how they can best navigate their lives through high school and beyond.

Profile 3 is of a teacher who situates the teaching of genetic inheritance in the real-life dilemma of a young couple seeking genetic counseling before they decide whether to conceive a child. This teacher specializes in the teaching of biology to English language learners.

Each profile includes sample artifacts of teaching and learning.

The profiles exemplify the kind of teaching that the Teacher Institute supports and that aligns with NGSS. They demonstrate the value and usability of the sequencing tools the TI has developed to help teachers create the storylines for the phenomena-based units. This approach to teaching enables teachers to draw from their own areas of expertise—including socio-cultural dimensions of some phenomena, such as identity—in ways that match their philosophies of student-centered, investigation-based teaching.

The profiles also imply some challenges of phenomena-based teaching. There is no cookie-cutter framework. The examples are neither simple or straightforward in the different ways that the three teachers frame the anchor phenomenon and its relevance to students. The profiles thus exemplify both the promise and the complexity of shifting the teaching of science closer to NGSS.

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The evaluation included:

- Semi-annual reflection and planning meetings with TI leaders
- Observations of NIH-SEPA summer institutes for teachers
- Interviews of participating scientists
- Surveys and interviews of participating teachers
- Interviews of teachers who created Digital Teaching Boxes
- Facilitation of teachers' reviews of the design and utility of Digital Teaching Boxes
- Interviews of TI leaders
- Sequence of interviews of "Darcy," profiled in Module 3
- Sequences of interviews of and artifact collection from the teachers profiled in Module 4

Findings and formative feedback were provided over time to TI leaders to contribute to their decision-making. Annual evaluation reports were submitted to TI staff.

MODULE 2
LESSONS LEARNED FROM THE TEACHER INSTITUTE: ADAPTING TO THE EMERGENCE OF NGSS

Evolving away from the initial vision of the project

The Teacher Institute leaders wrote the original NIH-SEPA proposal in 2011, prior to the publication of the Next Generation Science Standards (NGSS). Much in the world of science education improvement has changed in the intervening years. The field has evolved in its collective meaning-making and understanding of the NGSS as states and districts have worked to implement them. The uses of technology—digital resources, online courses, and e-books—have also played out differently than many anticipated. With the availability of curriculum resources lagging behind the pressure to adopt NGSS, the ways that teachers use the internet and online resources to plan their lessons has changed.[4] Importantly, Teacher Institute scientist-educators—who are steeped in phenomena-based teaching and experience with NGSS—have become increasingly sophisticated in their understanding about how best to support teachers in addressing the NGSS with their students.

This module summarizes why and how the NIH-SEPA work evolved away from the initial vision. It emphasizes the important lessons TI educators have learned about NGSS, supporting teachers in addressing NGSS, and the involvement of scientists in this endeavor.

The NIH-SEPA project initially aimed to produce "Digital Teaching Boxes" as web-based resources for teachers. The intent was to take the concept of Teaching Boxes that teachers have long created as part of the Teacher Institute (the physical box in which they file all of the tools and materials needed to teach a particular unit), but instead produce digital resources readily sharable with other teachers—so as to leverage the broadest reach possible through the internet:

> *[The proposal writers] were very clear that this was not about creating curriculum or an e-textbook, but it was about developing and using the original process for developing teaching boxes—as a professional development tool—to start to understand NGSS.*[5]

Digital Teaching Boxes proved to be useful for the teachers who created them, but not as useful for other teachers as the TI educators originally expected.

> *There was a piece of the original proposal that we have now gone away from and that is related to the evolution of these products created by teachers. The idea was, 'oh, well then [these teaching boxes] would be useful to everyone, and anyone interested could download this thing*

[4] Data from the Exploratorium show that teachers are more likely to search for and download materials for same-day classroom use than for planning or professional development.
[5] All quotations are from in-depth interviews with the lead scientist-educators who direct TI programs.

and be able to do more NGSS-aligned instruction in their classroom.' Now that we are on this side of it, it is pretty clearly not the strategy that we would want to continue doing.

The NGSS: A substantial shift in the approach to teaching science

The Next Generation Science Standards (NGSS)[6] are K-12 science content standards that involve three equally important and interwoven dimensions of science learning—Science and Engineering Practices (SEPs), Crosscutting Concepts (CCs), and Disciplinary Core Ideas (DCIs). Science and Engineering Practices are intended to represent the skills that science requires, what scientists actually do as they investigate the natural world, and what engineers do as they design and construct systems. It is within the SEPs that cognitive, social, and physical practices are combined and scientific inquiry is brought to the fore. In addition, the NGSS emphasize engineering design to a greater extent than previous science standards. Crosscutting Concepts are those that connect across four traditional science disciplines—Physical Science, Life Science, Earth and Space Science, and Engineering Design (e.g. cause and effect, scale, systems, energy, structure and function, etc.). Disciplinary Core Ideas are the essential important building blocks across multiple disciplines that can be built upon as students advance. DCIs are grouped into four domains: 1) physical sciences, 2) life sciences, 3) earth and space sciences, and 4) engineering, technology, and applications of science.

This three-dimensional approach to learning science and engineering represents a substantial shift from previous state science standards that laid out, in advance and in a more linear fashion, a sequence of often discrete topics that would be taught at each grade level. The design of the NGSS was intended to enable educators to have flexibility in designing learning experiences for their students that would stimulate their interests in science, while engaging them in the authentic processes of science—i.e., to mirror the ways in which science is conceived and done. Thus district leaders have discretion in how to implement the standards.

Lessons learned about NGSS

The realities of NGSS as they have played out in the field gave the Teacher Institute educators the challenge of adapting their SEPA project and the opportunity to learn about NGSS.

- **Many stakeholders have had a hand and voice in shaping the vision for the NGSS**

Teacher Institute leaders recognize that experts from a wide range of perspectives—learning researchers, scientists, administrators, leading practitioners—have played a role in shaping the NGSS, and that certain visions for NGSS have risen to prominence. For example, the practice of modeling and working from NGSS storylines have become high profile focal areas.[7] A TI scientist-educator explained how the TI wants to position their work:

[6] See https://www.nextgenscience.org/ for more information

[7] Examples include Brian Reiser and the NGSS Storylines team of Northwestern University (http://www.nextgenstorylines.org/storylines-team) and Cindy Passmore's modeling team at UC Davis (https://www.modelbasedbiology.com/front-page).

Particular people's and organizations' visions for them [the NGSS] come to the top … it just depends on where your connection to the ecosystem is. There are folks who are more research-interested, like NARST. Different groups carry different weight. I guess I would argue that we [Exploratorium] are trying to become a voice in California through our work with teachers, where we might pose our thoughts on what phenomena are or what modeling is.

There is nonetheless still a good deal of local discretion involved in implementing the standards in real contexts:

There are key researchers who really influence NGSS, and then what is interesting is how that gets taken up by different groups. I think a lot of people are getting their information from the rollouts, which are hit or miss, at best. It is interesting to see where the different people land on it. Just based on when I go to my kid's school, they haven't had a lot of PD around the NGSS. Their idea of modeling is very different from mine.

Will the assessment narrow the interpretation? Teacher Institute leaders believe that the assessments, as they are rolled out, will surely drive teachers' (and others') ideas of how to define particular elements of the NGSS, such as the criteria for anchoring phenomena, modeling, and analyzing and interpreting data. TI staff recall hearing Brian Reiser emphasize that NGSS should not be about the Performance Expectations, *per se*. Rather, teachers should focus on the three-dimensional aspect of NGSS and bringing together the SEPs, CCCs, and DCIs. Yet TI leaders have noted that that message has been lost; as the assessments are being developed, they are mirroring the Performance Expectations and teachers are wrestling with what they should focus on. It is an unfortunate possibility that as the assessments are developed, the NGSS will be reduced to a set of Performance Expectations:

It comes down to a test. It inevitably will. Unfortunately.

- ***NGSS does not involve teaching a predetermined sequence of topics***

The NGSS do not emphasize a particular linear order of topics or content that a student should learn in the way that a traditional textbook might. NGSS emphasize phenomena-based learning, modeling, concepts, and science and engineering practices that cut across different topic areas. Therefore, science teaching and learning may not be as predictable as it has typically been thought to be, or as systematic as it has been taught in the past. With NGSS, teachers determine the sequence of activities that makes the most sense given their students' current understandings and the nature of the phenomena they are investigating. The prospect of creating a "Teaching Box" made more sense when a certain order was expected or even known in advance.

