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Science hobbyists: active users of the science-learning ecosystem

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ABSTRACT

Science hobbyists engage in self-directed, free-choice science learning and many have considerable expertise in their hobby area. This study focused on astronomy and birding hobbyists and examined how they used organizations to support their hobby engagement. Interviews were conducted with 58 amateur astronomers and 49 birders from the midwestern and southeastern United States. A learning ecology framework was used to map the community contexts with which the hobbyists acted. Results indicated seven contexts that supported the participants' hobby involvement over time: home, K-12 schools, universities, informal learning institutions, hobby clubs, conferences, and community organizations. Three themes emerged that described how hobbyists interacted with organizations in their communities: (1) organizations provided multiple points of entrance into the science-learning ecosystem, (2) organizations acted as catalysts to facilitate a hobbyist's development in their hobby, and (3) the relationship between hobbyists and organizations they used for learning eventually became bidirectional. Results showed that both astronomy and birding hobbyists used science-learning organizations to meet their hobby-related learning goals. Most hobbyists in the sample (90% astronomers, 78% birders) also engaged in outreach and shared their hobby with members of their community. Patterns of interaction of the astronomy and birding hobbyists within the seven contexts are discussed.

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> [I learned about my hobby] through the museums and just reading. I read a lot. I was an astronomy minor in college. In high school, I was in science club. I always did the astronomy activities at [Science] Olympiad. I've attended workshops about astronomy … I attended a workshop at Bryce Canyon National Park, which was a phenomenal, life-changing experience. [I continue to learn more about my hobby through] the Internet and other hobbyists, mostly. A lot of 'learning more about astronomy' is just taking your star chart outside and just actually doing it.
> (Female astronomy hobbyist)

Science hobbyists are members of the public who are highly motivated to learn about the science topic that interests them, often spending considerable time and money in pursuit of that interest. Hobbyists seek out science-related learning opportunities, utilizing a range of resources in their communities, to meet their learning objectives and develop their science knowledge and expertise. The United States' free-choice science-learning landscape is thriving and is filled with many institutions and resources for learners to take advantage of including science museums, zoos, aquariums, national parks, and other organizations including clubs. Reportedly, the average American spends less than 5% of their life learning in a formal education environment and, as a result, it is clear

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that most science knowledge is learned outside of school in a variety of contexts and settings (Falk & Dierking, 2010; National Research Council, 2014).

Falk and Dierking (2010) found that the greatest contributor to adult science knowledge was adults own free-choice learning experiences and further noted that childhood free-choice learning experiences also contributed to adult science knowledge. By examining learner-initiated learning across settings, we may better understand how self-directed learners utilize the resources in their communities to meet their learning goals, and how their utilization of these resources changes as their interests and skills develop (Barron, 2006). In this paper, 'formal' learning institutions refer to colleges, universities, and K-12 schools, and 'informal' learning institutions refer to museums, science centers, national parks, and so on. 'Other' learning organizations or groups are also discussed, including hobby clubs, professional organizations, and conferences.

In the sections that follow, a brief review of relevant research is presented to establish the theoretical background for the present work. Next, the process by which the data used in the present study were collected is described. Third, the learning ecology framework and the three themes that emerged from the data are described. Next, the results of the research, including the frequencies at which the hobbyists in our sample engaged in various hobby-related educational activities is presented. Four cases of hobbyists who engaged with elements of the science-learning ecosystem while participating in their hobby are described to illustrate the findings.

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Theoretical background

An ecological perspective of science learning

Ecology studies interactions between organisms and their environment and employs schemata that may be used in education research to represent educational systems (Barron, 2006; Bell, Lewenstein, Shouse, & Feder, 2009; National Research Council, 2014; Traphagen & Traill, 2014). One such metaphor, a learning ecology, is a set of contexts that provide opportunities for learners to learn. The contexts may be physical or virtual, and include a unique blend of activities, resources, and relationships (Barron, 2006). The ecosystem metaphor evokes ideas of an inclusive endeavor that puts the learner at the center of the system, and focuses researchers' attention on the learner's activities across settings and time and not on any one particular moment of learning (Bell et al., 2009). The framework of a science-learning ecosystem, or a STEM (Science, Technology, Engineering, and Mathematics) learning ecosystem, provides not only the language to discuss such inclusive and learner-centric systems, but also delivers a roadmap for how to build collaborations and programs between community organizations and groups into the future.

As described by Traphagen and Traill (2014), a STEM learning ecosystem includes schools, community-based settings/programs, science centers, and informal experiences that may be engaged in at home. A learning ecosystem perspective attempts to understand and represent the dynamic and interconnected relationships among the ecosystem elements that provide community members with avenues by which they may become knowledgeable about STEM content at any age. Learners engage in STEM activities both in and out of school and the knowledge developed in some learning contexts may be brought into others (Barron, 2006; Bell et al., 2009; Jones, Howe, & Rua, 2000; Traphagen & Traill, 2014). The ecosystem perspective acknowledges that the boundaries between learning contexts are often porous, and this perspective overcomes artificial divisions between traditionally siloed learning settings (Traphagen & Traill, 2014).

The STEM learning ecosystem is diverse, and each element of the system has something unique to contribute. The challenge is for the network of settings to be an integrated system of learning and teaching so that each partner complements and build upon each other's efforts rather than duplicating programs (Traphagen & Traill, 2014). Such a system working at full capacity has been envisioned to distribute responsibility for teaching and learning among all of the ecosystem's elements (National Research Council, 2014). To sustain collaborations over time, STEM learning ecosystems must be

attentive to what Traphagen and Traill (2014) termed the 'enlightened self-interest' of their members; participating in the ecosystem must allow members to work toward their own organization's mission. Sheppard (2007) examined conversations of the Museum Loan Network, which discussed motivations for museums to collaborate with other kinds of institutions. Each motivation focused on using the partnership to extend museums' current capabilities, helping them to reach their own goals faster. The model of a STEM learning ecosystem is applied here specifically in the context of science learning, and is referred to as a science-learning ecosystem.

Free-choice learning

The field of science education has become increasingly interested in teaching and learning from a broader perspective, with learner-initiated activities that take place in non-compulsory and out-of-school settings, often described as free-choice learning, gaining attention (Bell et al., 2009; Falk, Donovan, & Woods, 2001). Researchers have shown that engagement in free-choice science-learning activities contribute to adults' knowledge of science content (Falk & Needham, 2013; Falk, Storksdieck, & Dierking, 2007) and positive attitudes about science and scientists (Rennie & Williams, 2006). Youth participation in such activities has been shown to contribute to interest in science and science careers (Dabney et al., 2011; Maltese & Tai, 2010). As boundaries blur and divisions weaken, researchers are calling attention to the overlap between learning settings, emphasizing that teaching and learning are situated in broad spaces, and that neither activity stops at the schoolhouse door.

Social interactions with others and learning

Within the ecosystem framework, other people, groups, and organizations play crucial roles in influencing learning. Much has been written on the subject of learning from others. Vygotsky's (1978) seminal work describing the zone of proximal development (ZPD) has been widely recognized as a significant process by which individuals learn from others. The ZPD is the distance between an individual learner's current developmental level and problem-solving ability and the learner's potential developmental level and problem-solving ability when assisted by a more capable peer (Vygotsky, 1978). The more capable peer may provide guiding advice and appropriate scaffolding for engaging in the learning activity, but still allows the learner to demonstrate initiative. Through these interactions, a learner may accomplish tasks she would not be capable of on her own. The ZPD and scaffolding are metaphors for the process by which a learner develops expertise by learning from and with others.

