Crowley, K., Barron, B.J., Knutson, K., & Martin, C. (2015). Interest and the development of pathways to science. In Interest in Mathematics and Science Learning. In K. A. Renninger, M. Nieswandt, and S. Hidi (Eds.). Washington DC: AERA.

# Interest and the Development of Pathways to Science

KEVIN CROWLEY, BRIGID BARRON, KAREN KNUTSON, *and* CAITLIN K. MARTIN

*In this chapter we review two lines of work that trace the ways interest in science is triggered in everyday activity and then, once triggered, is extended and deepened. We take an ecological view of interest development, exploring social, cognitive, cultural, and material resources that contribute to a pathway from interest to disciplinary expertise and engagement. The chapter brings together two complementary lines of empirical work. In the first line of work, Crowley, Knutson, and colleagues conducted 2-hour retrospective life-history interviews with adult scientists and engineers asking about their early disciplinary interests and the ways those interests developed and were supported throughout life. In the second line of work, Barron, Martin, and colleagues prospectively followed youth engaged in science and technology to identify ways their interests were supported and extended across everyday, informal, and formal boundaries. We first present examples from each of these two lines of work, and then a cross-study synthesis that points to new questions about interest development. Our findings suggest that individual interests in science often emerge before high school, and as learners become passionate about a particular interest, they increasingly seek out and create opportunities to learn by engaging parents and peers, taking on new projects, enrolling in programs or visiting informal learning settings, and/or pursuing resources in books or online.*

## Introduction

In this chapter we review two lines of work that trace the ways interest in science is triggered, extended, and deepened across time and place. We take an ecological view of interest development, exploring social, cognitive, cultural, and material resources that contribute to a pathway from interest to disciplinary expertise and engagement. The chapter brings together two complementary lines of empirical work from our groups in Pittsburgh and Stanford. In the first line of work, we conducted 2-hour retrospective life-history interviews with adult scientists and engineers asking about their early disciplinary interests and the ways those interests developed and were supported throughout life. In the second line of work, we prospectively followed youth engaged in science projects to explore how interests are supported and extended across everyday, informal, and formal boundaries.

Interest in science is a key aspect of encouraging students to pursue science careers. From autobiographical accounts of famous scientists (Wilson, 2006), to surveys of current scientists (Maltese & Tai, 2010), to longitudinal data tracking student interest and achievement from eighth grade through college graduation (Tai, Liu, Maltese, & Fan, 2006), we see evidence that children who grow up to work in science careers often report that their first interests in science were developed during childhood. Researchers, educators, and policy-makers have responded to these findings with calls to create educational experiences that do not just make children competent to do science but also nurture the interest and motivation necessary for children to pursue science pathways long term.

But what do these experiences look like? Where does the developmental path toward science begin? How does early interest arise? In what ways does it get picked up, overlooked, or discouraged across the different areas of children's lives? What kinds of experiences support the development of deep interest, and how are these interests connected to a trajectory of engagement that puts a child on the path to a science career? What are the roles of family, friends, school, and informal learning opportunities?

Our studies explore the developmental dynamics of early interest and focus attention on the resources and experiences that learners encounter that can trigger and sustain interest before children enter high school. We hypothesize that many of the resources and experiences important to early interest formation are rooted in the out of school world. From early ages, children become interested in science-related topics (Alexander, Johnson, & Kelley, 2012). However, children do not necessarily know that they are potentially positing themselves at the beginning of a science-learning trajectory when they, for example, begin reading books about dinosaurs, playing with building toys, or collecting bugs in the backyard. There is little direct evidence of how early interests transform into science trajectories and, importantly, of what can be done to increase the chances that early interest can be connected to later systematic pursuit of science per se (Renninger & Hidi, 2011).

Our work focuses on understanding interest as part of an ecological model of development. Our intent is to contribute to a larger collective research agenda that seeks to better articulate the interdependencies between child-level and cultural processes in development and to acknowledge the tight intertwining of person and context in producing developmental change (Bronfenbrenner, 1979; Cole, 1996; Lerner, 1991; Lewin, 1951; Rogoff, 2003). To do this, we investigate the experiences people encounter that initiate extended pathways of deepening participation through a "stabilization of situational interest" (Hidi & Renninger, 2006) or the development of a sustained "line of practice" (Azevedo, 2011). Our focus within this broad research agenda involves further specification of types of roles institutions and people play in a learner's knowledge network and how these support learning interactions (Barron, Martin, Takeuchi, & Fithian, 2009; Knutson, Crowley, Russell, & Steiner, 2011; Russell, Knutson, & Crowley, 2013), the nature of activities that propel learning, the ways that activities evolve over time, and the roles of distributed resources such as books or internet-based communities (Barron, 2006; Crowley & Jacobs, 2002; Palmquist & Crowley, 2007).

### A Retrospective Look: Early Interest and the Pathway to Science Careers

We interviewed 24 professors from academic science and engineering departments, 24 scientists working outside of the academy, and 21 people whose careers were involved with science, such as educators and agricultural extension agents. We used a snowball sample, roughly balanced between men ($n = 35$) and women ($n = 34$) and between baby boomers (born between 1946 and 1964; $n = 37$) and members of generation X (born between 1965 and 1981; $n = 32$). Forty-seven identified as white, 4 as African American, and 7 as of multiple or other ethnicities, and 13 did not identify a race or ethnicity. In terms of highest parent education, 26 reported that their parents completed master's, PhD, or MD degrees; 20 that their parents completed bachelor's degrees; and 23 that their parents completed below high school, high school, or associate's degrees.