How kids are making sense of things is different than it used to be.

In fact, what NGSS-aligned teaching looks like can be context- and moment-dependent.

It is not cookie-cutter, it is not conventional at all. Even for a teacher who has four periods with a similar student population, period one is still different from period three

- ***Professional development providers and teacher leaders are still (and will continue to be) making sense of NGSS***

A challenge that TI has had to deal with is the range of teachers' familiarity with the NGSS, even within one workshop cohort. As one leader said:

> *I don't feel like I yet have a way that I am super comfortable with to make explicit what I think is NGSS-y in a workshop. If you don't have time for a debrief where you can say, 'Let's all reflect on the practices and crosscutting concepts and the DCIs that appeared in this lesson and unpack how they tie back to a phenomenon'… I haven't found a way that feels good yet to be able to meet everyone on the continuum. And if we don't do that, they don't know.*

Further, helping teachers initially grasp NGSS and then translate them into classroom practice is such a complex endeavor that even the TI's scientist-educators are grappling with the challenge:

> *If you haven't started teaching them yet, maybe you still need introduction to NGSS. So how to make that clear to our audience, I think, is going to be important for us as the range just keeps growing. We are still figuring NGSS out ourselves.*

Lessons learned about supporting teachers

- ***Teacher Institute educators have become more deliberate in integrating the three dimensions of NGSS***

When the SEPA project started, TI leaders focused on the Science and Engineering Practices aspect of the NGSS because the practices felt familiar and well-aligned with the general Teacher Institute approach.

> *We did feel like a lot of the practices were built into how we had been working with teachers since the beginning and in working with the scientists: 'Oh, these scientists are kind of the working embodiments of why these practices might be useful'. They seemed to overlap well with what we were focusing on as a team within the department and with our teachers and given what the scientists could bring in.*

Since then, while TI still considers the SEPs, they have become more sophisticated in thinking about all three dimensions—the SEPs, CCCs, and DCIs. They have found that framing their work around anchoring phenomena has helped them illustrate that the three dimensions do not exist in isolation of one another.

- ***All teachers can learn to teach NGSS; however, teachers need differentiated supports***

In the same way that teachers differentiate their instruction for their students, TI educators are constantly reminded that they need to differentiate support for teachers who are learning about NGSS.

When asked if they felt there was a set of criteria that captured "readiness" for addressing NGSS, one TI leader said that teachers need to believe students can handle the demands of NGSS:

*I think you have to fundamentally believe that kids can do that work and that kids are capable of making sense of things. I think if you fundamentally **don't** believe that about kids, or you believe that you have to supply the knowledge before kids are able to take things up, that is the biggest challenge. I think that there are some teachers who really believe that you have to tell kids things to get them there.*

TI leaders feel that all teachers—from preservice to first-year to veteran teachers—can teach NGSS. However, it is critical to support teachers in taking incremental steps from where they are starting.

I believe that every teacher of science is ready to teach NGSS. They are in some ways like the kids, where we've got to help them teach NGSS with whatever they need. I think that is our job. Just like a teacher should think about this for students, for us it is, 'Okay for this particular teacher, what is it that he or she needs that might get them another step further in their journey in NGSS?'

Of course, differentiation is time-, resource-, and thought-intensive work and only a percentage of teachers are able to get direct, face-to-face support for NGSS. This is part of why TI leaders wanted to develop digital resources. Yet TI staff have learned that the resources that result from a development process that is particularly useful for one teacher may not be useful to another teacher, precisely because that other teacher is at a different point along a journey to teaching the NGSS.

I have zero guilt in saying that canned online resources are not what teachers need. They are not reflective of what we have come to believe that NGSS alignment is. [The teaching] is really in the context of the moment. It is having teachers helping students understand how to leverage all of the things that the students in that class are saying and doing and interested in and their curiosity …

- ***Phenomena-based learning helps teachers understand phenomena-based teaching and how to engineer it for their students***

A hallmark of Teacher Institute programs is that teachers engage in rich inquiries into phenomena as learners. These first-hand learning experiences are where teachers can have their interests piqued, experience the wonder, and come to grasp phenomena in such a way that they understand and appreciate how to engineer the same experience for their students. However, teacher Institute leaders have shifted their thinking and design of these pieces as they have come to better understand the role of three-dimensional learning in NGSS.

The one thing that is so consistently helpful is having the teachers experience that learning for themselves—but even what that looks like has changed over the last handful of years as our thinking around NGSS has changed.

After teachers have experienced phenomena-based activities for themselves, TI then supports teachers to connect activities in such way as to make the NGSS alignment journey for themselves.

So our shift from, 'Here is a set of eight [phenomenon-based learning] activities' to 'Here is a tool to help you connect your activities'… that is a parallel to NGSS itself.

Another TI leader added:

> *That is what I want a finding of this grant to be: there is no such thing as an NGSS aligned 'thing' that sits there by itself. [Teaching NGSS] is less a reliance on content and stuff and more a reliance on pedagogy.*

- ***Sequencing phenomena-based activities helps teachers integrate the three dimensions of NGSS***

Teacher Institute leaders have recently developed and honed a set of sequencing tools that help teachers articulate their purposes for engaging students in particular activities *and* how the three dimensions NGSS are illuminated through those activities.

> *I am thinking about the sequencing piece and thinking about how to help teachers think about a bigger picture than just this one activity where you use these practices. It feels more complete or deeper: yes, you need these activities where students are doing science and engineering practices… AND to get at the three dimensions to understand that content and weave through the crosscutting concepts, it really is about the sequence of activities… That has been a good evolution and is truer to what NGSS really is.*

One TI leader recalled a teacher leader who recently described how teaching the NGSS has changed teachers' orientation to designing instruction:

> *We have changed the 'why' we do [phenomenon-based learning activity].*

The idea for developing a tool to help teachers think about the 'why' behind engaging their students in activities and sequencing multiple activities in a particular way was driven in part by teacher demand. As TI leaders designed workshops that introduced teachers to phenomena that were unfamiliar to them, and as teachers engaged in activities around the phenomena, the teachers' their own questions drove what activity TI leaders would facilitate next. Feedback on these workshops was so positive—particularly about the teachers' opportunities to think about activities in a sequence—that TI leaders began incorporating this element into workshops more often. They realized how powerful it was for teachers to engage in this process first as learners, and then as designers who could leverage phenomena and students' questions to propel curriculum and instruction.

The development of the sequencing work was a natural extension of how the TI workshops were evolving to help teachers streamline their approaches to implementing the NGSS in a more digestible way. The sequencing tool is a concrete device for teachers to hold onto as they go through the journey of figuring out how they will teach the NGSS. It is not as overwhelming as an entire curriculum and yet it is not as minimal as a single activity[8] might be.

- ***Teachers need to engage in conversation and meaning-making as they address NGSS***

Teacher Institute staff (and others) initially believed that the collection of Digital Teaching Boxes would be a repository of resources that other teachers could use:

[8] Or "snack" in TI parlance. https://www.exploratorium.edu/snacks/about

The whole idea was teachers would have 'stuff'—classroom materials, activities, videos, and the teachers would put that 'stuff' together, and then it would all be in a collection. I think one of the things that has changed my thinking is that the real work of moving towards NGSS doesn't feel as much to me as just pulling together a bunch of new stuff.

In fact, more important than pulling together a collection of artifacts is the conversation that needs to take place around the artifacts. As a teacher collects "stuff" for a teaching box (digital or physical), they are going through an annotative process in their minds—explaining to themselves why something might be of value and how they might use it. When that 'annotation-through-thinking' is not transparent to another teacher who looks at the teaching box, much of the actual value is missing. As one TI leader said, the NGSS alignment comes in as the teacher puts all of the resources together, works to frame the challenge, and thinks through how teaching and learning is likely to happen. Generating and organizing the "stuff" is the valuable process of interpreting the NGSS.