Greenfield (1984) described how interactions with others through informal, cooperative learning lead to the development of individual skills. She concluded that this phenomenon is general and may be applied to learning in many different situations and contexts. Astor-Jack, Kiehl Whaley, Dierking, Perry, and Garibay (2007) discussed Vygotsky's views that speech combined with practical activities are important to cognitive development, and suggested that these ideas are particularly important to understanding socially mediated learning in the museum context. The authors also described how social interactions among peers serve as a form of distributed meaning-making. The specialized understanding of a specific group of people resides within the group, rather than any one individual member of that group. Learning in multiple contexts, being a member of multiple communities of learners, is beneficial as it provides the learner access to a range of knowledge.

Rogoff (1984) contended that cognitive processes and activities are not context-free. Indeed, the context incorporates the problem's physical and conceptual structure, the purpose of the activity, and the social situation in which it is embedded. A spectrum of learning environments should be examined if one wishes to get a full picture of an individual's learning as different environments and contexts may incorporate distinctive sociocultural activities and knowledge. Wertsch, Minick, and Arns (1984) discussed how Vygotskians view the adoption of

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socioculturally evolved activities as important to cognitive development. The sociocultural view of learning can be particularly useful in helping us to understand teaching and learning in free-choice education contexts.

Adults who engage in science hobbies are members of a population who have elected to engage in free-choice learning activities. Studying the development of such people in their hobbies and hobby-related activities may give us insight into the ecological system that guides and supports their participation. Interviews, because they provide in-depth interaction, allow us to gain a sense of the operation of the ecosystem as it influences and is influenced by the individuals acting in the system.

Methodology

This study reports an initial study in a larger series of investigations of science hobbyists. Broadly, the goal of the larger study was to understand who participates in hobbies, how they participate, goals and motivations for participation, how individuals become involved in their hobby, and how interests and participation change over time. One hundred and seven adult science hobbyists, 58 amateur astronomers and 49 birders, were recruited to take part in this study. In the United States, the country in which this research took place, racial context can be important. Ninety percent of the astronomers were Caucasian, 2% reported their race to be African-American, 2% as Asian, 3% as Hispanic/mixed race Hispanic, and 3% as Native American/mixed race Native American. All birders reported their race as Caucasian. Seventy-nine percent of the astronomers and 24% of the birders were male. All participants were at least 18 years of age. The astronomers had a mean age of 51 and a median age of 53; the birders had a mean age of 56 and a median age of 59.

Astronomy and birding hobbies were chosen as the focus for this study as they represent a physical science and a biological science interest, respectively. Careers and courses in the biological and physical sciences are often perceived differently in American and other world cultures. As such, it is important to understand how these attitudes might influence participation in science hobbies. In order to examine the ecological system with sufficient depth, one physical science and one biological science context were chosen for participant interviews.

Researchers recruited hobbyists to be interviewed through astronomy and birding hobby clubs in the southeastern and midwestern United States as well as through national clubs; invitations to participate in the study were also distributed through listservs, websites, newsletters, and in person at club meetings. All volunteers were included in the study. Semi-structured interviews were conducted in-person or over-the-phone and took about one hour to complete. The interview protocol was designed to explore characteristics and behaviors of science hobbyists. The interview included 56 questions that asked about the hobbyist's participation in their hobby, motivation to engage in their hobby, hobby-related learning opportunities, hobby-related outreach opportunities, development of their hobby over time, benefits and drawbacks to hobby participation, in addition to personal information about the hobbyist.

The interview protocol was shaped by the goals of the study, described previously. Falk and Dierking's (2013) contextual model of learning also informed the development of the interview protocol. The contextual model of learning proposes that informal learning is shaped by (1) the personal context of the learner, (2) the social context, including interactions with others, and (3) the physical context in which learning takes place. The personal context focuses on the individual's interests, motivations, and past experiences. To explore this context, participants were asked questions such as 'Were there any critical junctures or experiences that influenced your involvement in your hobby?'. The social context was explored through questions such as 'Would you tell us about how you interact with others in your participation in your hobby?', and the physical context was explored through questions like 'Where do you usually work on your hobby? Would you tell me about any kind of space in your residence or elsewhere that is devoted to your hobby?'.

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Each interview was audio recorded and the interviewer took notes during the interview. The recordings of the interviews were transcribed and coded. Each interview was read several times by members of the research group. A grounded theory approach was used to collect and analyze data from the interviews (Cresswell, 1998). Notes were taken on each interview and an open coding scheme was created to capture participants' education-related interactions with organizations in their communities. All interviews were coded based on this coding system; the researcher also took note of where the codes did not fit the dataset and how they could be improved to better capture the experiences of the interview subjects. The results from the first round of coding were discussed and revisions were made in the codes. The interviews were recoded to capture specific hobby-related educational activities with community-based organizations and groups (e.g. universities, K-12 schools, museums, parks, hobby clubs, scout groups, etc.). Frequency counts were tabulated to note whether hobbyists engaged in each category of activity. Inter-rater agreement for the second round of coding was found to be 93%.

The results from the second coding were analyzed and frequency counts of education-related interactions and events were obtained. The cases of two astronomers and two birders were selected to illustrate themes that emerged from the full set of interviews. Two cases were chosen per hobby to demonstrate the diversity of hobbyist perspectives, and because the four cases could be discussed in depth whereas this would not have been possible with a larger selection of cases. These cases are not meant to be representative of the 'average' hobbyist in the sample, but rather to illustrate one path a hobbyist might take through the science-learning ecosystem as they pursue their hobby interest.

Analysis

How do science hobbyists interact with learning institutions? A learning ecology framework

A learning ecology framework is applied here to illustrate the many contexts in which the hobbyists in our sample engage with others (experts/scientists, members of the public, other hobbyists, etc.) to learn and/or teach about their hobby. The analysis began with an examination of the transcripts for hobby-related activities and physical contexts for hobby engagement. Seven contexts were identified: home, K-12 schools, universities, hobby clubs, conferences, community organizations, and in formal learning institutions (Figure 1). Listed with each context are examples of education-related hobby activities the hobbyists in our sample took advantage of in those settings. For example, while interacting with informal learning institutions, the hobbyists in our sample learned about their hobby through workshops and courses, short-term educational activities (e.g. a museum exhibit or program, a planetarium show, etc.), by having access to specialized resources (e.g. telescopes, a museum collection of bird specimens, etc.), and mentoring relationships. Peer–peer relationships were found in most of these contexts.

Next, activity outcomes (i.e. what the hobbyist gains from engaging in the activity) were identified (see the circle in Figure 1). These activity outcomes include types of knowledge learned by interacting with organizations in the science-learning ecosystem. Participants would identify a hobby-related learning need and, filtering that need through their personal context (their prior experiences, interests, knowledge, motivations, beliefs and values), often identified an opportunity to engage with community-based elements of the science-learning ecosystem to meet that need. Connections between learning settings were noted in the coding; science-learning ecosystem elements often partner with each other to develop resources and programs for community members. It is often through a close relationship with one element of the ecosystem (e.g. hobby clubs) that hobbyists are introduced to other ecosystem contexts (e.g. K-12 schools).