In 2-hour life-history interviews, we explored the extent to which our informants were interested in and engaged with science throughout their lives. We focused separately on elementary, middle school, high school, college, and postcollege years, probing in each epoch the extent to which school, friends, family, and out-of-school activities played a part in participants' science learning trajectories. In this chapter we concentrate on findings that are directly relevant to early interest development and the beginning of a science pathway.

We found strong evidence that people who go on to have careers in science are often interested and engaged in science during childhood: 86% of our sample reported strong childhood interest in science-related topics or activities. We heard about three major categories of interest, with some participants reporting more than one category.

First, 54% of the sample reported interests in science-related topics. Topical interests could be broadly construed, with adults describing general areas of interest, such as the outdoors, animals, and biology. These adults changed their focal interest through time, and although they ended up in science careers, their careers may not be so tightly bound to the topic areas that fascinated them in childhood. For 16%, however, these interests were specific and deeply held throughout childhood and into adulthood, even driving the choice of a career. For these subjects, there was a very direct path: A topical interest emerged in early life, was maintained strongly throughout the school years, and then continued through university and into a career. We have paleontologists, avian experts, zoologists, and astronomers in this category.

Second, 32% of our sample reported early interest in tinkering, understanding how things work, or taking things apart. We heard stories about making robots, fooling around in dad's workshop, experimenting with ingredients in the kitchen, or building LEGO structures. As one might expect, some of the early tinkerers went on to become engineers (half of the engineers in our sample fit this pathway), but tinkering was also an early orientation for people who went on to become other kinds of science professionals.

Finally, problem solving or mathematics was an orientation that 19% of our sample shared. These adults talked about how they were compelled by problem solving, loved logic puzzles, and enjoyed the precision and rigor of counting or mathematics. Many of people in this category talked about how they were drawn to the mathematics in the science careers they ultimately pursued.

Where did these interests originate and how did they initially develop? When we asked adults specifically about their elementary or middle school science experiences, only 28% reported positive experiences in school. Some adults recalled specific teachers who were enthusiastic about science or who recognized their interest or proclivity toward a topic, or provided additional material or direction for an independent study or an afterschool club.

Some recalled hands-on activities that included documenting plants and bugs, testing water, or building models. Some of the experiences were field trips or outdoors excursions, on which they recalled science being connected to a real-world applications. Two adults mentioned the importance of their participation in gifted and talented programs in their school.

But most adults reported that they either could not remember any elementary or middle school science or else they remembered only negative experiences. Adults reported finding school science activities focused on rigid processes such as note taking or recalled that they found science classes boring and book focused. Several adults talked about their early recognition that science could be something other than what they were being taught in school. Some recalled seeing interesting experiments outlined in textbooks, but then being disappointed when the class did not get around to doing them. Others remember noticing that their teachers did not appear to like science and were unenthusiastic in the classroom. Some also commented on their teachers' lack of science knowledge, noting that they challenged their teachers on factual points, and sometimes had to back down: "I knew she was wrong, but my mother told me not to fight it." Finally, some commented that their schools did not have enough resources to do science. Adults seemed to have noticed later in life that their science programs were lacking, saying things such as "our school was in a poor neighborhood and we didn't have science fairs or competitions."

Out-of-school science experiences were cited as playing a significant role in supporting early interest by 45% of our participants. We saw three common themes here. First, museums were cited by 19% as having a pivotal role in an early pathway. We heard about memorable visits that exposed participants to new subject domains, such as astronomy, paleontology, and zoology. In some cases, special programs and museum-based clubs were important in building a relationship between the child, museum experts, and museum experiences. Some enjoyed museums with their families, as something that they always did together at home and while traveling. For some, museums were conveniently located and low cost or free, thus allowing the children to use the museums after school or on the weekend as daily or weekly locations to connect to science.

A second theme was fathers, who played an important role in developing an interest in science for 25% of our sample. Some fathers were scientists themselves, and involved children in science activities. But more often, we heard about nonscientist fathers with science-related interests such as mechanics, gardening, or camping. Fathers were important in involving children in science-related activities, such as the one subject who reported that he and his three brothers had a "shop night" once a week when they tinkered with their father in his workshop. Fathers also had an important role later in helping make college and career choices. Mothers were mentioned as well, but more often in terms of general support for education and interest development. Fathers were more associated with shared science-related activities whereby skills and dispositions were developed.

A third and less common theme was organized out-of-school activities, cited by 10% of our sample as being highly influential. For example, two African American foresters talked about their love of the Boy Scouts, how they progressed from Webelos to Eagle Scout and how the Boy Scouts provided a window into a future career. We note that when programs were mentioned, they were not universally motivating. Several of our other participants were involved with Girl or Boy Scouts or other groups but commented that the experiences were not fun because the activities were too structured.

We next present four brief cases that highlight interesting dynamics among early interest, the learning ecology, and the subsequent pathway to a science career. The first pathway illustrates how a single early passion can sometimes be extended and connected to a later career. The second is about a general interest that drives wide exploration and eventually leads to a specific career niche. The third example highlights how an early career interest can motivate the pursuit of science, even as the early interest morphs and changes over time.