Lessons from working with scientists

Biology and health sciences present intrinsically interesting ways to engage students in natural phenomena. Whether it's questions about themselves or the living things around them, students are predisposed to be curious about life and health. Involving active research scientists working in these fields can infuse the science education with relevance that connects students' day-to-day lives with cutting edge scientific research.

- ***Make explicit the connections between science and the learning of science***

The plan to include scientists in this TI SEPA project built on TI's previous SEPA project with Caltech. Through that project, TI addressed modern health science topics by incorporating practicing scientists to provide the latest information and perspectives on health science research. That work proved to be fruitful in a reciprocal fashion, with teachers having access to currently practicing research scientists and scientists increasing their knowledge and understanding of what K-12 science education involves.

In this second SEPA project, the TI staff learned to become more deliberate in scaffolding the scientists' involvement to better contextualize their work for teachers and for students.

What I have thought a lot about is how to use scientists in a more interesting and beautiful way. I feel like I have a series of tips and tricks that I can sort of synthesize into a presentation about bringing scientists in and making that meaningful. I've thought a lot about how to frame scientists' research and how to engage students in considering the research questions before the scientists give their eloquent presentation. How to make activities that you can actually do in the classroom that will get at those questions that scientists are looking at from a high level. That was my big take-away from the scientists that came in.

- ***The challenge to connect on Practices***

Bringing in scientists also made sense to the TI team because the NGSS emphasize science and engineering practices. Program leaders thought that scientists could help teachers understand what

science practices look like in real life. One key to making this connection was to ask scientists to explain how their work is related to the Science and Engineering Practices in NGSS.

On the whole, however, connecting on SEPs did not work as well as the more content-related connections. The TI team discovered that, while "the idea of focusing on the science and engineering practices rang true," working scientists tend to engage in a vast array of science and engineering practices that are either not what NGSS emphasize or are not appropriate for a secondary science class. Some TI leaders feel that the NGSS SEPs are a "funneled" down version of what scientists actually do. As a result, the scientists' involvement was less helpful in this area than as originally envisioned.

- ***Embedding scientists in teachers' professional learning***

For some institutes, TI leaders were able to embed a working scientist for the full week. Attending the entire workshop allowed the scientists to engage in the work alongside teachers as well as to interact with them informally, rather than just during the sessions they presented.

> *I was really happy with asking the scientists to come to the whole workshop and have them go last so that they spent this time with teachers. Not all of them, but definitely some of them responded really positively to that: 'Oh I am listening to these teachers' conversations, and I am understanding what their concerns are, and what they think about, and what are middle school kids in the science classroom really experiencing right now?' That is not irrelevant to practicing scientists.*

Summary results

What Teacher Institute educators ultimately learned through the SEPA project has affirmed some elements of their core work with teachers but has also led to a significant shift in their strategy for supporting teachers with NGSS.

- **Teachers need supports for learning from experience, reflecting, and re-designing for the classroom**

TI staff know it is important for teachers to experience first-hand the same phenomena-based learning opportunities that their students experience—and this is an area that TI has long excelled in. Beyond this, TI educators have learned that teachers need to be given a significant amount of time and space to have meaningful, facilitated conversations so they can make sense of their learning experiences and re-engineer them for their own students.

> *We and they need to experience through models, plus phenomena-based experiential learning. And it helps to have some tools for them to be able to reflect on their own learning experiences and then reconstruct them for their own students and their own context and their own subject area. And they need to be given time and space to work together to do all of this.*

While TI staff recognize that they can provide these ingredients for the teachers who participate in their programs, they can only hope that the majority of teachers will receive from their administrators the time and space required for learning from experience, reflecting, and engineering for the classroom.

- **Pivoting to a new strategy to support teachers with NGSS-aligned resources**

TI leaders have moved away from a strategy of supplying teachers with a plethora of lessons that other teachers have adapted to be more aligned with NGSS. They are moving toward a strategy of providing teachers with tools and supports to help them go through the process of aligning activities with NGSS. TI educators believe the power of "making something NGSS-y" lies in the teachers' experience of that process. Rather than simply posting Digital Teaching Boxes that other teachers have created to support their own teaching—and that might only be seen by a handful of other teachers—TI is using a strategy to assist teachers in "NGSS-ifying" the phenomena-based activities (referred to as "Snacks") that already exist on the Exploratorium website and draw over two million educators every year.

> *That was a change in strategy that was both influenced by how we started to feel about the digital teaching boxes, and what is really useful, and also taking advantage of the separate audience [for Snacks] that was built through another project. So what is important here is we do believe that Snacks on that scale can be useful. We don't label them as 'NGSS' because as they are written and on their own, they aren't authentic to all of the NGSS. But we do feel like many of them are appropriate or ready to be implemented in NGSS-style, and so our attention is now on building out the section that is about 'how do you use snacks in NGSS,' which is really about how do you use any activity in NGSS.*

The SEPA project provided opportunity for the TI educators to learn how best to leverage existing resources while making them more relevant to the age of NGSS.

> *Those online resources are a huge potential opportunity to reach so many more people and this project has helped us further develop that, one by expanding our life science focused aspects in terms of new snacks, many of which were developed through workshops in this project over the last two years. Building out the NGSS resources and the sequence tool is part of that. So while we don't have a website of 50 digital teaching boxes, I think we do have a website that already has a much larger audience that is going to do more and go further for helping people understand how to do NGSS. I think it is a pivot, rather than a complete discard of our plans.*

Over the past couple of years, the NIH-SEPA project (and others) have learned more and become smarter about supports that are most useful to teachers as they work to integrate NGSS into their instruction. When the TI NIH-SEPA project started, everyone was operating under the assumption that giving teachers more "stuff" would help them shift to NGSS. Having more Snacks or even a full Digital Teaching Box—turns out not to be sufficient, even with the support of a coach or mentor. Rather, teachers need time, space, and support to sit with and think through the rationale and foundations of the activities. Teachers also need determine for themselves how they will sequence activities and contextualize them for their own students and their own schools, given a range of conditions, e.g.., school requirements, what their colleagues are teaching, their own calendars, and so on. Even in TI's work to help support teachers in sequencing snacks, they are not telling teachers, "This is what the sequence of activities *should* be." Rather, the sequencing tool TI is designed[9] to encourage teachers to reflect on the assumption that the value will come in the meaning-making and customization.

[9] TI staff are creating the sequencing tool through multiple rounds of prototyping, testing, and refinement.

These shifts in strategy are consistent with the overall stance of the TI scientist-educators. They know that teaching is not just a disciplined endeavor but is also a personal experience, and they respect teachers as agents of their own learning and their classroom instruction. TI operates from the assumption that what is most useful for teachers is to provide high quality and effective resources for teacher learning—along with the time and space for teachers to customize their learning and instruction, all in dialogue with one another and with TI scientist-educators.

MODULE 3
A TEACHER'S LENS ON THE TEACHER INSTITUTE'S SEPA PROJECT AND NGSS

> *I get the same feeling every time I leave one of [the Teacher Institute] workshops, which is like, 'Oh man, this is so fun, and I have so much more to learn.'*
>
> *–Darcy, high school biology teacher*

Darcy[10] teaches biology in a high school district in the San Francisco Bay Area. She originally became involved with the Teacher Institute as a member of the *new teacher induction program* in her first and second years of teaching. She returned as a *participating teacher* in the regular TI program through one of the early NIH-SEPA life science workshops with scientists. As an *active TI alumnus* Darcy contributed to the development of Digital Teaching Boxes and other TI resources. Later, Darcy contributed to the Teacher Institute work as a *Teacher-In-Residence,* helping to design and lead TI workshops for other teachers. In her current role as *instructional coach* for her district, Darcy continues to incorporate what she learned through the Teacher Institute and to learn about supporting teachers in addressing NGSS.

Darcy's work before and during the time of the SEPA project was shaped by and in turn shaped the Teacher Institute's perspective on teacher professional development in the NGSS era. Thus her case provides a teacher's lens on the lessons that TI has learned about NGSS and on the supports that teachers need to address NGSS in their own practice. Her lens also puts the spotlight on the challenges that district leaders face in implementing the new standards.