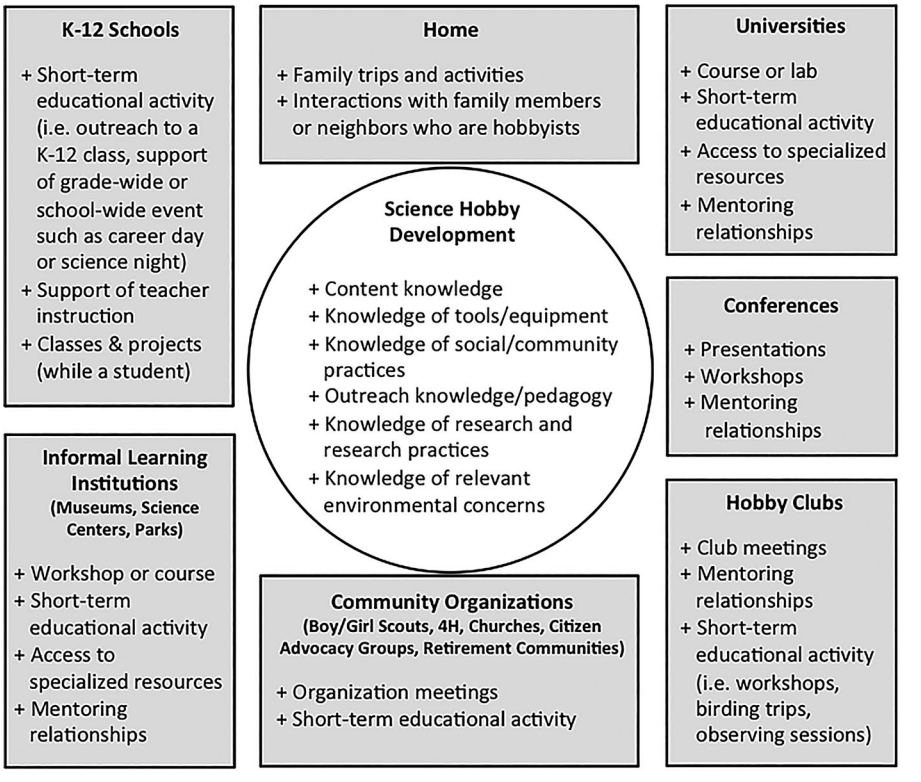

Figure 1. Contexts and activities for Hobbyists' engagement in the science-learning ecosystem.

Results

Hobbyists' participation in the science-learning ecosystem: three themes

Through reading the interviews of 107 science hobbyists, it became clear that there were as many patterns of interaction with science ecosystem elements and paths for hobby development as there were hobbyists. Three common themes emerged from the interviews as the participants described how they interacted with the science and STEM organizations in their communities.

(1) *Multiple points of entrance:* Hobbyists can enter the science-learning ecosystem at any point.
(2) *Organizations as catalysts:* A hobbyist's development in their hobby advances when they participate with organizations in the science-learning ecosystem.
(3) *Bidirectional exchange:* The relationship between hobbyists and the organizations they use for learning eventually becomes bidirectional.

Themes 1 and 2 describe characteristics of the relationships that all science hobbyists in our sample who interact with the science-learning ecosystem have with that ecosystem. While hobbyists do not immediately exhibit theme 3, for many hobbyists there was a shift in their relationships with formal and informal educational organizations. With sufficient time, nearly all hobbyists will exhibit such a shift with at least one element of the science-learning ecosystem. Details of the emergent themes are described below.

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Theme 1: multiple points of entrance

After a community member identified their hobby interest and decided to nurture and cultivate that interest, the new hobbyist reached out to an organization in their community to support their learning. This reaching out to others occurred immediately after becoming interested in the hobby for some and later, after a period of self-study or hobby dormancy, for others. The hobbyists in our sample often first reached out to a university, museum, or a hobby club. Theme 1, hobbyists entering the science-learning ecosystem at any point, refers to both the point in time the hobbyist entered the science-learning ecosystem and the organization the hobbyist interacted with when they entered the ecosystem.

Theme 2: organizations as catalysts

Though they may have been 'hooked' through involvement with a significant person, resource, or event and may have developed an interest in their hobby during childhood, many hobbyists in our sample cited their relationship with a science-learning organization as invaluable to getting them more involved in their hobby. Often the organization provided a structured learning experience (e.g. course, workshop) and assisted the hobbyist in fulfilling a specific need she was unable to meet on her own (e.g. determine what telescope to buy, learn how to identify birds in the wild). The organization may have also provided an opportunity for a hobbyist to meet a peer, or peers, who assist and mentor the hobbyist as they are getting started. When recalling their initial involvement with a science-learning organization or group, hobbyists often specifically recollect the relationships they form through these organizations and cite them as crucial to their development and continued enjoyment of the hobby.

Theme 3: bidirectional exchange

Hobbyists tended to get more involved with science-learning organizations as their expertise increased. These unidirectional relationships (hobbyists as learners) became bidirectional as a hobbyists' involvement expanded to include activities that supported the organization's efforts. Common ways of getting more involved and contributing to science-learning organizations included doing hobby-related outreach and taking on a leadership role within the organization.

Hobbyists' participation in the science-learning ecosystem: a portrait of four cases

Four cases are described below that illustrate four possible pathways through the science-learning ecosystem as the hobbyists engage in and develop their hobbies. These cases are provided to illustrate four possible histories of science ecosystem interaction rather than to prove the ubiquity of any one pathway.

The first case describes Sheila's[1] experience as an astronomy hobbyist and illustrates how learning from formal learning organizations and being connected to professional organizations and researchers provided her with the knowledge and expertise to contribute to the field of astronomy at a professional level. Next, Anthony's experience as an astronomy hobbyist highlights the importance of hobby clubs with regard to a new hobbyist's development. Through his club affiliation, Anthony found learning opportunities, connections to other elements of the science-learning ecosystem, and opportunities to do outreach. Third, Blythe's experience as a birder illustrates how a hobbyist with little formal hobby learning may develop expertise by taking advantage of the expertise of more experienced hobbyists and new environments. Last, George's experience illustrates how a hobbyist, who largely pursues his hobby alone, occasionally with friends and family, may sporadically interact with elements of the learning ecosystem.

Case 1: formal learning sparks hobby interest and leads to scientific contributions

At the time of her interview, Sheila was a 53-year-old woman who had been an Astronomy hobbyist for 24 years. Sheila is African-American and holds an MD degree as well as an MBA in Health Policy, and had recently retired from a career as a physician. She reported spending 7–8 hours per week participating in her astronomy hobby.

An active hobbyist for 24 years, her interest in astronomy started more than a decade before she became active in her hobby, as a high school student:

> I: How and when did you first become interested in and involved with your hobby?
> S: When I was in high school, I think I was a sophomore or a junior, I was taking high school physics. The physics instructor was interested in amateur astronomy and a lot of the physics projects were geared towards astronomy. He had his own observatory and he would invite students that were interested to his observatory at nights or on weekends … that is when I first saw Saturn through a telescope. I just became hooked … and also, at the same time, I was taking a Greek mythology course as an English credit. Every time we would learn about a particular myth like Andromeda, at the end of the myth they would say: she was placed in the sky like a constellation. I always wanted to go out and find a constellation that was associated with that myth. So, it was a combination of Greek mythology and high school physics that really got me hooked into astronomy.