*Barry: A Lifelong Passion for Dinosaurs*

> That feeling that a lot of people struggle with… especially in college, where they're trying to decide what to do with their life and stuff like that, I never had to go through that. I just always knew what I wanted to do. And I can't explain it. I just never thought really of doing anything else.… I can distinctly remember as a young elementary student, like in second grade, asking my teachers, "When are we going to talk about dinosaurs?" And they would say, "Oh yeah. We cover that in sixth grade science." And I would look forward to sixth grade because of that.

Barry (Subject #30) is a paleontologist who works as a curator in a natural history museum. He knew from a very early age that he wanted to be a paleontologist, and his life history shows a steady and solid commitment and passion for the pursuit of knowledge about his interest. Each career transition point helped him further his study of his topic of interest. Barry's story is one of an early interest, intensely specific and internally motivated, that was supported by family and school. His interest did not change or really waver throughout the long road between age 3 and age 35, and through his life, he has become savvy in marshaling available resources to support his development.

Barry described his interest as initiated and supported first by books. During his interview, he pulled the seminal books from his childhood off of his office bookshelf. He still has the first dinosaur book he ever looked at—*The Big Golden Book of Dinosaurs*—and he also pulled out a few issues of *National Geographic* from the early 1980s that contained articles about dinosaurs that were important to his developing interest.

Barry was lucky in that his family and school supported his interest. Books were purchased, trips were taken to museums, and his teachers even allowed him to teach younger-grade children about dinosaurs. Barry talked about the importance of supportive teachers and the gifted program in elementary school. He felt very comfortable being the expert on dinosaurs, and he pursued his interest into middle and high school, even though he recalls feeling as if he "was sort of in the closet about [his] fascination," as an interest in dinosaurs as a teenager was a potential social impediment. Arriving at a bonfire party, he was embarrassed when he heard some kids saying "Here comes Barry, you know, that kid who likes dinosaurs." Although some people were disparaging of his interest, he recalls that most of his friends were respectful, or at least amused by it.

Barry stuck with his interest throughout high school, and had a normal social life. He did not get involved in organized out-of-school activities, but he played football and hung out with neighborhood kids. Through high school, he pursued his interest by himself, mostly out of school. Barry did not apply to very many colleges. He chose to attend a college that was reasonably close to his family's home. He met with a geology professor during his interview, and the college was keen to have him enroll; he managed to create a program that supported his desire to work toward paleontology. He found a professor he wanted to work with for his graduate school training, went on his first digs, and ultimately graduated with a PhD. His first job out of college was as a curator at a natural history museum, where he now has great collections to study, and plenty of opportunities to travel and continue to pursue his research interests.

*Berta: Creating the Conditions for Interest to Grow*

> It would be romantic to be committed to doing something that you wanted to do and to really excel at it.

Berta (Subject #65) is an astrophysicist. Her story is filled with strong personal motivation, within a working-class family and culture that was not particularly supportive of her goal to achieve in science. Her idea to commit to an interest emerged as a young girl when she watched *The Nun's Story*, in which Audrey Hepburn played the stubborn daughter who left against her family's wishes to enter a convent and become a nurse in Africa.

As a girl she loved the night sky. She recalled the moon landing and, at age 11, asking her parents if they could get up in the middle of the night to watch it. She spent her pocket money on astronomy books. She wanted to be an astronaut and even applied to be one, but was turned down. Her family had thought she would never work for a living, but would get married. In fact, she never really thought about astronomy as a career choice per se, but rather a way to pursue her interest in the topic. Although she spoke of the challenges of pursuing a path her family did not understand, her family did support her. Growing up in the German educational system, in which high school started at age 9 (and vocational and academic tracks diverged), her all-girls school was not planning to offer advanced science and mathematics classes. Berta talked to her friends and rallied them to agree to also take science. She then got her mother to speak with the principal, and the track was added. Although she was strongly committed to pursue astronomy, she did not necessarily love all aspects of science. She spoke about how she realized that she would have to "get through physics" if she wanted to pursue her love of astronomy.

At age 14, Berta joined the local amateur astronomy club. She was involved in school and family sports activities. She was dropped off for dance lessons and instead went to the observatory. She spent a lot of time at the observatory and that year convinced her parents to let her go on a trip to Africa with a group to see a solar eclipse. She recalls that this experience was pivotal to her career trajectory. The club was fun, and she loved the people, and the instructor was a great mentor. Between the ages of 14 and 18, she spent a lot of time working on research projects with the club, learning to do a lot of different, "neat" measurements, using mathematics skills she had not yet learned in school. Her strong interest and desire to be the best kept her moving toward a career as an astrophysicist at a top university.

*Martin: A Pathway Through Many Interests to Robotics*

> Growing up, I was not very social. Instead, I was typically in the basement taking things apart. And then putting them back together again in different ways. And there's lots of specific examples of that, but the general idea was to take something apart, see how it works, and then put it together, kind of, in an odd way. And I would do that a great deal. And those were all really adventures in robotics early on. I did that from about five to six years of age on.

Martin (Subject #27) is a robotics professor. He described his father as a great mentor, always talking about science. His father was a doctor, and his mother was an early childhood educator. He went on rounds with his father every week, and that experience taught him that he did not want to be a doctor. It was too much doing the same thing over and over again. His parents thought that Martin would go to college and then get a job, but they did not understand a broad range of careers, so they did not suggest or push the academic path that Martin would ultimately take. Martin felt that he always just pursued what interested him, regardless of practical career outcome.