Darcy's evolution with the Teacher Institute

➢ An "Aha" moment with scientists in the SEPA workshop

The idea for the SEPA workshop on 'Nature versus Nurture' was to draw on scientists' expertise in both content and SEPs (science and engineering practices), in such a way that teachers would learn actively, by working alongside scientists, how to incorporate them into their classroom instruction. Darcy chose to participate because the workshop was focused on genetics and the environment, an area she needed to teach.

> *I signed up for that workshop because here was a new part of the standards that had to do with genetics and the environment, and that was part of my genetics unit that I never considered teaching…I didn't have enough content knowledge in the subject…I didn't really know how to incorporate that into my class.*

[10] A pseudonym

Darcy says the scientist-in-residence that summer was very helpful as a resource to whom she could ask questions about the science. She remembers doing activities on cancer and seeing cells in the Bio Lab, which prompted her to confront all of the assumptions she had made about her own students' experiences in the lab.

> *I appreciated that we went and looked at cells in the Bio Lab and it made me realize 'Oh my god, I assume so much of my kids.' When I looked at the cells, I couldn't tell which were cancer cells and which were normal, because I didn't actually know what a normal cell is supposed to look like. 'If I don't know what a normal cell is supposed to look like, I don't know how my kids are supposed to figure that out?'*

- **A first Digital Teaching Box based on her teaching experience**

As part of the SEPA-funded project, Darcy created a Digital Teaching Box. Free to choose any life science topic, Darcy chose topic homeostasis.

> *During the teaching boxes time,[11] [workshop leaders] said 'We want these digital teaching boxes to be a resource for teachers, in which you have thought through a unit or a lesson sequence and provided your "teacher take" on how to do particular activities.' I wouldn't say that it was necessarily geared towards or that it was supposed to be aligned to NGSS or anything like that. Because what we were doing in the institute was relatively new to me, I felt more comfortable working on a teaching box that had to do with a unit that I had already taught and so I did the homeostasis one.*

Only in retrospect did Darcy consider that it was "not aligned to NGSS at all." Darcy says the decision-making process that she went through in developing the homeostasis teaching box was very different from how she thinks about lesson sequencing now.

> *Back then, it was a lot of what made sense to <u>me</u> in my mind, but there were no attached phenomena, and I didn't really think about, 'What are the SEPs that students are going to be using for each of these activities?' and 'Am I giving students a breadth of SEPs and cross-cutting concepts?' None of that was in my planning process at all. I made some instructional decisions that made sense to me because I knew the order and the sequence that I wanted, but it definitely was not aligned to the new standards.*

At this early stage in the SEPA project, NGSS had so recently appeared on the horizon that TI leaders had not yet begun to adapt to the standards.

- **As a Teacher-In-Residence, creating a first 'NGSS-aligned' Digital Teaching Box**

Later, Darcy contributed to the Teacher Institute work as a *Teacher-In-Residence* who helped to design and implement TI workshops for other teachers. At this time, the Digital Teaching Box (DTB) strategy still seemed viable, but the TI leaders wanted teacher-developers to align them with NGSS. Darcy describes the "big changes" that NGSS brought about in her design.

[11] Some afternoon sessions in the 5-day workshop were devoted to teachers' time to plan and develop the digital teaching boxes.

That Digital Teaching Box is a lot stronger. We had an initial phenomenon and we provided some resources for how you might present that phenomenon to students. Then the sequencing was really more about 'Okay, what have the students figured out from this activity, and what questions are they still going to have, and then what activities should come next to address those questions?' Which was not the way I used to do my lesson planning at all. I think that was a big change. And just having the phenomena was a really big change.

Darcy's prior lesson planning process, in contrast, was a more linear process that reflected her own understanding of science content and the order in which she learned it.

It would make sense to me because I already knew the science content and so I thought, 'Well, to understand this concept, you have to understand this before, and this after'… but it wasn't driven by students' questions, and it wasn't driven by what they were interested in. So that has been another big change.

Darcy feels the more recent approach to lesson design is both inherently stronger and more effective for learning, as well as more aligned with the NGSS. She points out that a large part of NGSS emphasizes that students should be engaging in the Science and Engineering Practices (SEPs) and figuring things out for themselves. Darcy believes it is more motivating for students to want to learn the content if the sequence of investigations is driven by their interests.

Darcy was able to be more intentional in addressing NGSS for this later Genetics DTB because she was sitting with TI educators who were instrumental in moving her thinking toward sequencing activities based on students' questions and interests, rather than solely on her own assumptions.

I think actually just sitting next to [a TI educator] as I worked was really influential. She is a super good resource in terms of NGSS, and the way she thinks about how to organize a workshop is the way I wish teachers would. She was the first one to really introduce me to, 'Okay, so after each activity, we really need to think about what can students figure out from it, and what questions do they have next.' And that was a big change for me. I had never thought of planning that way.

The one-on-one mentoring (guidance and feedback) made it possible for Darcy to follow through with this new approach to sequence a unit plan.

Darcy's thoughts on NGSS

- **Students using SEPs to "figure things out"**

This is how Darcy would describe the key design features of NGSS to someone who is unfamiliar with them:

I would start with the whole idea that students are no longer learning about something, they are trying to figure out something. I think that is the biggest shift. And that in order for students to figure something out, we have to have them using the science and engineering practices to do that. So, it is no longer a list of facts or even just, 'Here is a hands-on activity, here is a hands-on

activity, here is a hands-on activity.' It is, 'What practices is each activity providing for the students to engage in?' And 'How is that activity going to help students address something that they are figuring out?'

She shares a concern with Teacher Institute leaders, which is that not all teachers believe their students are capable of engaging in the SEPs and learning according to NGSS.

> *I think one of the hard things is that a lot of teachers just don't think their students can do it. I think a lot of teachers have this idea that the students just aren't going to be able to figure it out, and that it is just more efficient for [the teacher] to just tell them the science.*

- **Teachers facilitating language-intensive, non-linear learning**

In addition, as others have pointed out, NGSS (particularly in Life Sciences) is language-intensive, which can pose access issues for English language learners. It is up to the teacher to create the conditions in which learners can ask questions. Darcy knows that teachers are very concerned about how to facilitate all-important science talk among students, especially in heterogenous classrooms.

> *I think that there are also a lot of issues about equity, because this new model really has like a focus on, the students have to be talking to each other to figure something out. So, you have to basically create a classroom environment where if you are in a heterogeneous classroom, the kids are comfortable talking to each other… and the kids are comfortable not knowing something, and they want to take academic risks and suggest something that they are not sure is correct. That is something that I think even [native speaking] students are not comfortable with yet. I am finding that that is something that a lot of teachers are worried about.*

Darcy points out that the NGSS are not linear, but instead rely upon teachers' facilitation of student dialogue and questioning. She knows that many teachers are fundamentally uncomfortable with this approach.

> *I think a lot of teachers are just uncomfortable giving up control because a lot of this is kind of like you really have to give students a chance to ask questions. You can kind of plan for that and you can kind of figure out what questions you think the students will ask, but there is a piece of NGSS that is a bit unpredictable.*

How Darcy's district approached NGSS

Now that Darcy is the instructional coach for the same district where she started teaching, she has the perspective of a teacher who taught in the district prior to NGSS, who was teaching as the district decided to adopt NGSS, and now as a lead point person for supporting teachers in the district as they continue to address the NGSS.

- **The school site dives in first**

Darcy remembers that the NGSS came out in Spring of 2013 and that as soon as they were released, her school site decided to dive in. She recalls that the NGSS were "super overwhelming" and she didn't even

understand how to read them. That was her and her fellow teachers' first hurdle. In 2014, Darcy started actively searching for workshops and professional development so she could become more familiar with NGSS. She went with a colleague to a week-long workshop on the Science and Engineering Practices sponsored by the California Academy of Sciences. That workshop helped her understand that the three dimensions of the NGSS were supposed to be integrated, but she still was not clear how to do that.

At Darcy's school site, they decided to take a small initial step of incorporating more claim, evidence, and reasoning (CER) pieces into the curriculum. She describes it as "the first itty-bitty steps that we took." Her own district offered professional development that provided a graphic organizer that teachers could use with their own students on which they would write down a claim, then complete a column for their evidence and a column for their reasoning. CER became the instructional focus for 2014 and 2015.