Despite this early interest in astronomy, Shelia chose not to participate in the hobby for many years. Though she was interested in taking university-level courses in astronomy, she cited not needing that coursework to fulfill her medical school requirements and a busy schedule as reasons why she did not pursue her hobby interest immediately after high school.

> I: Have you taken formal secondary or post-secondary courses in science that are related to your hobby?
> S: While I was in college, even though I was interested in taking astronomy in college, I didn't because I didn't need it. I wanted to go to medical school and I didn't need [astronomy coursework] to get into medical school. As soon as I finished medical school and residency, I did want to do some formal learning in astronomy. So, I actually went back at night to take college level astronomy courses to have some formal level astronomy classes. They were college level astronomy courses … I think I took two or three semesters of astronomy.

In addition to enrolling in university courses as a non-degree-seeking student to increase her hobby-related content knowledge, Sheila cited two additional events that were important to jumpstarting her hobby engagement after a decade-long dormant period: joining an astronomy hobby club and purchasing her first telescope:

> I: Were there any critical junctures or experiences that influenced your involvement in your hobby?
> S: … going to an astronomy club was when I first started to seriously become interested [after medical school and residency] … that gave me an opportunity to see what amateur astronomers were doing and it helped [me] to get advice on buying a telescope. So, joining an astronomy club was the second most helpful thing that increased my enjoyment of astronomy.

During her succeeding 24 years of hobby involvement, Shelia interacted with many groups and organizations while participating in her hobby. She became a highly skilled amateur astronomer as illustrated by her patterns of participation. She attended meetings of her local astronomy club, and occasionally traveled to give lectures to other astronomy clubs.

Ten years after rekindling her interest in astronomy, Shelia wanted to do something 'more scientific in the hobby of astronomy.' To support this interest, she built a house with an observatory on top. This observatory housed a telescope and camera that she controlled remotely from her computer. She joined the American Association of Variable Star Observers (AAVSO), which she described as an 'amateur professional organization.' Sheila used her telescope to monitor the brightness of variable stars and contributed her findings to the organization, which are often used for research purposes by professional astronomers. She would often observe specific targets at the request of professional astronomers. Sheila also participated in AAVSO's workshops to increase her technical skills in processing and sharing her data, and helped teach one of these workshops.

After getting more involved in image processing with AAVSO, Sheila took an astronomy course at a university to improve her image processing skills. The professor invited her to be on his research team, and she assisted them in their search for exoplanets[2] by processing data. She was the only astronomy hobbyist on the team. Sheila also contributed to the field of astronomy by discovering a nova, a star that showed a sudden and unexpected increase in brightness.

Sheila was involved in public outreach, mainly through her astronomy club involvement. She participated in the club's observing events for the general public, supported her local science museum's

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astronomy-themed events, and visited schools and boy/girl scout groups with her telescope. She also interacted with teachers, encouraging them to incorporate more astronomy into their lessons and to use her as a resource for their content questions. To support her interest in outreach, Sheila purchased a more 'kid-friendly' telescope to take into the community. She is particularly motivated to introduce girls and African-American children to astronomy, children who, she explains, usually do not get exposed to telescopes and the field of astronomy.

Case 2: new hobbyist mentored by club members enjoys doing outreach and organizing club-related events to engage potential future hobbyists

Anthony, a 30-year-old Caucasian man, had been an Astronomy hobbyist for 4.5 years at the time of his interview. His highest level of education completed was a master's degree in Business Administration, and he was employed as a classical musician and part-time software engineer. He reported spending up to 8–10 hours per week participating in his Astronomy hobby.

Anthony's interest in Astronomy started in childhood:

> I've had a fascination with science in general and astronomy in particular since I was a little kid. I remember being in first grade, and I wanted to be an astrophysicist … So it's been a lifelong fascination. I never acted on it because I was consumed with other things.

He decided to buy his first telescope in his mid-twenties at the encouragement of his girlfriend. While researching telescopes, he joined the email list of his local astronomy club and started asking hobby-related questions. The other hobbyists were very helpful in getting him set up. Anthony identified joining the astronomy club and subsequently meeting and learning from other hobbyists as the single most important event that helped him get involved in astronomy.

> I: Were there any critical junctures or experiences that influenced your involvement in your hobby?
> A: Definitely. Hands-down, the most important thing for me has been the astronomy club I'm a member of. … Literally the next day after that [telescope discussion], I signed up on [the club] email list. I started asking questions and these guys were the most friendly and helpful people you could ever ask for. Very eager. And I found that to be a trend everywhere I go, at every astronomy event you go to outreach is a huge aspect. People love it. People really genuinely enjoy sharing this [hobby] with other people. So that was tremendous in terms of just helping me learn how to get started, what should I be buying, and then what should I do with it. And then when I showed up that first time, taking [my telescope] out into the field at one of their events, it was tremendous. There were a couple of guys that spent the whole night with me: with my telescope showing me how to use it and then at their telescope showing me everything. [They showed me] what we're going to look for and went through the process of finding it: looking up in the sky, finding your guidepost, and all that stuff. And, in those first couple of months, a lot of involvement from them was tremendous. It made all the difference.

Most of Anthony's hobby-related learning experiences had been informal. When asked to elaborate on his educational experiences related to his hobby, Anthony responded:

> Very slim. No classes. No degrees. Aside from up through high school, whatever kind of general science everybody gets … but it wasn't particularly thorough. Other than that, I'm self-educated, I guess. Just learning from the people around me, and a lot of reading.

Anthony attended star parties and learned about astronomy from presentations at these events. Anthony also spent many hours listening to and learning from an astronomy professor's podcast. Though he identified the podcast as a series of lectures from two university astronomy courses, he did not consider this as taking a course related to his hobby.

Anthony did not often attend astronomy club meetings due to constraints in his schedule, but found the time to participate in other club-sponsored events, especially those that involved outreach. With other astronomy club members, Anthony volunteered at an annual astronomy-themed outreach event at a local science museum. He and other club members also supported the outreach efforts of a local planetarium by bringing their telescopes to the planetarium's observing sessions and engaging with the public. Anthony was actively involved in organizing the astronomy club's observing sessions, and regularly attended those events. He was also one of several club members

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who gathered to observe at a state park several hours away, in a darker sky location. Through regularly using the park facilities, these astronomy hobbyists developed a relationship with the park rangers. In discussing his interactions with the state park, he described:

> It's an interesting spot right on I-95 and it's a nice park: nice facilities, beautiful area, walking trails and everything. So you get a lot of people stopping there who are just driving up and down I-95, up and down the coast, they need a place to stop and camp. It's a real variety of people. The rangers are great about telling them whenever we're going to be out, that we're friendly and that they should come over and have a look. The rangers know that we enjoy sharing the hobby with these people. I think the rangers also appreciate that we are kind of keeping an eye on the place after dark and establishing a rapport with the people who are staying there. In that respect, we're doing outreach almost every single time we go out there. Just whoever happens to be there. It is amazing some of the people you meet.