Martin was strongly interested in understanding how things work, and this passion appears repeatedly throughout his examples, which wander through artistic, scientific, and engineering and robotic pursuits. Martin had a lot of resources around the house to help feed his interests. He loved using his dad's old microscope. He had the "250-electronics-kit-in-one" to do electronics experiments. And he had a chemistry set with real vials of acids and bases in it. He used it to electroplate a penny. He also had a basic set of tools, but he did not have a hacksaw. For Martin, this was an opportunity to build something:

> And it never occurred to me that we could go to the hardware store and buy a hacksaw. So I'd take—I want to make a hacksaw, right? So I would take the, uh, aluminum foil box. I would take the little teeth—teeth blade off the box and call it a hacksaw blade. And then I'd get some wood and screw together a little wooden rectangle and nail this on it. And that was my hacksaw. Now I can cut things. And I would get really excited and cut things. Nobody told me to do that. So I was trying to just reformulate things.

Martin believes in the power of adult relationships in shaping his life. Although his early examples revolved around his parents, as he moved into high school, teachers became highly influential. For example, he worked with his ninth grade science teacher on projects after school. This teacher facilitated Martin's building a working mercury barometer. The two also sailed, and eventually built a sailboat together.

> This teacher was genuinely excited about science and taught me that science can be fun. I mean I'm one of these stereotypical examples of a person who's been formed by their teachers. Where I'm this—the perfect example of somebody whose teachers' positive impact has really caused me to become whoever I am… at least the good parts.

Martin talked a lot about his curiosity in pursuing many different things. He said that when he started college, he would have been equally happy doing English or engineering. His diverse interests exist to this day. As he described,

> The profession I have now isn't due to an innate drive to be this—I could easily be not doing science. I could be literally building portraits or making good food. Um, it's just that the people along the way have pushed me into this particular pathway that I've ended up on. And I like it. I wouldn't change it for the world. But I would, you know, have been easily in an alternate universe—a carpenter full time and that'd be fine.

*Joe: Early Tinkering and Instrumental Use of Science*

> I took a lot of history courses, and in junior year, my professor said, "Why don't you major in history?" And I said there's a real obvious reason. I'm working construction. I'm the lowest man on the totem pole. I'm digging ditches, and I was talking to the two guys who were helping. They both had BS degrees in history!

Joe (Subject #51) is a chemistry professor. He was one of eight children in a working-class family. Growing up with eight children in the family was chaotic. There were four boys, and to give mom a break, once a week his dad held shop night, when the boys would hang out in dad's workshop. His dad brought home things from his construction job site (e.g., Joe told us about an old washing machine), and the boys would disassemble and then reassemble it. They did a lot of electronics experiments, learning how to test radio tubes and build circuits. Dad would help them with projects and how to use the tools.

Joe talked about his elementary and middle school as being one without many resources. He knows they had English and mathematics, but he does not recall anything about science class, and remembers a few field trips to places such as the Coca-Cola bottling plant. His mom was a stay-at-home mom raising 8 kids and his dad was a high school graduate. He did not really have access to adults with science careers as a boy, and he recalls his first interests in science being around medicine. He would pretend to be a doctor and read books about medicine. He saw chemistry as a means to an end rather than as a strong driving interest in the science. Upon reflection, he remembers that his dad was a natural scientist. In addition to the tinkering, his father was a gardener who did a lot of canning and raised daylilies, cross-breeding them and keeping detailed records of his work. Joe thinks back and says that his dad was probably his biggest influence; he just did not know it at the time.

The third oldest, Joe was the first in his family to go to college. He did not know much about potential careers, or how to pick a college. He applied to two nearby colleges, picked the closest one and went to college as a commuter student and took chemistry as a way to get to medical school. There was no special attraction to chemistry, and he had only had one chemistry class in high school, but he thought that more people took biology to get into medical school, so chemistry might give him an advantage. In his second-semester class, his professor suggested that he might go and work with a colleague as a research student in the summer. He did that and continued through the school year. Pre-med until junior year, he liked the chemistry people better than the pre-med students—they were "more interesting"—and he had begun to see a career path emerge in chemistry. So he stayed with chemistry.

Our findings suggest that an early passion for science is a typical part of the developmental trajectory for adults who work as scientists or in science-related careers. The early interest was, in most of our interviews, paired with an early engagement in out-of-school learning opportunities, through museums, programs, or family activity. School was sometimes an important part of the early pathway. But it was rarely the beginning of the pathway, and it was rarely the dominant early formative influence in the early years. School took on much more importance in high school and in college, as one might expect. But by then, most of the science-bound adults already had years of pursing their passions in out-of-school settings.

### A Prospective Look: Tracking Interests in the Moment and Across Settings

We now present findings from a prospective study that considers interest development at a shorter time scale and finer grain size than the retrospective study just described. We chart the relations among (a) a potentially inspiring activity, (b) appraisal of that activity in relation to a child's out of school pursuits, (c) broader identification with science as a domain, and (d) a child's set of learning partners including parents and friends.

This study is situated in the context of Vital Signs, a classroom-based citizen science experience involving investigation of invasive species in the state of Maine. During the classroom unit, which spans 2 or 3 weeks for one investigation, students go into the field during class and on their own time, and use digital cameras and Global Positioning System receivers to monitor freshwater, upland, and coastal ecosystems for native and invasive species. A Web site is designed to help students organize and analyze the data collected in the field, help teachers better understand the program and share curriculum materials and best practices, and help scientists and citizen scientists understand where invasive species live in Maine. Using geographic information system capabilities, the Web site's data exploration section allows anyone interested in invasive species to see what Vital Signs program participants have collected. The Vital Signs program has high potential to generate a desire to learn about the natural world by engaging learners directly in observing, documenting, and sharing information about real-world phenomena. Students participate in learning activities designed around scientific issues in their local communities using authentic tools and collaborating with scientists.