- **The district dives in, but with insufficient preparation**

The next step the district took in trying to address NGSS has had lasting implications for the teachers. In 2015 and 2016, the district asked groups of three to four teachers to (on a voluntary basis) develop their own curriculum that was "NGSS-aligned." However, the district did not provide any guidance, preparation, or training in large part because district leaders did not fully understand what was required.

> *Basically, we were trying to make NGSS fit into things that we were <u>already</u> doing, and so what we ended up with was not well aligned with the standards at all. We basically kind of said, 'Okay, well in this activity, the kids are kind of planning and doing an investigation and so we will tag that as an SEP that they are going to use.' But there were no phenomena and the sequence wasn't great. Each group of teachers basically did the same thing: they kind of cobbled together what they already had, slapped on some SEPs and crosscutting concepts, and called it a day.*

When it became clear that these products were "seriously lacking," the teachers felt frustrated and unsupported. This was the climate Darcy encountered when she returned to her district in 2018 as a leader for NGSS.

> *A lot of teachers were kind of feeling like oh, we keep kind of doing these things, but then backtracking and realizing that it wasn't good enough.*

In hindsight Darcy wishes they had started with greater awareness:

> *We started too early I think. I think we probably should have spent that time becoming more familiar with NGSS first. We kind of jumped the gun so that was definitely something that a lot of people are still grumbling about. We just ended up with a product that we are not all happy with.*

- **Key administrators remain unaware of what it takes to support a shift to NGSS**

Darcy is aware that many, if not most, district and school administrators are themselves so new to NGSS, that they are not always sure how best to support teachers.

It is very rare for an administrator to even have a science background. If I think of all of the principals and vice principals in our whole district, I only know of one who used to be a science teacher. So yeah, they are not comfortable with NGSS at all, which makes some of their decisions a little bit difficult.

She cites the district's decision to ask teachers to align their curriculum with one another, while simultaneously aligning it with NGSS, as an example of their incomplete understanding of what is required.

The administrators said, 'Since you are going to get aligned with each other, you might as well align all of your curriculum with NGSS.' When I heard that, I thought, 'Whoa, those two things can be very different.' To cram both of those things into one school year is pretty much impossible and that is basically what happened. Teachers became sort of more aligned with each other, but their curriculum is not aligned to NGSS at all. I think that has to do with the fact that the administration doesn't really understand how much work it takes to become aligned with NGSS. I think they thought that adding on that NGSS piece just involves putting a checkmark after each activity saying that we did an SEP maybe. But that is not what NGSS looks like. I would say that I wish the admin were more familiar with what the changes that are required, but they are not.

Darcy's experience that district administrators are not well enough informed about the NGSS or what it takes to support teachers mirrors the experience of many teachers across the state. A survey of 233 teachers in 2018 showed that 26% of administrators understand NGSS and 36% of teachers do.[12]

How Darcy supports teachers in addressing NGSS

Starting in 2018-19, Darcy has been providing NGSS support for four comprehensive high schools in her district, along with one charter school. She describes her job as providing any support that teachers need to align their instruction with NGSS.

- **Introducing teachers to key shifts in practice**

Even though the district dived early into re-tooling the curriculum, 2018-19 is the first year the district has required any mandatory preparation in NGSS for teachers; in the past, it has been voluntary. Darcy has the responsibility to design and implement three full days of professional development for all biology teachers in the district.

The goal for the three days is to get teachers to understand the shifts that are required for NGSS—mostly that the students are figuring something out instead of just learning about a topic. Then I provide teachers with protocols[13] for how to plan their lesson sequences in order to get that kind of change in practice to happen.

[12] Conducted by Inverness Research for the statewide initiative of the Exploratorium's teacher education program.
[13] To fashion protocols for her context, Darcy drew from the Teacher Institute's sequencing tool (See Module 2) and other tools she gained from the Teacher Institute as well as from other NGSS learning opportunities.

Two professional development days in February were spent engaging teachers in first-hand learning through a lesson sequence that is aligned with NGSS and includes embedded SEPs and crosscutting concepts. Teachers also explored how to present phenomena and provide support for student discourse. Darcy has provided teachers with some structured talk routines to use to foster students' discussions about the phenomena.

- **One-on-one coaching**

Much of Darcy's work with teachers involves one-on-one support or facilitating small groups of teachers who are working to change one particular element of their practice. Darcy helps them plan, observes their instruction, and debriefs with them. Many of the resources she shares are not specific activities, but "overarching things like protocols for how to plan and how to get teachers to engage as learners." This approach is in line with the Teacher Institute's discovery that teachers need tools for changing their approaches, not "canned stuff."

- **Challenges of implementation in district context**

The lack of time and structure for teachers' professional learning. Regardless of the expectations of NGSS, the teaching profession remains one that does not provide adequate investment in professional learning. In Darcy's district, teachers either have to leave their students with a substitute or take vacation time.

> *We as a district have been trying to figure out how to best support that [NGSS] work and how best to use teachers' time. Teachers were already frustrated with me because they had to take three sub days to come to my training session, which is not ideal, but then not every teacher can work during the summer, which was another option. Not every teacher can work winter break. So it is tricky to figure out how to get teachers to commit to training. I don't really have a clear explanation or a good idea for how to get that to happen with every teacher. It is a struggle.*

The need for *differentiated* professional learning. Darcy has observed what TI staff have also observed, which is that teachers are in vastly different places on a trajectory of familiarity with and understanding of NGSS. Shifts toward NGSS have been slow even for the earlier adopters.

> *It is definitely a bit more difficult for a support provider because there is a very wide range—there are teachers that have been teaching for over 30 years and they don't feel like they need to change. And then there are new teachers that are super excited about it. I actually feel like a lot of the new teachers from the last couple of years probably have a better understanding of NGSS than a lot of the veteran teachers. So, it is a very wide range that you have to plan for…Even for the [veteran] teachers that are further along, there are still a lot of legacy practices that are in place. The idea of phenomena-based teaching and having students figure something out is not happening as much as it should be.*

District curriculum policy. Another reason for the slow shift is that the district's requirements for teachers are not as well aligned with the spirit of NGSS as they could be. Darcy's third full-day workshop will allow teachers to spend time looking at student work and planning. The district's mandate for planning, however, is that the Bio teachers develop a scope and sequence for their curricular units.

While this requirement may make sense from a district perspective—where administrators want to show that all biology courses will address certain topics—this traditional approach can be seen as undermining a shift toward more flexible sequencing based upon student investigations of phenomena.

Darcy's reflections on the evolution and influence of the Teacher Institute

- **The TI's evolving approach**

Darcy offers a teacher's eye view of how the Teacher Institute has changed to adapt to NGSS. While earlier workshops focused on exposure to hands-on interactions with phenomena, later workshops focus on sequencing of hands-on activities to support meaning making and scientific argument.

> *I have been with TI since like my first and second year of teaching because I was part of their teacher induction program. I will say that their workshops have changed because of NGSS. The workshops that I used to take early on in like 2009-2010 were very much, 'Oh here is a bunch of fun hands-on activities' and that was really great, but now I see that their workshops have changed. I think I saw the change when I went to the one on plate tectonics and they presented three possible explanations for why different fossils of the same species were found on vastly different continents.*
>
> *I can see how they presented a phenomenon and then how we collected data over time to either prove one argument or prove another. I think that was in 2016. That was when I started realizing, 'Oh, okay, even their workshops are changing and their focus has now become, how do we put together a sequence of activities to get a student or a teacher to figure something out?' So that was super helpful.*

- **Professional learning in the Exploratorium's culture of curiosity—a rare privilege**

Only when Darcy joined the TI as a Teacher-In-Residence in 2017, however, did she have the immersion in the Exploratorium's culture that enabled her to more deeply understand phenomena-based learning and how to create an NGSS-aligned lesson sequence.

> *While I was working on my own as a classroom teacher, I still didn't have a very good sense of what NGSS looked like. It wasn't until I became a Teacher-In-Residence and had the time to figure these things out that I thought, 'Oh, okay, now I get it a lot more.'…*
>
> *…TI does a really good job of creating the conditions where you ask questions. Even just working with them for a year, I kind of got a taste of how they do it. It has definitely been super, super influential on me. Just being around people that are curious about things was super influential also.*

Even with this immersion, Darcy feels she is still learning, just as the TI educators feel they are still learning. She says, "I still don't have a perfect solution, and there isn't a step one, step two, step three for how to ask questions."