Anthony described how the rangers had recently invited the hobbyists to take a more active role with the park and partner with them more directly. The rangers put together several programs that they advertised to the public and invited Anthony and the other astronomy hobbyists to attend with their telescopes and share their hobby with the park's visitors. Anthony spoke positively of the developing relationship between the hobbyists and park staff.

Case 3: active birder becomes a lister and engages more with birding tours and clubs

Blythe was a 74-year-old Caucasian woman at the time of her interview. She held a Ph.D. in sociology and demography, and was retired from a career in international public health. She had watched birds since her childhood and considered herself to have been an active birder for 25 years. She described having a high level of engagement in her hobby as she was always aware of the birds around her.

Her parents were birdwatchers and would identify the birds in their yard. She recalled being aware of birds ever since she was 5 years old and saw a kingfisher. Blythe became more active in her birding hobby when she was in her late 40s and had the opportunity to travel to Kenya with a colleague for a work-related conference.

> [W]e came down to breakfast and were sitting at a table and on the back of the chair opposite me was this absolutely spectacular bird. It turns out it was something called a Superb starling and there are a gazillion of them but I didn't know that then. My friend and I were just totally wowed by this bird. We signed up for a little trip to the Nairobi [National Park] that same afternoon. You know when you see elephants and giraffes and zebras you know what they are right away? I didn't know what any of the birds were. And I always have to know what it is I'm seeing, so we rushed out and bought a bird book and hired a guide to take us out all of the next day—take us anywhere he wanted. And we both came back confirmed, active birders. … I think that a lot of people get hooked with what I call a 'wow bird.' It's a bird that makes you say (gasp) 'I've got to know what that is!' And it's not usually a little brown job[3].

Blythe described how meeting her second husband, a fellow birder, also encouraged the development of her birding hobby. He influenced her to become a 'lister' and keep track of all of the birds she observed.

> … I met my husband, my second husband, and he was a very active birder. It was his goal in life to see 800 birds in the ABA [American Birding Association]. And (laugh) one of the first questions he asked me was: 'so how many birds have you seen?' Almost hoping I hadn't seen more than he had! And I said 'I don't know.' He said 'Don't you count them?' I said 'No, that's far too much trouble.' Two weeks later this birding software arrived in the mail. I had fun entering all my birds because I used to just write in the field guides. And so then I knew how many I'd seen; I suddenly wanted to see more. So my husband, before we were even married, turned me into a lister. So, that was a fairly critical juncture.

Blythe took note of the birds in her yard and observed birds while taking her daily walk. An important aspect of Blythe's birding hobby was that, in addition to observing the birds around her home, she would travel to birdwatch. While active in her career, she found opportunities to birdwatch while traveling domestically and internationally for work. Blythe also took trips and vacations for the purpose of birding. She described an upcoming trip to Mongolia, as well as past trips to

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Ireland, Greece, India, Alaska, and off the North Carolina coast for pelagic birding. She had birded in dozens of countries, and had a list of more than 50 birds spotted for 20 countries. On these birding trips, she would often bird with an organized expedition or knowledgeable guide to help her learn more about birding. When asked to describe how she learned about her hobby, Blythe responded that she did not learn about birding, but rather absorbed it. She had never taken a birding-related course at a university, but ' … if I were ever in one place long enough I would like to [take a course].' She had participated in workshops to learn about her hobby, including a two-day course in Arizona with a well-known hummingbird authority.

Blythe was a member of a local bird club, as well as a regional (two-state) bird club. She attended birding club meetings to learn about her hobby, and had given a talk at her local bird club. At the time of her interview, she held a leadership position in the bird club and was the editor of its newsletter. Blythe also had attended birding festivals in various states. She did not often participate in hobby-related outreach events with museums, but had occasionally brought dead birds to her local science museum to donate.

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Case 4: backyard birdwatcher interacts with museums, clubs, and parks in his community for learning opportunities

George was a 56-year-old Caucasian man at the time of his interview. His highest level of education completed was high school, and he was employed as an inventory analyst at a textile company. An active birder for 15 years, George described his current level of hobby involvement at about 5 hours per week.

He explained becoming interested in birding almost by accident. One day in his early 40s, George purchased seed for birds and set up the feed on his deck. The birds that visited his backyard fascinated him. Purchasing that first seed bail led him to buy feeders, more seed, binoculars, and books. Joining a local birding club also helped George develop his hobby interest, even though he did not often attend club meetings. When asked if there were critical junctures or experiences that influenced his hobby involvement he replied,

> Yes. When I joined the bird club. I think that was a pivotal moment for me. I don't attend that many meetings, but they have an online listserv where the pros go to post their sightings and their opinions about a certain sighting. Looking over their shoulder and reading their posts has just been amazing. I pick up a lot there.

George also attended an eight-week course, 'The Basics of Birding,' at his local science center when he started his birding hobby.

George enjoyed birding with friends and attending organized birding walks with other hobbyists. Two local parks, in partnership with a birding club he is not a member of, sponsored birding walks every other Saturday during the spring and fall months to observe migrating birds. He would occasionally join these groups at the parks to bird. George also attended bird-related programs at his local science center to learn more about his hobby. He especially enjoyed the program where the educators displayed live birds and discussed different species of birds. He had attended this program on multiple occasions. He also attended an event that was hosted by a professional hummingbird bander who demonstrated how he caught and banded hummingbirds.

George had three varieties of bird feeders at his house for different birds and spent most of his hobby time observing his feeders. He and his family would take vacations to locations where birding opportunities were readily available. According to George: 'It seems most vacations are birding vacations.' He described himself as slightly more knowledgeable than the friends and family members he birded with and enjoyed answering their bird-related questions.

In addition to teaching his friends about birding, George was interested in doing outreach and speaking to members of the community about his hobby. He was once asked to speak to a local Boy Scout troop about birding. He agreed to, but the opportunity did not materialize. He was interested in finding similar opportunities in the future.

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Hobbyists' participation in the science-learning ecosystem: an overview of hobby-related education activities and interactions in ecosystem contexts

Results showed that both astronomy and birding hobbyists used community-based science-learning organizations to meet their hobby-related learning needs. Some hobbyists' relationships with these organizations were bidirectional; these hobbyists worked with and through these institutions to share their hobby interest with others. Tables 1–3 present the frequency with which the hobbyists in our sample interacted with formal learning organizations, informal learning organizations, and other learning organizations, respectively.

Hobbyists as learners

These science hobbyists engaged in free-choice learning: they were learners who had the autonomy to decide which organizations to interface with and which activities to engage in while realizing their personal learning agenda. While learning about their hobby interest, 100% of astronomers and 98% of birders in our sample reported utilizing universities, informal learning institutions (e.g. museums, science centers, state/national parks), or some other group or event that encourages social learning (e.g. hobby club). Nearly all science hobbyists in our sample utilized at least one of the elements of the science-learning ecosystem (e.g. universities, state parks, hobby clubs, etc.) to further their learning.

Some hobbyists sought out learning opportunities at formal learning organizations, such as colleges and universities, to increase their hobby-related content knowledge. These hobbyists found the formalized nature of the instruction to be valuable and believed that it provided them with a strong foundation on which to develop their hobby. Seventy-two percent of astronomers and 37% of birders utilized formal learning institutions, such as universities, as learners. Sixty-six percent of astronomers and 29% of birders in our sample took a semester-long course or lab at a university that was related to their hobby interest. Approximately half of learners who interacted with formal learning institutions (34% of astronomers and 14% of birders of the total sample) did so while not enrolled in a degree program.