To look at the relationship between experience with Vital Signs and learners' broader ecology, we recruited four middle school teachers who represented varied levels of engagement with Vital Signs and higher and lower levels of school community affluence. Each teacher taught multiple periods, and we collected data from at least two of each of their classes over one year, resulting in a total of 218 participants. Surveys were used to gather data from the entire sample on a wide range of topics, including general interest in science, nature experiences, parents' roles as learning partners, and the use of science resources to learn science for school and for fun. Documentation of fieldwork and classroom activities were undertaken in all classes, and interviews were carried out with a subset of 35 students, chosen to represent a mix of boys and girls and a range of interest in science learning and in the specific Vital Signs work, as determined by survey responses and teacher feedback.

Our interview protocol was designed to create a portrait of activities across the contexts of home, school, and community, attending to how the youth found and used science-related tools and knowledge in these contexts. This interview also explored the student's sense of what it takes to be good at science, their plans for learning, and how they see themselves in relation to science. Photographs of the youth interviewee engaged in Vital Signs work and PDF files of their final Vital Signs submissions were used to prompt the students to tell us about their experiences, including stories of what they were doing and how they felt. A diagram illustrating different phases of the Vital Signs project (e.g., coming up with a question, gathering data in the field, submitting data online) was used to help focus the children's and interviewer's attention.

Our qualitative and qualitative analysis suggested that some students who were highly engaged in Vital Signs did not identify with the broader domain of science, whereas others who loved Vital Signs also gave us enthusiastic reports of their out-of-school science activities. We also found students who were not enthusiastic about their Vital Signs work and reported little or no interest in science, and students who were passionate about science but neutral about their investigative work in Vital Signs.

To look at how science interest varied across our sample, we created a general "interest in science learning" proxy by taking the average rating of student agreement with three statements—"I find learning science is satisfying," "I want to learn more about science," and "I find science interesting"—on a 5-point, Likert-type scale. There was wide variation among learners in their general interest in learning science, with scores ranging from 1 to 5, though the distribution was negatively skewed, with a mean of 3.13 and a mode of 4. To find out more about students with more or less general interest in science, we used a median split to form two groups, higher and lower science interest. In this sample, science interest was not associated with gender or socioeconomic status (SES). Forty-eight percent of male students and 52% of female students were in the higher interest group. Fifty-five percent of students in schools with lower rates of free and reduced-price lunch (indicating higher SES in the district), and 52% of students in schools with higher levels of free and reduced-price lunch were in the higher interest group.

Consistent with the findings from the retrospective study, comparisons of the two interest groups suggest that for students with more interest in learning science, knowledge extended beyond the walls of the science classroom. Higher interest students reported use of more science learning resources, were more likely to have science-related plans, and had access to a greater number of social partners who shared an interest in science.

Learners with higher interest were more likely to participate in activities exploring and documenting the natural world, such as observing wildlife (59% compared with 42% of those with lower interest), and photographing or drawing nature (57% compared with 39%). After the Vital Signs unit, the majority of all students reported that they looked at plants differently and noticed focal species elsewhere, but still the difference was apparent between groups, with approximately 50% more students in the higher interest group reporting this to be true. Although the two groups reported using resources similarly to learn science for school, the higher interest group used more learning resources for fun, including being more likely to use the Internet (46% compared with 22% of those with lower interest), view documentaries (44% compared with 20%), and read books (31% compared with 9%), to learn on their own. Three students (4%) in the lower interest group predicted that they might become scientists, science teachers, or citizen scientists. By contrast, 37% of the higher interest group indicated that they saw one of these as a possible future.

Attention to the role of social networks invites researchers to look more closely at the variety of ways learning partnerships emerge and function—as forms of joint activity and more broadly as relational ties that help bridge contexts, settings, or opportunities for learners (Barron et al., 2009; Borgatti & Cross, 2003). Students in the higher interest group were more likely to report that one or both parents played specific learning support roles, especially the roles of learner (80% compared with 50% of less interested students), teacher (75% vs. 40%), encourager (73% vs. 51%), and collaborator (67% vs. 43%). Echoing the retrospective finding that fathers were commonly significant learning partners, 61% of students in the higher interest group reported that their fathers taught them about science, with only 31% reporting that their mothers played this role. Students in the higher interest group were also more likely to report that their friends, too, were interested in science (71% compared with 20% of less interested students), again supporting the idea that the social network a child has access to may influence the development of science-related interests.

To complement and deepen our understanding of the quantitative results and the origins of student interest, we share narrative accounts for four learners that represent different science-interest relationships.

*Gill: Disinclined to Identify With Science Though a Devoted Tinkerer*

> When [my dad] was working on his trucks or something out in the garage, I'd usually just go out there and watch what he does and now, if you plant a motor in front of me, I can take it all apart and put it back together. The way he learned how to work on stuff like that, the very first engine he worked on was a little 2-stroke chain slot engine. He watched my grandfather do all that stuff and that's how he learned, so I'm learning the same way.