Darcy laments the fact that most teachers don't have the luxury of obtaining an appointment such as a Teacher-In-Residence position with Exploratorium's Teacher Institute program.

> *Unfortunately, that is not a path that a lot of people can take … I think a lot of teachers have had to do what I was able to do during my time in TI on their off time, so they don't have as much time to really get to know the standards very well, which is really frustrating.*

- **Conditions for learning**

Darcy continues to incorporate what she learned through Teacher Institute and to learn about supporting teachers in addressing NGSS. She sees a link between the NGSS questioning-based approach for students and the TI's questioning-based approach for teachers working to strengthen their teaching.

> *Those were the two biggest things that I got from my years in TI: we really need to create the conditions for students to figure something out and then the students should be driving the sequence. Their questions should be the ones that we are using to guide the next activity in the sequence, instead of what makes sense to the teacher who already knows the content…*
>
> *What I like about TI is that it makes me question a lot and it is not like 'Oh, here is a dump of a bunch of activities.' It is a place you can go to for a resource. I get the same feeling every time I leave one of their workshops which is like, 'Oh man, this is so fun, and I have so much more to learn.'*

MODULE 4
THREE PROFILES OF PHENOMENA-BASED CLASSROOM TEACHING

The scientist-educators of the Exploratorium's Teacher Institute encourage teachers to base their teaching of science on the study of phenomena. For the Exploratorium, phenomena-based teaching is not only an approach to the three-dimensional science teaching called for in the NGSS. More fundamentally, the approach reflects the Exploratorium's history and mission, which is to offer anyone—teachers, students, all members of the public of all ages—opportunities to engage their curiosity in exploration of phenomena.

Teachers have the added responsibility to tap and nurture students' curiosity such that they learn science and in the process, discover that they want to continue learning science. In the words of the Exploratorium's visionary founder, Frank Oppenheimer, "The remarkable feature of the process of individual discovery, whether of detail or of generality, is that the first taste of success can be addicting. For some obscure reason we, as teachers, are committed to turning on addicts."[14]

This module includes profiles of three San Francisco Bay Area teachers who anchor their teaching of science to phenomena that have immediate relevance for students:

Profile 1 is of a teacher who uses the phenomenon of coral bleaching—relevant to youth in the time of climate change—to teach matter and energy cycles involved in cell respiration and photosynthesis. Her approach emphasizes the scientific practice of modeling.

Profile 2 is of a teacher who uses the phenomenon of identity to explore the question of "*nature vs. nurture*" with respect to traits that form who we are. This teacher, who works in a continuation high school, wants to explore with his students how they can best navigate their lives through high school and beyond.

Profile 3 is of a teacher who situates the teaching of basic genetic inheritance in the real-life dilemma of a young couple seeking genetic counseling before they decide whether to conceive a child. This teacher specializes in the teaching of biology to English language learners.

Each profile includes sample artifacts of teaching and learning.

The teachers have been willing to make their full units plans and resources available to their colleagues.

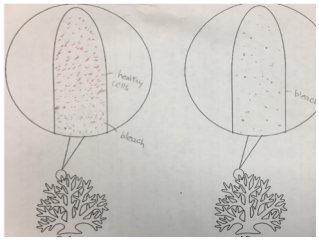
[14] From "Everyone is You…Or Me," Frank Oppenheimer, in a 1976 issue of MIT's *Technology Review*. https://www.exploratorium.edu/files/about/our_story/history/frank/pdfs/everyone.pdf

PROFILE 1
USING THE PHENOMENON OF CORAL BLEACHING TO TEACH CYCLES OF ENERGY AND MATTER

Elizabeth Doggett has been teaching for five years and currently teaches freshman biology at San Mateo High School. Before she began her teaching career, she was a research assistant in a molecular biology lab investigating Parkinson's disease. She favors phenomena-based instruction not only because it aligns with NGSS, but also because it mirrors her personal educational philosophy:

> *I find that it makes the learning more meaningful and relevant and weaves together the content and science skills. I can't imagine teaching any other way.*

One of her favorite examples of this approach is using the phenomenon of coral bleaching to teach cycles of energy and matter. She typically likes to use phenomena that are immediately relevant to her students. In this case, although students can't see coral locally, the phenomenon is tied to global warming, an especially hot topic for youth. When Elizabeth studied coral bleaching during a summer research experience at Stanford University, she became so fascinated that she decided to bring it to her classroom. She saw the phenomenon as a means for teaching photosynthesis and respiration, two central topics that can be rather technical for high school freshman to learn. In the lab she learned that coral have algae living symbiotically inside of them and certain environmental stressors—such as warming ocean temperatures or acidification—cause the algae to leave the coral. Without the algae, the coral lose their color; they also lose their source of glucose and slowly starve. Coral can recover if the environment stabilizes and the algae return.

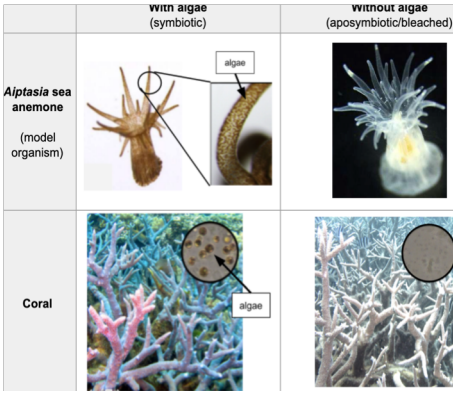


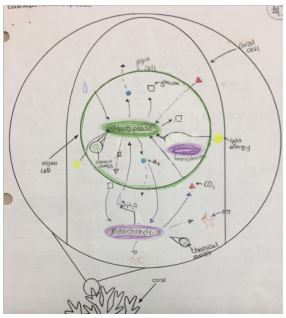
Elizabeth launches the exploration by having students view pictures and videos of healthy corals, bleached corals, and maps of coral bleaching events. At this point she has the students draw what they think is going on with coral bleaching as a pre-assessment.

She then brings in the small anemone with algae inside of them that is used as a model organism in the Stanford lab so the students can observe anemone with algae and without. The students make observations, ask questions, and choose an overarching question to answer, e.g., What is bleaching and why is it happening?

Then they start learning about corals, algae, and how algae make food.

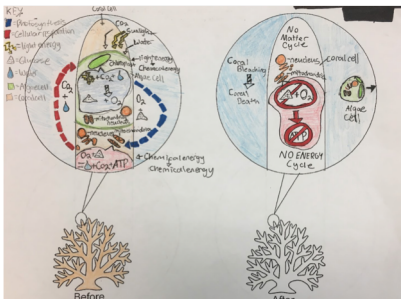
To study photosynthesis, they do a lab with discs of spinach. Throughout the unit Elizabeth has students make their thinking visible by drawing models of what they think is happening and slowly building up a complete model of the relationship between the coral and the algae.

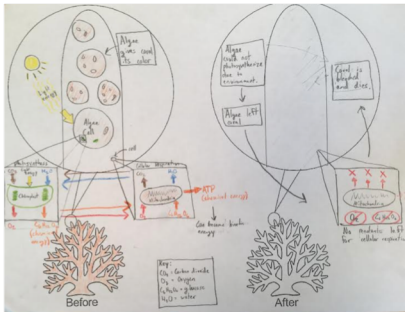




At this stage, a student might draw a coral with an algae cell in it and then draw photosynthesis inside the algae showing how it is producing oxygen and glucose. Students then learn about cell respiration and the causes of bleaching while constantly weaving back and forth between their investigations and their emerging model for understanding coral bleaching.

At the end, students are able to develop a model that explains how matter and energy cycle between algae and coral through the processes of photosynthesis and cell respiration and predict what happens inside coral as a result of bleaching (i.e., loss of algae).

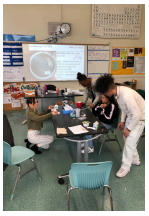




PROFILE 2
ANCHORING TO THE SOCIAL-BIOLOGICAL CONSTRUCT OF IDENTITY

Robert Coverdale is in his fifth year of teaching math and science within a theater context at Downtown Continuation High School, a project-based interdisciplinary school in San Francisco. Robert studied Evolution and Ecology before he earned his teaching degree, but always kept up his involvement in theater. When the opportunity to combine his two interests arose, he jumped at the chance.