Informal learning organizations, including museums and parks, also offered many opportunities for hobby learning. Most hobbyists in our sample used these institutions, and at similar rates: 90% of astronomers and 80% of birders reported engaging with informal learning institutions as learners. Informal learning organizations provided an environment for the hobbyists in our sample to engage in self-directed hobby learning (e.g. interacting with museum exhibits, examining museum artifacts, and using the park environment to observe astronomical objects or local birds). Some informal learning organizations also offered more structured learning opportunities, utilized by approximately one-fifth of participants. Twenty-one percent of astronomers and 18% of birders took a workshop or course at an informal learning institution to learn about their hobby.

The hobbyists also reported the important influence of other groups on their hobby learning. Hobby clubs proved to be an important avenue through which hobbyists learned about their hobby; 83% of astronomers and 73% of birders in our sample report attending club meetings to learn about their hobby. Some hobbyists in our sample, 24% of astronomers and 12% of birders,

Table 1. Hobbyists who interact with formal learning organizations.

	Percentage of hobbyists	
Learning or teaching activity	Astronomers ($n = 58$) (%)	Birders ($n = 49$) (%)
Interact with formal learning organizations as learners	72	37
… while not pursuing a degree	34	14
… and take a semester-long course or lab	66	29
Interact with formal learning organizations as educators	67	39
… while volunteering with the organization	55	29
… by teaching a sporadic University activity	16	6
… by doing outreach to a school K-12 group	53	16
… by teaching about the hobby to K-12 students while employed as a K-12 teacher	10	12

Table 2. Hobbyists who interact with informal learning organizations.

Learning or teaching activity	Percentage of hobbyists	
	Astronomers ($n = 58$) (%)	Birders ($n = 49$) (%)
Interact with informal learning organizations as learners	90	80
… and take a workshop or course	21	18
Interact with informal learning organizations as educators	74	45
… while volunteering with the organization	64	41
… by teaching a workshop or course	24	2
… by teaching a program for a K-12 school group	19	20

attended conferences on topics related to their hobby to further their learning. Examples of conferences and conventions attended by hobbyists were meetings of the Astronomical League, Lunar and Planetary Science Conference, Stellafane Amateur Telescope Makers, Wildlife Rehabilitators Association, Trumpeter Swan Society, and the Iowa Prairie Network. Other important learning opportunities for the hobbyists in our sample were hobby-related organized educational activities, such as star parties (festival-like astronomy education events) or birding field trips. Universities, hobby groups, museums, parks, or a combination of several of these ecosystem elements hosted these activities. In our sample, 47% of astronomers and 51% of birders learned about their hobby by participating in such organized gatherings.

Hobbyists as educators

The majority of hobbyists in our sample enjoyed sharing their hobby interest with others and sought out opportunities to act as educators. Ninety percent of astronomers and 78% of birders in our sample reported teaching others about their hobby interest. These hobbyists were connected to outreach opportunities in their communities by working with formal learning institutions, informal learning institutions, or with other community organizations and groups.

The hobbyists also partnered with universities and K-12 schools in several different capacities to educate others about their hobby interest. Overall, 39 astronomers (67%) and 19 birders (39%) interacted with formal learning institutions as educators. Many of the hobbyists who partnered with formal learning organizations did so as volunteers (55% of astronomers and 29% of birders). Some hobbyists in our sample, 16% of astronomers and 6% of birders, educated others about their hobby at a sporadic, university-sponsored, activity. Such activities included hosting an observing session for the public through the university physics department, and starting/participating with a bird discussion group at their university. Some hobbyists found hobby-related outreach opportunities with K-12 schools. Indeed, 53% of astronomers and 16% of birders in our sample engaged in outreach to at least one K-12 school and worked with students. Additionally, 10% of astronomers

Table 3. Hobbyists who interact with other learning organizations.

Learning or teaching activity	Percentage of hobbyists	
	Astronomers ($n = 58$) (%)	Birders ($n = 49$) (%)
Attends hobbyist club meetings		
… to learn about the hobby	83	73
… to educate others about the hobby	36	39
Attends conferences or conventions		
… to learn about the hobby	24	12
… to educate others about the hobby	12	4
Attends organized educational activities		
… to learn about the hobby	47	51
… to educate others about the hobby	19	24
Engages in outreach to the broader community, or to specific community organizations	74	41

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and 12% of birders in our sample incorporated their hobby interest into their instruction while employed as K-12 teachers. Hobby-related instruction was incorporated into science classes, but also augmented the curriculum of music classes and first grade classes.

Hobbyists found opportunities with informal learning organizations to educate others about their hobby. In our sample, 43 astronomers (74%) and 22 birders (45%) worked with informal learning organizations as hobbyist-educators. Many hobbyists (64% of astronomers and 41% of birders in the overall sample) worked with at least one informal learning organization in a volunteer capacity. The hobbyists in the study found many different ways to volunteer. Nearly one-fifth of hobbyists, 19% of astronomers and 20% of birders, taught a hobby-related program for a K-12 school group on behalf of an informal learning organization (e.g. a group on a field trip visit to a museum). Twenty-four percent of the astronomers and 2% of the birders taught a workshop or course related to their hobby at an informal learning organization.

The hobbyists found other contexts to educate about their hobby, in addition to universities, K-12 schools, museums, and parks. Approximately one-third of hobbyists, 36% of astronomers and 39% of birders, taught others at hobbyist club meetings. Nineteen percent of astronomers and 24% of birders in our sample shared their hobby while participating in organized educational activities, such as a star party or birding field trip. A smaller proportion of hobbyists in our sample, 12% of astronomers and 4% of birders, shared their hobby-related expertise while attending a conference or a convention. As many as 74% of astronomers and 41% of birders engaged in hobby-related outreach to the broader community or to specific segments of the public through organizations including the boy/girl scouts, churches, and retirement communities.

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Discussion

Hobbyists' participation in the science-learning ecosystem: a discussion of four cases

Engagement in a science hobby can span multiple decades and involve a variety of people, resources, and institutions to support hobby-related learning. The cases of the four hobbyists, Shelia, Anthony, Blythe, and George, were presented to illustrate four possible paths a hobbyist might take through the science-learning ecosystem as they pursue hobby-related learning opportunities and develop their hobby interest over time. These cases illustrate that the science hobbyists in our sample may or may not have formal training in the sciences, and they may or may not hold post-secondary or advanced degrees. The hobbyists in our sample started their hobby involvement at many different ages, though often became interested in their hobby during childhood and revisited that interest as adults.

These four cases also served to illustrate that the hobbyists in our sample began interacting with the science-learning ecosystem by engaging with any of its elements. Hobbies developed as the hobbyists continued interacting with this ecosystem element, and/or expanded their hobby interactions to include multiple elements of the system. Over time, as hobbyists developed hobby-related expertise, their relationship with that organization might have changed so that the hobbyists engaged in hobby-related activities that also supported the mission of the organization. The three analytical themes will be discussed in the context of the four cases presented.