Gill's survey responses placed him at the lower end of the science interest distribution (10th percentile), despite an active interest in building and taking apart motors of all kinds, LEGO construction, and regular participation in a host of outdoor activities, including hunting, fishing, and exploring the countryside on snowmobiles and bikes. He did not feel that science was an interest of his parents, and he did not feel that they interacted around science content in any way. Nonetheless, Gill told a strong story of intergenerational learning. Gill's dad, whose primary work is in construction, is a "big-time" hobby mechanic, and Gill's expertise has developed from watching and helping his dad work on dirt bikes, four wheelers, tractors, and backhoes. Gill was somewhat interested in the work he did for Vital Signs. He had fun outside but enjoyed the "technical stuff and typing" more than the investigation itself. His interest in typing dated back to elementary school, where they had a computer lab. At home, the family shares a desktop computer and uses a dialup Internet connection. Although his father does not use the computer at all, Gill helps his mom use Facebook, suggesting that he had the most technical expertise in the house. Although he did not share his Vital Signs work at home, he indicated that he thought about it. He reported on the survey that he looked at plants differently and had noticed more invasive species since the investigation. And he thought he might someday submit an independent observation, if, for example, he saw a really unusual fish again, recalling a time when he was ice fishing and saw someone catch a highly invasive koi that had been let out in a local lake. Gill's denial of interest in science or valuing of his own science knowledge was stark, but the interview suggested that his out-of-school activities might not be difficult to connect with ones that we think of as building science knowledge. It turns out that although Gill was an enthusiastic computer user, he had never connected his interest in building with computational activities such as robotics. In fact, he mostly used the computer to share photos and chat with friends on Facebook, play games, and watch YouTube videos. Nonetheless, when the interviewer showed him the LEGO Mindstorms site, his response was quite enthusiastic, immediately imagining the possibility of making a controllable miniature dirt bike or four-wheeler.

*Laura: Contradictory About Her Science Interests*

> Like [my science teacher] was like, "Since you guys know all this, you guys are going to see a plant and think about what it is, and maybe even know what the tree is or whatever." Now every time I see a purple plant I will go, "Oooh, Purple Loosestrife," and my mom will go like, "How do you know what that is?" and I will go like, "Science." Yeah, it's weird. Or with plants, I will go, "Wow, those are some long lance-shaped leaves," and my mom will be like, "What the heck?" and I'll be like, "Sorry, it's a habit!"

Laura's end-of-year survey found her in the lower spectrum of science interest and neutral about how much she valued knowing about science. She reported that she definitely could not see herself becoming a scientist when she grew up. Other indicators, however, such as her interview quotation above about looking closely at the natural world around her, suggest a more complicated picture of the role of science in Laura's life. During her interview, she explained how in elementary school, she enjoyed mixing household products together to see what would happen. During her first Vital Signs investigation, Laura and a teammate set up a mini-experiment within their observation of a purple loosestrife plant: They captured a bug they knew ate the plant they were looking for and put both it and a leaf sample from their plant in a container to watch what occurred. On the end-of-year survey, after her class went through multiple species investigations, her rating of enjoyment of Vital Signs work was neutral, but she was one of 14% who reported that they might conduct a species observation over the summer. Some contributing factors to Laura's conflicted reflections on her science learning may be found through an analysis of her immediate social network. Although her survey data indicate that she did show her parents the Vital Signs Web site and that they encouraged her science learning, the data also indicate that she did not talk to them about invasive species or about science topics in general and that she did not consider any of her family members to be interested in science. Laura reported an emphatic "No!" when asked both if she talked with her friends about science or if they thought science was cool.

*Jeff: A Passion for Planets That Is Largely Invisible at School*

> My mom and kinda my dad are into science like that; they're not geeks about it, but lately they've been into the new planet Navaro.… I don't know how it formed but it's like in our solar system but it's kind of far away, probably way far away to see. They say if you look up by Leo you can see a little red dot and that's the little dwarf star, but… I've seen a little red dot by the Big Dipper, I think.… You can't see when you look up you kind of have to look close.

Jeff's science interest index score was near the top of the distribution, and he was one of the 15% of students who reported a possible future as a professional scientist. Like Gill, Jeff watched and occasionally helped his father, a mechanic, work on old cars and dirt bikes, but during his interview, he discussed his more intense interest in space, planets, and global positioning. Jeff and his parents fostered this interest within the family and often sought out science resources together, watching documentaries, looking through telescopes at home, and searching for information online. Jeff indicated that both of his parents played multiple roles to support his science learning, including learning from him, teaching him, brokering new experiences, and collaborating on projects. Jeff also indicated that he used multiple resources to learn about science on his own for fun, including documentaries, Internet searches, books, and magazines. Science and technology learning activities were often family oriented, including watching his father create a still-image movie for his grandmother's birthday, and learning to use Google Earth with his parents to find the houses of relatives in different states. Despite his deep topic explorations and co-learning and supports at home, it appeared that Jeff's science interest was relatively invisible at school. Although the Vital Signs interest proxy reported on his survey was high, his science teacher believed that he was one of the less engaged students in the class, and he was quiet with his teammates and was often observed physically lagging behind the group. Jeff reported that he looked at plants differently after Vital Signs, noticed his focal species, the broad-leaved cattail, in other places, and talked to his parents about invasive species, but he did not use the Web site on his own as a resource and did not even think of doing so. Jeff was able to take some of the new knowledge gained from Vital Signs into his personal and home science worlds, but Vital Signs seemed to remain a school-based project, and school was not the primary context where Jeff engaged with science.