Robert appreciates how phenomenon-based science instruction supports social justice-based education. What unfolds in the classroom is truly accessible on some level to all of his students, enabling them to explore complex issues such as identity and race. He also finds that the process of inquiry into the phenomena supports the development of critical thinking skills:



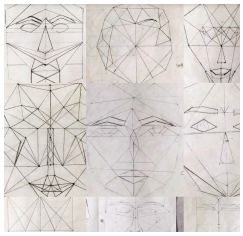
> *I think that you get to do science with students instead of teaching at the students...I never wanted to be up front preaching science, I always wanted to be doing science with the students. I think phenomena-based education is a perfect framework for students doing science and tackling issues. My frame is social justice, and so how can we use science to make change? You can find phenomena in your city that you can investigate with the students in order to propose changes.*

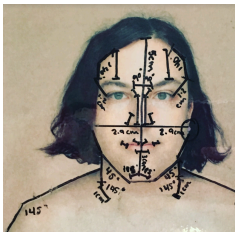
Robert and his students explore complex phenomena that have personal and social dimensions—from identity, race and gender to climate change—weaving NGSS core ideas, concepts, and practices. Robert's recent choice of identity as an anchor phenomenon was inspired by the question of "nature *vs*. nurture" and by Robert's own inquiry into how his students see themselves in light of this question: Do his students believe they are able to make changes in their behaviors?

> *It feels like they arrive at school with this idea of, 'hey this is who I am,' and so [I wondered] do they believe that those things are genetic, or do they believe that those things are because of the environment? Then when we are unpacking those things—if they realize that it is not in their DNA (or* vice-versa*), will they be able to make changes? How does that knowledge help them navigate as they move throughout the rest of high school into life?*

Robert points out that "All high school students struggle to discover who they are within a social framework." He hopes that by tackling phenomena like identity, race, and gender, his students "will leave with a more realized sense of self that is mindful and critical of the social pressures that work to push them into categories and stereotypes."

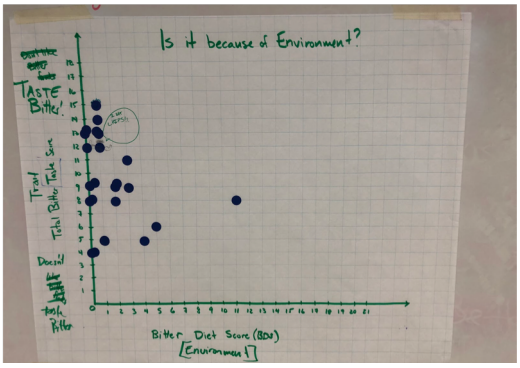
Leaders of the Exploratorium's NIH-funded institute developed a tool that Robert used to create the narrative framework of the unit by mapping each activity, the questions they answer, and the questions that lead to the next activity. He used this tool to help him frame the journey his students would take through the exploration of identity. Robert summarizes the core elements. In his words:

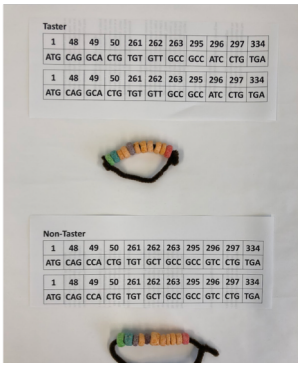




"The students start by exploring race in order to come to the conclusion that genes and the environment work together to shape different traits.

"From there, students explore the phenomenon of taste (in food) using data from class, heritability, twin studies, and genome-wide association studies to discern the relative influence of genes and the environment on taste.





"Finally, students explore personality using a similar process. All of this is culminates in students writing 10-minute plays about their lives in which the main character reflects on how family, genes, and the environment have worked to make them the person they are today."

In the mind of a boy

By, _____

A 13 year old boy just lost his mother, he's watching a documentary on National Geographic. The feelings he has are explained by the narrator in the Documentary.

In our brain we have these things called neural pathways. They are like paths in our brain, every time we do something repeatedly the path becomes strong and these repeated motions are called habits. When we change a habit the pathway slowly starts to go structure into a different path. For example if you are a boy and your whole life you have been taught to suppress your emotions, it is going to be hard to show your emotions because it has become a habit. Your mother dies and then the thinking part of your brain shuts off. And you know what part is activated? The feeling part of your brain. You're sad, you start crying, but you haven't cried in years. You see your family around you at the funeral, you feel like a pussy. The feeling part of your brain starts releasing stress hormones. The primitive part of your brain reacts you're in a flight or fight response, adrenaline releases as a stress hormone. The boy's 3 section of his brain start running into each other: Motion, Feeling, And thinking. He now feels anger he starts ruining the funeral in heat of the moment. And that's one example of how gender stereotypes can trigger many different things inside the mind of a boy. And from that point on men are programmed by society to release success hormones when not showing emotions. Hormones that should be released when accomplishing something good.

For each activity, Robert creates a review template and assigns a mini-performance, written argument, oral presentation, or poster. These, along with rubrics, help students track their learning on each topic throughout the unit.

Presentations - Share Out (10 min)

4 Exceeds Expectations	3 Meets Expectations	2 Approaches Expectations	1 Attempts Expectations
I speak clearly, audibly, and appropriately at all times	I am almost entirely clear, audible, and appropriate	I cannot be heard well or use inappropriate language	I cannot be heard at all or are blatantly inappropriate
I speak in well-prepared conversation with audience.	I am well prepared to present and my presentation is largely memorized.	I largely read information from notes to the audience but attempt to make eye contact.	I read my entire presentation and make almost no eye contact.

At the end of each major unit, the students produce and perform a theater piece that synthesizes and expresses what they have learned. A review template for the unit as a whole helps them prepare.

PROFILE 3
ANCHORING THE BASICS OF GENETICS TO A TRUE-LIFE DILEMMA

"Lauren"[15] has been teaching for nine years and currently teaches in a large, suburban public high school in the heart of the Silicon Valley. She began teaching in order to combine her love of biology (her degree area) with her desire to work with students who typically do not have easy access to science.

As part of her school's biology team, Lauren teaches freshman biology and science for English language learners who have been in the country for 1-2 years. She is currently involved in the Teacher Leadership program at the Exploratorium's Teacher Institute.

Lauren loves phenomenon-based instruction because it is grounded in what is real and relevant for kids. Also, since some of her students have had lots of science and others have had none, she finds that experiencing phenomena as a springboard to instruction provides equitable access for all students.

She acknowledges that it can be difficult to find a phenomenon that can serve as the anchor for a unit. In order to teach the basics of genetics using this approach, she and her biology team decided to appeal to their students using a dramatic portrayal of a real-life dilemma. The team expanded an initial activity into a short play about a couple who schedules an appointment with a genetic counselor in order to learn about likelihood of conceiving a child who inherits Huntington's or Tay Sachs. The team went through the NGSS storylines to pull out the concepts, topics, and the vocabulary words for the unit, and then wove them into the play. To answer the couple's urgent question, "Will our child inherit these diseases?", the students will have to ask questions about, investigate, and ultimately understand the core concepts of genetic inheritance.

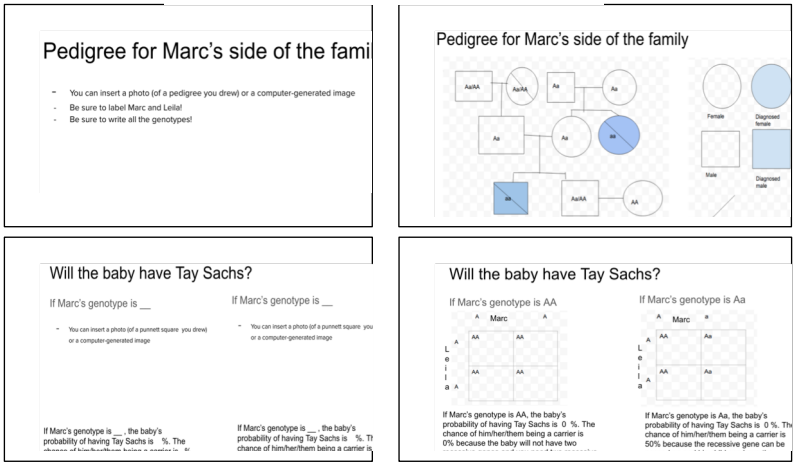
The students begin by reading the play (see full text on the following pages). After looking for patterns and brainstorming questions, students dive deeper into selected questions curated by the biology team. The unit includes core ideas in genetics such as Punnett Squares,[16] dominant and recessive traits, how sperm and egg are made, and the inheritance of traits.