Theme 1: multiple points of entrance

Many study participants' interest in their hobby started years before they began to actively participate in hobby-related activities. Anthony and Blythe both cited a lifelong fascination with astronomy and birds, respectively. Sheila's hobby interest started during a specific period of time, when she was a high school student learning about astronomy in both her physics class and her English class. All three hobbyists waited decades before actively pursuing their hobby interest. Some hobbyists recalled a 'wow moment' that either initially piqued their interest in the hobby or rekindled an existing, yet dormant, interest. Sheila reported having a 'wow moment' when she viewed Saturn for the first time

through a telescope during an evening observing with her high school physics teacher and classmates. Blythe also reported having such a moment, her interest in birding was reawakened by observing an unfamiliar and beautiful 'wow bird' while visiting Nairobi, Kenya.

Regardless of how they initially became interested in their hobby, study participants reached out to an organization in their community when they decided to develop and cultivate that interest. Some hobbyists reached out to an organization as soon as they first became interested in the hobby to nurture their hobby interest immediately, while others waited decades to do so. Study participants selected a variety of organizations to reach out to, illustrating that hobbyists may enter the science-learning ecosystem at any point, through any science-learning organization.

When Sheila decided to start her astronomy hobby, a decade after becoming interested in astronomy, she utilized the offerings of a university to begin her hobby learning. She took several semesters of college-level astronomy coursework. Once Anthony decided to develop his astronomy hobby, one of his first actions was to join an astronomy club. Anthony had many questions about starting his hobby, including what equipment he should purchase and how to use it. After doing some research on his own and not being fully satisfied with the results, he identified the astronomy club as a source of expertise in his community that could help him address his questions.

After viewing the 'wow bird' while on a work trip in Nairobi, Blythe was inspired to plan a visit to Nairobi National Park and use the park environment and resources to bird. Her experience of seeing more spectacular birds in Nairobi National Park and not being able to identify them on her own inspired Blythe to seek out additional hobby-related learning opportunities and resources. George joined a birding club soon after developing his interest by observing the birds in his backyard. He used his affiliation with the club to learn from the more experienced birders, and found it particularly useful to read the reports they posted to the club email list and to follow their discussions about what they were observing.

Theme 2: organizations as catalysts

Many participants reported their hobby-related development advanced when they participated with organizations in the science-learning ecosystem. Hobbyists reported that their relationships with these organizations, and the people they met through the organizations, were invaluable in getting them more involved in their hobby. Indeed, the affiliation often helped the hobbyist fill a specific need she or he was unable to meet on his or her own.

Sheila's hobby involvement was propelled forward on two occasions, the catalyst was her introduction to two additional elements of the science-learning ecosystem: an astronomy hobby club and AAVSO. It was through the hobby club that she met other astronomy hobbyists, learned how others participated in the astronomy hobby, and received advice on selecting and purchasing her first telescope. Shelia developed expertise as a hobbyist through her continued involvement with the astronomy club and its members, and was exposed to opportunities that allowed her to broaden how she participated in her hobby (e.g. attending observing sessions, presenting at club meetings, engaging in outreach). Sheila later joined AAVSO, and did so out of a desire to develop the technical aspects of her astronomy hobby. She attended several workshops on methods of data analysis, rapidly expanded her hobby-related skillset, and was able to participate in a wider array of hobby activities as a result.

Anthony's knowledge and expertise as a hobbyist quickly advanced under the direct tutelage of more veteran astronomy club members. He cited being shown how to use his equipment and where to look for objects in the sky as essential to his early learning. Anthony started participating in outreach events and enjoyed providing similar learning opportunities to the potential future hobbyists in his community. Through his affiliation with the hobby club, Anthony found many opportunities to develop his outreach skills. Through his club involvement, he also began to participate in outreach events in collaboration with a state park, a science museum, and a planetarium, which furthered his growth.

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After her visit to Kenya, Blythe continued to seek out hobby-related learning opportunities. She enjoyed interacting with others to learn about her hobby, especially with birders who were more knowledgeable than her. To this end, Blythe participated in dozens of birding trips to locales all over the world. She sought out trips that were led by knowledgeable guides or birding experts, and even participated in multi-day birding workshops with expert educators. Blythe also joined two birding clubs, a local and a regional club, and attended meetings to learn from more experienced hobbyists. She sought out new organizations to interact with and opportunities to learn to further her hobby development.

In addition to being a member of a hobby club, George interacted with other elements of the science-learning ecosystem while participating in his hobby. He participated in the birding events at his local science museum, including an eight-week workshop for new birders, and regularly attended bird-related education programs to increase his hobby-related content knowledge. George also went on bird walks with other birders in his community, co-sponsored by a park and another hobby club, to improve his observational skills.

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Theme 3: bidirectional exchange

Results showed that the hobbyists were not limited to the role of consumer in their interactions with hobby-related organizations and programs. Most astronomers and birders in our sample gave back to their communities and taught others about their hobby interest. As illustrated by the four cases, this giving back took the form of activities including the teaching of hobby-related workshops and contributing to outreach efforts. The common thread is that the hobbyists' relationships with organizations changed as the hobbyists evolved into a teacher or facilitator.

As shown in the case of Sheila, she deepened her involvement with both the astronomy club and AAVSO. When working with both organizations, she most often engaged in activities that gave back to and supported them in some way. Sheila gave multiple lectures to astronomy clubs and was very involved in doing outreach through her astronomy club to scout groups, K-12 schools, and to the general public. She purchased an additional telescope that was portable and 'kid-friendly' so she might be able to do more outreach with kids, especially with underserved populations. Sheila also gave back to AAVSO by using the skills she learned from this organization to contribute to their database of observations. She would also, on occasion, make specific observations to assist professional astronomers in their work. Due to her high level of skill and involvement in the organization, she had started to teach AAVSO workshops to newer members. Through her continued involvement with the hobby club and AAVSO, Sheila was recognized as a highly skilled hobbyist. She started supporting the educational mission of both organizations by sharing her knowledge and skills with the public, professional astronomers, and hobbyists with less expertise.

Anthony expanded his participation in the hobby club to include a leadership role. Pursuing his interest in outreach, Anthony organized outreach events for the club. Additionally, after initially using a state park's dark sky resources to observe and support their own hobby interests, Anthony and the other astronomy hobbyists began to informally invite other park visitors to join them and observe through their telescopes. The park's rangers supported these activities, and eventually organized and advertised sporadic park programs for the hobbyists to interact with the park visitors. What started as the hobbyists using the park's resources to support the pursuit of their own hobby interests evolved into the hobbyists volunteering to support the park's educational programming efforts.

Through her many educational experiences and years of hobby participation, Blythe developed expertise in her hobby. She spoke at bird club meetings to educate other hobbyists. She was the editor of her birding club's newsletter, and used her writing expertise to give back to the club. Blythe was also willing to support other elements of the science-learning ecosystem, including K-12 teachers and museums, though she had not yet had much direct activity with them.

At the time of his interview, George had not yet taken on a role in which he supported the efforts of the organizations he had used to support his own hobby learning. He was on the cusp of doing so, and spoke of his desire to engage in outreach. An event he had volunteered for fell through, but George was interested in participating in similar events in the future.