*Catherine: Connecting Personal Interests and Citizen Science Practice*

> I like Vital Signs a lot but I am not espe—I don't really like science. I mean I guess I shouldn't say it because I have enjoyed it this year with all the interactive things, but I would never like see myself doing it as a career unless it was probably like art.

Catherine was a gifted and talented student at a school in a community with many social and monetary resources. On the survey, both Catherine's interest in science and her interest in Vital Signs ratings were relatively high, falling into the top 25% ranking for both measures. Although doing well in school was important to her, she did not connect science as a field to her own personal passions. She was an avid fiction reader and was crazy about animals, with a particular fondness for pigs, dogs, and cats. She pursued music and artistic activities at home and during after school and community classes and clubs and had immediate and extended family members who were professional or artists and musicians. Interviews with Catherine and survey measures about her future revealed that Catherine definitely did not see herself becoming a scientist, "because I'd rather be a horse trainer, and if I was doing science I would want it to be science that interested me, like being a veterinarian." Although Catherine often used YouTube do-it-yourself videos as inspiration for her art and design activities, she reported that she did not seek out science information for fun on her own time on the Internet or through books or other material resources. Although she reported that her friends thought science was cool or okay, she also shared that she did not talk to them about science topics outside of school. Vital Signs provided Catherine with a compelling pathway into science practice. Catherine enjoyed the hands-on experimental nature of the project and getting online feedback from experts. She was particularly drawn to sketching and photography of the found species during fieldwork. Catherine had ideas for similar investigations that would tie into her own interests, including tracking animals and the well-being of the animal populations, and thought that it would be helpful to have social networking features to interact with and learn about other participants. Through the Vital Signs project, her perception of the beach that is close to her house and that she frequents regularly during the summer shifted to a more informed understanding of the habitat. She was struck by the difference between reading about the invasive species and actually seeing them for herself on the beach:

> When we like read how invasive species are all over, it was just kind of like yeah, okay, whatever. But then we went out and like they were everywhere. And I just didn't ever realize it. And like whenever I go down to the beach, I see that orange goop all over and I just never really knew what it was. And then I read about it and then when I went again, I saw it everywhere again and I was like, "Oh no! What?!"

Catherine explained that how doing the investigation changed the way she looked at the beach near her house. In the fall of 2012, we heard from Catherine's science teacher that she had been spotted on the beach over the summer babysitting a small group of kids and showing them how to identify the "orange goop," an invasive coastal species called orange sheath tunicate, and to move it beyond the high tide line so that it could not reproduce.

## Concluding Thoughts

Across these two studies, we identified five converging themes that reflected how early interest might connect, or fail to connect, to a pathway for lifelong science learning. First, out-of-school activity is a common location for the germination and growth of strong early interests in science, but school-based activity can also engage students, particularly when it is inquiry-based, connects to learners' concerns, or involves enthusiastic teachers who share their passion through classroom or after-school activities. Practicing scientist Barry and middle-school-aged Jeff both developed topical science-related interests (dinosaurs and space, respectively) with a variety of material and social resources at home and on their own time. For others, school was an important point of engagement. Martin recalled a high school science teacher who recognized his interests and worked with him after school on highly specialized engineering projects, including a mercury barometer and a sailboat. Laura and Catherine, neither of whom had friends or parents interested or involved in science, found new ways of interpreting the natural world around them through participation in their classroom Vital Signs unit.

Second, strong interests in science that are rooted in out-of-school engagement do not necessarily translate to a strong school-based science interest or deep engagement. We saw many examples of a disconnect between rich science interests out of school and a lack of engagement in the classroom, because of mismatches in content of the science, processes used to engage with science, or the attitudes of teachers and students toward science and school. Examples include Jeff's reticence during the class project, Joe's lack of many school-related science memories prior to college, Berta's feeling that she'd just have to "get through" physics to be able to study what she wanted, and Laura's descriptions of her school social scene as antiscience. But we also saw the opposite, such as Laura and Catherine, whose work in a school project, Vital Signs, sparked new ideas, such as continuing investigations during the summer on their own time. Barry found ways to link his own early individual interest in dinosaurs, which began at home, to school-based opportunities, such as a teacher who allowed him to teach younger grade children. For the memories of both the retrospective and prospective cases, when school was successful, it was often a specific project or person, as opposed to a subject or a class, who was able to make the connection.

Third, interests are not just about topics, but also include ways of engaging with science-related pursuits, general settings such as the outdoors, and sometimes projected career choices. Interests are most often connected to particular content and activities as opposed to a general disciplinary frame of science, technology, engineering, or mathematics. Barry and Jeff self-identified their topical interests as science related, and enjoyed the pursuit of finding out more through varied resources. Catherine's fondness for drawing and animals was connected to science through her participation in the inquiry-based Vital Signs project work. A number of the participants enjoyed the practices of tinkering, making, and experimenting, including Gill taking apart old cars with his father, Laura mixing household products and conducting a live beetle experiment, and Martin creating his own hacksaw. Joe, the first in his family to attend college, is unique among the retrospective cases in that at different stages in his story, choices were informed by interests that were in part pragmatically based on decisions about possible careers.

Fourth, children vary significantly in home resources that can nurture and sustain participation in science-related activity, but lower resources do not preclude science interests or careers in science. Early science activities do not necessarily involve buying complicated kits, although this was true for Martin, who remembered both a chemistry set and an electronics kit. More traditional resources such as books and magazines were remembered by 35-year-old Barry, and Web-based tools such as YouTube were cited by 12-year-old Jeff.