At the end of the unit, students prepare a report that concludes with their writing of the genetic counselor's recommendation to the parents.

Lauren scaffolds the report writing by having students work from a PowerPoint template that asks for definitions (with sources), Punnett Squares, "pedigree" or family tree charts, as well as a recommendation that is well reasoned.

Samples

Template section **Student work**



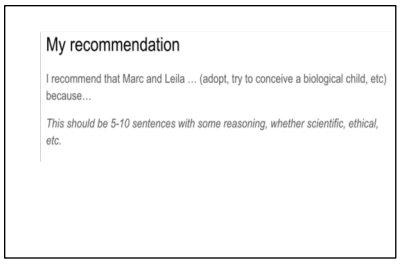
[15] This teacher preferred that her real name not be used.

[16] Graphical representations of the possible genotypes of an offspring arising from a particular breeding event.

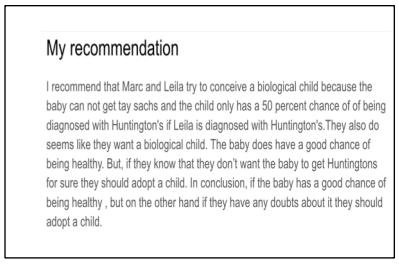
Lauren believes the personal feel of this unit—the relevance beyond the molecules and cells—helps to draw in students that are sometimes more hesitant. The students like working with a true-life story and tend to develop empathy for the family. They find it satisfying to understand at the end why the family member died and to predict the likelihood of the potential child inheriting the disease.

Sample: Counselor's recommendation

Template



Student work



The team has taught this unit for four years. Along the way they have added more scaffolding around reading, writing (e.g., the report template) and the citing of evidence.

****

The Play: A True-Life Dilemma of Inheritance—

Mark and Leila's appointment with the Genetic Counselor

You, the genetic counselor: Welcome, Mr. Shapiro and Ms. Thompson! It's great to meet you! Please have a seat!

Marc: Thanks so much for seeing us. Please call me Marc.

Leila: Hello! Good to meet you too! I'm Leila.

Genetic counselor: Tell me a little about what brings you into my office this morning. I see on my chart that this is a prenatal visit. Are you currently pregnant?

Leila: No, no, not yet! Marc, do you want to explain our situation?

Marc: Well, Leila and I got married more than five years ago, and those years have been the happiest of our lives.

Leila: Definitely! We traveled the world, moved to the west coast, bought a house...it's been incredible! We've talked about it a lot, and we think we're finally ready to have a child!

Genetic counselor: That's wonderful! It sounds like you have had so many amazing experiences together.

Marc: Yes, but...we're nervous. We have some unique family histories.

Genetic counselor: You've come to the right place. I see people who are one in a million every day.

Marc: It's just that we have all sorts of medical problems on both sides of the family, and we want to make sure we have all of our facts straight before conceiving this child.

Leila: Of course, we'd love our baby no matter what, but we know first-hand how difficult it can be to see someone die young or to battle a chronic disease their whole life. We want to understand all the risks and weigh all of our options before trying to get pregnant. We'd consider adoption too.

Genetic counselor: I understand your concerns and see many patients for very similar reasons. Why don't we talk a bit more specifically about your family histories? Leila, why don't we start with you?

Leila: Sure. Well, my mom died young, when she was only 50 and I was 14. She died from Huntington's Disease. The truth is that I knew she wouldn't live long enough to see me get married. Even when I was a little girl, I remember her walking kind of funny. Eventually, she couldn't walk at all, couldn't remember much, and then...she passed away.
Genetic counselor: I'm very sorry to hear that. That must have been tough on you and your family.

Leila: It was. My dad was great through it all. He and my mom didn't really burden me with the details until they absolutely had to, so for a while, I just thought my mom was kind of funny. It wasn't until I was about ten that I knew this was something really serious. They sat me down and told me about Huntington's, how my grandpa, my mom's dad, died from it and how my mom would eventually die too. When it happened, I wasn't exactly ready, but, well... I knew what to expect.

Genetic counselor: I see. Thank you for sharing that. What about your dad and his family? Any history of Huntington's or other genetic disorders there?

Leila: No, nothing like that on his side. My dad is pretty healthy, just some weight and blood pressure issues. My grandparents on that side of the family have had some issues with Type II Diabetes, but the doctors say that's more of an obesity issue and not really genetic. As far back as I can remember, we've been having burgers and fries for lunch every Sunday!

Genetic counselor: And your maternal grandmother? Is she still alive?

Leila: No, she passed away in a car accident after grandpa died. She was pretty healthy, though. My mom said she was strong but exhausted from taking care of my grandpa for all those years. I guess back then they didn't have good nursing homes or in-home aids like they do now.

Genetic counselor: Have you been tested for Huntington's?

Leila: No. For a while, we couldn't afford the tests because we didn't have insurance. Now that we do, I just don't want to know. It might seem silly, but I want to feel in control of my life for as long as I can. If I get the results and know I have the disease, I don't think I could handle it and live my life to the fullest. I'd be so worried all the time. It's part of the reason Marc and I got married young and traveled so much. In case I have the Huntington's allele, I want to experience as much as I can in life, and that includes motherhood.

Genetic counselor: I respect that decision. Of course, if you ever change your mind, the test is simple enough, and the results come back quite quickly.

Leila: Thanks, but I think I've made up my mind.

Genetic counselor: Sure, I understand. Marc, what about you? Any concerns on your side of the family?

Marc: I guess my childhood was a bit more...typical. My parents are and have always been quite healthy. They are active in their community, play golf on the weekends, and run almost every day. They get yearly check-ups, and their doctor always says how she wishes more patients were like them! I don't really remember him, but I had a brother one year younger than me. He died when I was four, and he was almost three. He had Tay Sachs, so I guess the death and whole process beforehand were pretty tough on my parents.

Genetic counselor: Yes, Tay Sachs is a particularly difficult disease since the kids die so young after looking perfectly healthy at birth.

Marc: Yup, that's what my parents said- that Dustin was happy and healthy for a while, even started to walk and talk, until it all reversed itself...My mom had a sister who also died from Tay Sachs when she was young, so I guess her family was familiar with it. For my dad, though, it was a total shock.

Genetic counselor: And what about your grandparents? Are they still alive?

Marc: My paternal grandma died from a heart attack when she was 64 or 65, I don't quite remember. My other three grandparents are alive and well, though.

Genetic counselor: Great, I think I have all the information I need in terms of family history. So, what kind of information or advice are you looking for?

Leila: Well, I guess we want two things. First, we want to understand these diseases better. I feel like our parents told us what happens but not why or how. I still don't really get what's wrong in someone's body when they have Huntington's...why are they fine for a while and then all of a sudden get worse? Why do some people inherit Huntington's and Tay Sachs, but other don't?

Marc: Yes, I definitely want to understand that too...It just seems unfair that my baby brother died, but I'm alive. I mean, I am grateful, but why did that have to happen?
Also, we just want to know what you think we should do. We definitely want a baby, and I think both of us would love to have our own biological child...But, we can't imagine going through the pain of losing a child. We want to know our chances. Is there any way, any chance at all, that we'd have a healthy baby? Is it 50/50?

Leila: Like I said earlier, we've talked about adoption, and we're both fine with it, but we want to have all the facts before we decide either way. It's so tough because I've always wanted my own baby, to be pregnant, to feel them kicking inside me, but like Marc said, I couldn't bear to watch that baby die.

Marc: We just want another opinion, an expert opinion.

Genetic counselor: I fully understand, and I appreciate your openness and trust. I'll talk to a few colleagues to give you a more complete picture, write up a report, and talk to you next week. Is there anything else you want to ask or share before then?

Leila: No, thank you. We'll see you next week.