Hobbyists' participation in the science-learning ecosystem: a discussion of the frequency of hobby-related educational activities in ecosystem contexts

It is notable that, overall, the astronomy hobbyists in our sample accessed elements of the science-learning ecosystem at higher rates than the birding hobbyists in the sample. This is especially true when comparing the rates at which the astronomers and birders accessed formal learning institutions (either as learners or educators), attended hobby-related conferences (as learners or educators), partnered with informal learning institutions to teach others about their hobby, and engaged in outreach to the broader community. What accounts for these differences?

A novice may start a hobby in either astronomy or birding and participate in that hobby with few to no resources at first. As time progresses, a birder may continue learning about their hobby with the aid of a guidebook and binoculars, perhaps a bird feeder. The birders reported that their birding was often solitary as it was frequently an opportunistic activity: birding is easily engaged in without prior planning, in the moment, and blended into other daily activities (e.g. taking a hike, walking to the car, doing the dishes in front of the kitchen window, etc.). Astronomy, in contrast, quickly moves into involving more sophisticated tools (i.e. telescopes), highly scientific content, and a greater level of expertise is needed to engage in the hobby. Some astronomers in the sample spoke of the large amount of preparation that often goes into planning an observing outing. In short, astronomy hobbyists may not participate in their hobby as casually as the birding hobbyists at higher levels of involvement as astronomy requires more preparation and access to more knowledgeable 'others'.

Additionally, astronomy is a topic that is more readily studied in formalized learning environments than birding because astronomy, as an introductory course, is commonly included in college curricula. Astronomy hobbyists might find the learning resources of formal educational environments more suitable to their needs than birders. We can posit that the astronomers in our sample are more likely than birders to access formal learning institutions and conferences while participating in their hobby because these settings provide an avenue for astronomy hobbyists to easily access scientific content material and knowledgeable experts.

With the proper training, a dedicated and skilled astronomy hobbyist may apply their knowledge to contribute to the field of astronomy, often by participating in tasks that assist professional astronomers in their work. As these lifelong learners engage in their astronomy interest, the lines may begin to blur between a casual leisure activity and an activity that begins to look like an authentic scientific pursuit (Stebbins, 1982). The astronomy hobby is unique as appropriately trained hobbyists have the ability to significantly contribute to the work of professional astronomers. While individual amateur astronomers can make significant contributions to the field of astronomy, it should also be acknowledged that data gathered by birders are often collected into large datasets and used by ornithologists and conservation biologists for research purposes. In another study underway, we are currently investigating the motivation of science hobbyists to contribute data to scientists.

Both the astronomers and birders in our sample accessed informal learning institutions such as museums/parks (as learners) at similar rates. A larger proportion of astronomers and birders also accessed informal learning institutions when compared with access of formal learning institutions while participating in their hobby. These data may suggest that the hobbyists in our sample deemed the resources and 'science experts' at museums and parks to be more available to them than the resources and science experts at colleges and universities. The higher participation numbers with informal organizations, as learners and educators, may also indicate that museums and parks are very accessible to the hobbyists in their communities, or region,

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regardless of hobby type. Indeed, most hobbyists in our sample used parks to engage in their own self-directed hobby activities by using the park environment to observe either celestial objects or birds.

The astronomers and birders in our sample also accessed hobby clubs (as learners and educators) and outreach educational activities such as star parties or birding trips (as learners and educators) at similar rates. Hobbyist clubs and organized educational activities for hobbyists are examples of settings and activities that are designed to target the interests and needs of science hobbyists, specifically. In particular, as hobby club meetings are the one context in the science-learning ecosystem that expressly exists for the benefit of hobbyists, and is run by hobbyists and adaptive to their hobby-related needs, it was expected that astronomers and birders would take advantage of this space at similar rates. As previously discussed, due to the fact that many study participants were recruited through hobby clubs, it is not surprising that many hobbyists reported they used hobby clubs as a context for hobby-related learning.

As seen in Tables 1–3, when considering several specific ecosystem contexts, a higher proportion of the sampled astronomers engaged in outreach when compared with the birders in the sample. Overall, looking across all science-learning ecosystem contexts, 90% of astronomers engaged in outreach with at least one ecosystem setting while 78% of birders did so. These results point to the fact that the astronomers in our sample appeared to be more active in their outreach efforts, and were more likely to do outreach in multiple contexts, when compared with birders. This is possibly due to the different nature of the two hobbies. Indeed, a large group of astronomy hobbyists or astronomy-interested members of the public can gather together to observe and will not scare away the stars. The same cannot be true for those engaging in their birding hobby, which seems to focus more on one-on-one or small group interactions. Established astronomy hobbyists are also often needed to introduce astronomy-interested members of the public to the hobby because participation may require specialized equipment and tools. Conversely, birding-interested members of the public can dabble in birding and explore their interests from the comfort of their homes or backyards without specialized equipment. Additionally, while hobbyists from both hobbies reported doing outreach to K-12 schools and enjoyed sharing their hobby interest with children, the specific motivation behind such actions may have been different. Some astronomers spoke of the importance of doing outreach to 'inspire the next generation' and to provide students with opportunities to learn more about the world around them that they might not normally have. The astronomers may have viewed their role as pivotal in providing students these opportunities as, often, the astronomy hobbyists brought specialized resources (e.g. their telescopes) to the schools to provide these experiences for the students. Birders may not have felt the same need for their involvement from K-12 schools, as observing birds may be considered to be a fairly accessible activity and something the teacher is able to do without the aid of an experienced practitioner.

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Conclusions

This paper examined how the hobbyists in our sample accessed elements of the science-learning ecosystem, picking and choosing activities to further their own learning agenda and, often, to teach others about their hobby. Hobbyists developed significant relationships with these organizations and groups. Not only did these organizations emerge as critical factors in sustaining and developing an individual's hobby, hobbyist-educators also supported the mission of these organizations and strengthened the science-learning ecosystem by educating others about their science hobby. The data presented suggest that the science-learning ecosystem model is a useful organizing framework to examine the interactions between science hobbyists and the resources and organizations in their communities that support their participation in their hobby. Additionally, the three themes that emerged from the data (1: multiple points of entrance, 2: organizations as catalysts, 3: bidirectional

exchange) were also effective in framing the story of a hobbyist's pathway of involvement, often occurring over many years, as he/she developed from a novice to an experienced practitioner.

The astronomers in our sample were more likely to utilize colleges and universities as learners, and were more likely to engage in outreach to K-12 schools, when compared with the birders in our sample. They were also more likely to attend hobby-related conferences and conventions. The astronomers and birders in our sample interacted with informal learning institutions and hobby clubs at similar rates, as learners and educators. Most hobbyists in our sample accessed informal learning institutions and hobby clubs to further their own learning. This information is of use to researchers and educators who wish to better understand how hobbyists and other adult members of their community engage in sustained, lifelong learning activities and is also of use to educators and organizations that wish to capitalize on this sector of science expertise in their communities, hobbyists-educators, to support their organization's education efforts. Clearly, these hobbyists illustrated that they are lifelong learners and valuable educators for the formal and informal education communities.

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Notes

1. Pseudonyms are used for all participants.
2. "Exoplanets" are extrasolar planets; planets orbiting stars outside Earth's solar system.
3. "Little brown job" or LBJ is a term used by birders to describe unremarkable birds that are difficult to distinguish and identify.

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