There are many examples in our data of children who found their first connections to science through a relationship with nature or through taking apart used machines, such as Joe and Gill taking apart old cars, Laura exploring in her backyard, and Catherine sharing information about invasive species on the beach near her house. Although all of these participants are using resources to learn, there remain important questions about how the resources are used, specifically in ways that can further interest development and new opportunities for learning. Often, adults play an important role in navigating resources, including helping learners understand the increasingly complicated and often unreliable range of Web-based resources.

Fifth, parents were often pivotal resources, involving children in activities that are connected to science, even if those activities are not identified as "science" per se at the time and even if parents and their children do not see their identities as connected to the discipline of science or conceptualize their relevant lines of practice as related to science, technology, engineering, and mathematics (STEM) at all. Joe detailed multiple ways both of his parents were influential to his learning about science, including scouring the Web together looking for interesting topics. Martin remembered using his father's old microscope and recounted his parents financing and supporting his learning endeavors. As an adult, Jeff was able to reflect on his time with his father as highly linked to his own developing science interests, citing family mechanic workshop nights taking apart appliances. Although, much like Joe, Gill shared stories of tinkering with his father and a number of interests that could be connected with engineering activities, it is not clear whether a connection to STEM learning will be made that will further develop those interests and activities and connect them with a possible longer term trajectory of science-related learning or work.

In summary, there is evidence that individual interest in science often emerges early, and as learners become passionate about particular interests, they increasingly seek out and create other opportunities to learn by engaging parents and peers, taking on new self-directed projects, enrolling in programs or visiting informal learning settings, and pursuing resources in books or online. As we understand more about interest and its role in long-term engagement, we are poised to begin not just describing the learning ecology but actively engineering in the ecology by increasing the number of children who bump into science early in their lives, find it interesting, and then begin a supported, connected, and valued journey toward a life that includes science.

*Acknowledgments*

The research reported by Crowley and his colleagues in this chapter is a product of the Science Learning Activation Lab, funded by the Gordon and Betty Moore Foundation (http://activationlab.org). The work of Barron and her colleagues is supported by the National Science Foundation program Cyberlearning: Transforming Education (Grant REC-1124568), the Learning in Informal and Formal Environments Science of Learning Center, a National Science Foundation–funded (Grant REC-354453) effort seeking to understand and advance human learning through a simultaneous focus on implicit, informal, and formal learning, thus cultivating generalizable interdisciplinary theories that can guide the design of effective new technologies and learning environments. We also thank the teachers, students, and parents who contributed their time.

## References

Alexander, J., Johnson, K., & Kelley, K. (2012). Longitudinal analysis of the relations between opportunities to learn about science and the development of interests related to science. *Science Education*, *96*, 763–786.

Azevedo, F. (2011). Lines of practice: A practice-centered theory of interest relationships. *Cognition and Instruction*, *29*, 147–184.

Barron, B. (2006). Interest and self-sustained learning as catalysts of development: A learning ecologies perspective. *Human Development*, *49*, 193–224.

Barron, B., Martin, C. K., Takeuchi, L., & Fithian, R. (2009). Parents as learning partners in the development of technological fluency. *International Journal of Learning and Media*, *1*, 55–77.

Borgatti, S. P., & Cross, R. (2003). A relational view of information seeking and learning in social networks. *Management Science,* 49(4):432-445.

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design*. Cambridge, MA: Harvard University Press.

Cole, M. (1996). *Cultural psychology: A once and future discipline*. Cambridge, MA: Harvard University Press.

Crowley, K., & Jacobs, M. (2002). Islands of expertise and the development of family scientific literacy. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), *Learning conversations in museums* (pp. 333–356). Mahwah, NJ: Lawrence Erlbaum.

Hidi, S., & Renninger, A. (2006). The four-phase model of interest development. *Educational Psychology*, *41*, 111–127.

Knutson, K., Crowley, K., Russell, J., & Steiner, M. A. (2011). Approaching art education as an ecology: Exploring the role of museums. *Studies in Art Education*, *52*, 326–338.

Lerner, R. M. (1991). Changing organism-context relations as the basic process of development: A developmental contextual perspective. *Developmental Psychology*, *27*, 27–32.

Lewin, K. (1951). Field theory in social science. In D. Cartwright (Ed.), *Selected theoretical papers*. New York: Harper & Row.

Maltese, A. V., & Tai, R. H. (2010). Eyeballs in the fridge: Sources of early interest in science. *International Journal of Science Education*, *32*, 669–685.

Palmquist, S. D., & Crowley, K. (2007). From teachers to testers: Parents' role in child expertise development in informal settings. *Science Education*, *91*, 712–732.

Renninger, K. A., & Hidi, S. (2011). Revisiting the conceptualization, measurement, and generation of interest. *Educational Psychologist*, 46(3), 168–184.

Rogoff, B. (2003). The cultural nature of human development. New York: Oxford University Press.

Russell, J., Knutson, K., & Crowley, K. (2013). Informal learning organizations as part of an educational ecology: Lessons from collaboration across the formal-informal divide. *Journal of Educational Change*, *14*, 259–281.

Tai, R. H., Liu, C. Q., Maltese, A. V., & Fan, X. (2006). Planning early for careers in science. *Science*, *312*, 1143–1144.

Wilson, E. O. (2006). *Naturalist*. Washington, DC: Island Press.